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100 K.W. SHORT WAVE BROADCASTING TRANSMITTER. TYPE S.W.B. 14 & 18.

The demand for higher power in short wave broadcasting is increasing. To fulfil it, the Marconi Company have developed a transmitter with a wave range 13.5 to 80 metres giving a carrier output of 100 kw. Four or more spot waves can be provided by means of circuit trucks, and the wave change time is less than eight minutes.

Both series modulators and Class B modulators have been developed capable of giving good frequency response between 30 and 10,000 cycles and 90 per cent. modulation with less than 4 per cent. distortion.

THE success of Empire Broadcasting on short waves, and the regular transmissions on these frequencies by other countries, has gradually led to an ever increasing demand for higher power transmitters. As early as 1935 the Company were approached for a broadcast transmitter of 100 kw. carrier power. Prior to this the highest powered short wave broadcasting transmitter manufactured was the S.W.B.9, the prototype of which, the S.W.B.7, was described in the January, 1933, issue of this journal and supplied to the League of Nations. The rating of the latter transmitter was 15.8 kw., and that of the former 34 kw. unmodulated carrier, which represented about the maximum possible output on the 21 megacycle band with the valves available at that time. Therefore, before development work on the design of such a high powered transmitter could be commenced, the valve company were approached as to the possibility of manufacturing valves of higher power suitable for operating on such frequencies.

The C.A.T.14 valve, with an anode dissipation of 150 kw., was already in existence for use on longer waves and a modified version, to be known later as the C.A.T.17, was produced, and proved capable of the output required. Two such valves therefore were selected for the Final H.F. Amplifier. In addition to the increased power, the transmitter had to fulfil a number of other special requirements, among which may be mentioned the following:—

Power Rating	...	100 kw. unmodulated
Modulation	...	100 per cent. Max.
Distortion	...	4 per cent. at 90 per cent. modulation.
Waverange	...	13.5/80 metres, with quick wave-change to any of four spot waves within this range.
Carrier Stability	...	±1 part in 100,000.
Frequency Response	...	±2 dbs. between 50 and 10,000 cycles.
Scintillation	...	Less than 1 cycle per second with 80 per cent. modulation.

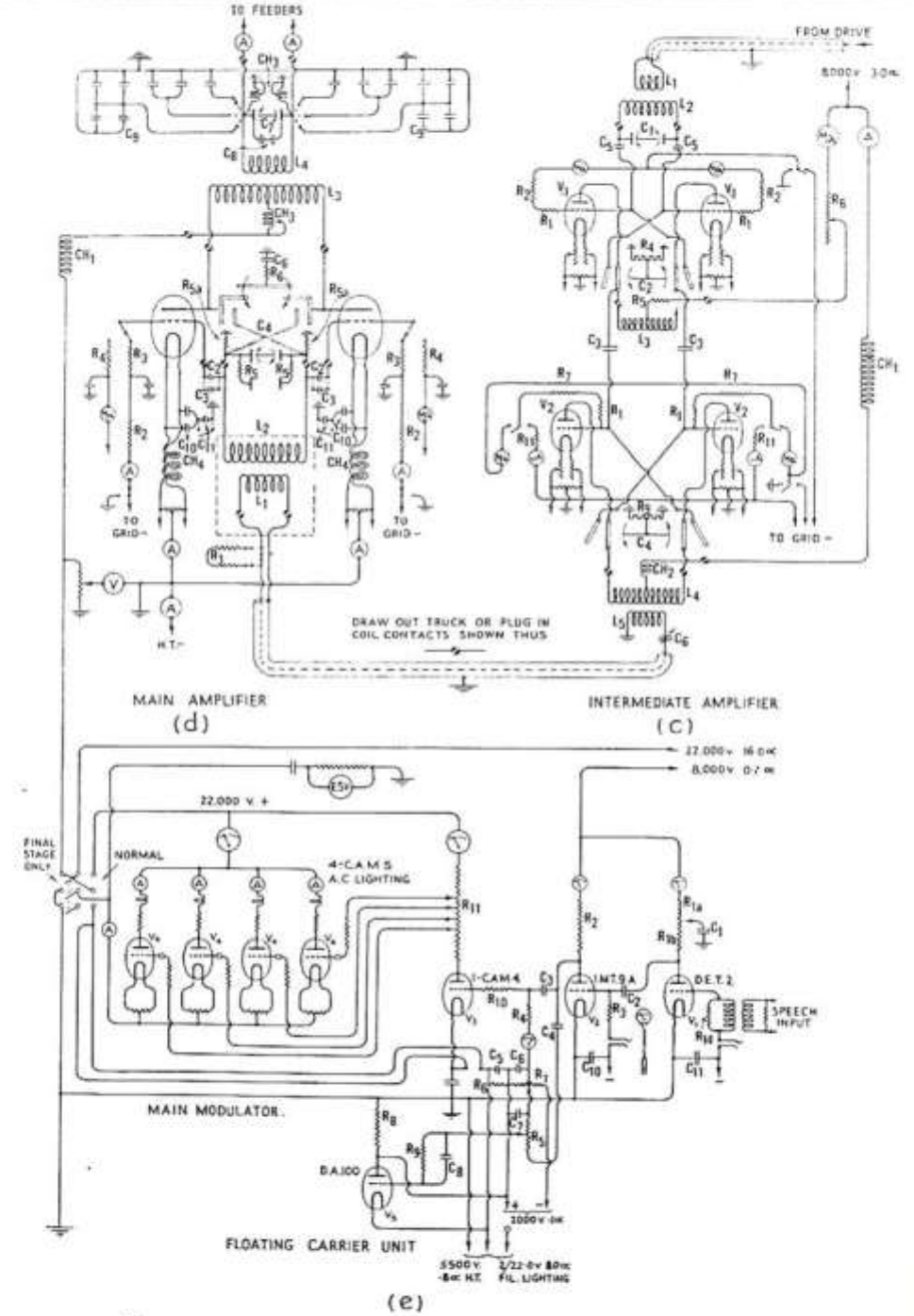
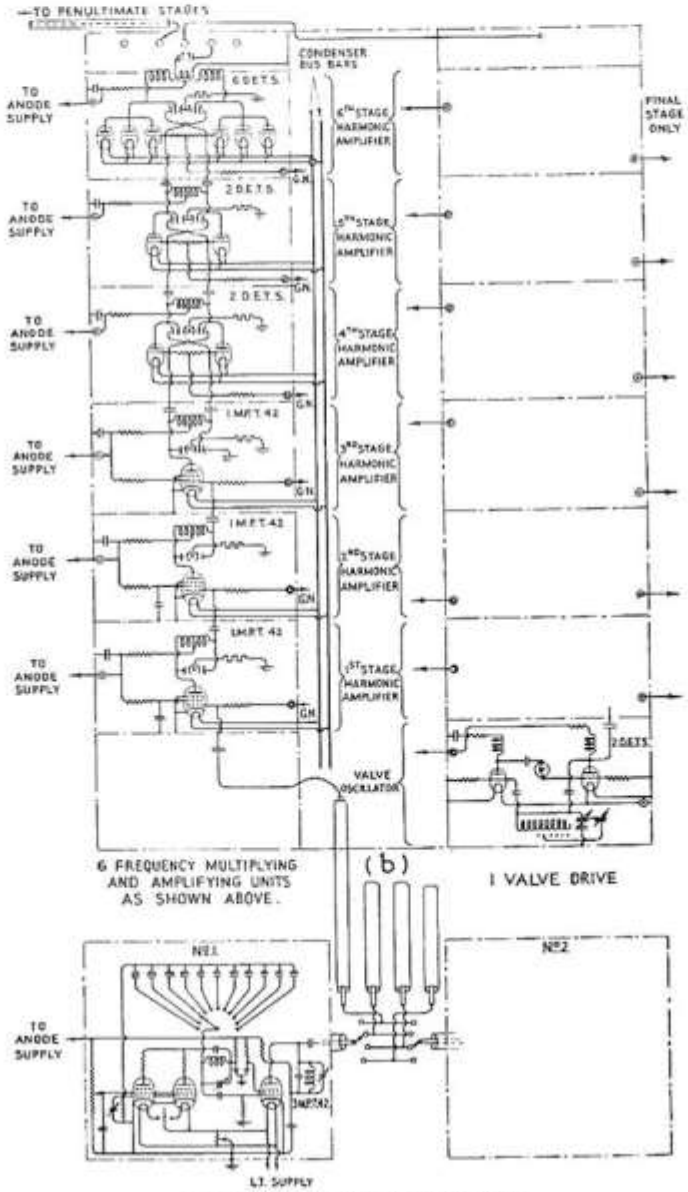

TO FEEDERS
FROM DRIVE
8,000 v 30 m/a
TO GRID –
DRAW OUT TRUCK OR PLUG IN COIL CONTACTS SHOWN THUS
MAIN AMPLIFIER
(d)
INTERMEDIATE AMPLIFIER
(C)
22,000 v 16 0 m/a
8,000 v 0.7 m/a
22,000 V +
FINAL STAGE ONLY
NORMAL
4-CAMS A.C LIGHTING
1-CAM 4
INT 0 A
DET 2
SPEECH INPUT
MAIN MODULATOR.
DA 100
FLOATING CARRIER UNIT
3500 V -8m/a H.T.
2/22-0-v 80 m/a FIL. LIGHTING
(e)

FIG. 1.



ELEVEN CRYSTAL DRIVES IN DUPLICATE AND ASSOCIATED APPARATUS

(a)

FIG. 1.

The design of the transmitter, to be known later as the S.W.B.14 High Power Short Wave Transmitter, was commenced in 1936. A schematic diagram is shown in Fig. 1, and a front view in Fig. 2. The high frequency section is divided into four main panels (A) Crystal unit, (B) Harmonic amplifier, (C) Intermediate amplifier and (D) Final amplifier. The modulator (E) forms a fifth unit, and may be of series type with floating carrier as shown, or Class B type.

Except for the early frequency multiplying stages, which use pentodes, all stages use triodes in normal push pull neutrodyne circuits. The connection between stages in any unit is by fixed capacity coupling, while between units tuned inductive coupling and concentric feeder are employed. Variable inductive coupling is also used on the final stage to transfer the energy to the 500 ohm. twin wire feeder.

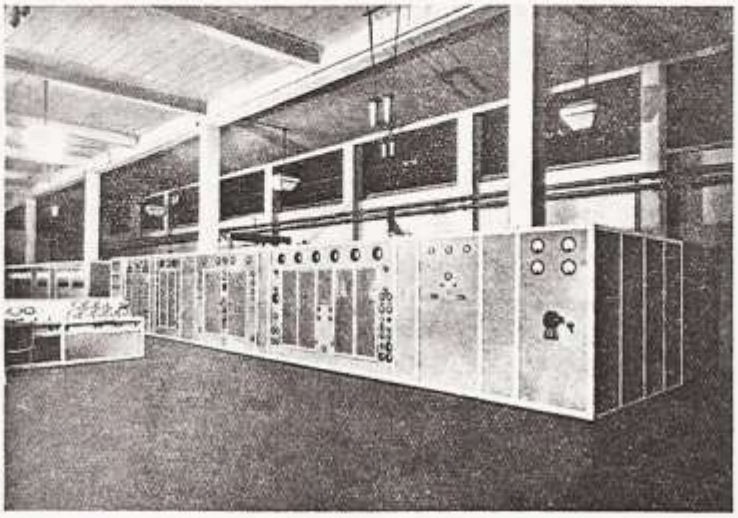


FIG. 2.

On the intermediate and final stages, change of wave length is effected by means of pre-set circuits, mounted on trucks which are wheeled into position on guide rails, all connections being made automatically. This method has certain advantages over the more usual turn-table method, *i.e.*, any number of spot waves can be provided. No idle circuits remain in the high frequency field. Trucks, not in use, can be set up to new wave lengths while the transmitter is working.

Another novel feature is the use of Lockheed hydraulic controls on the final stage. All adjustments are made from a single handle in combination with a three-way selector unit.

All stages are built as compact composite units, which, except for the last stage, are assembled externally, and then fitted in the various panels, and require only the addition of filament, grid and anode supplies. Each high frequency stage is well screened, and the panels themselves are completely enclosed in perforated metal, so that stray coupling between stages is avoided. Complete screening and inductive coupling on the output stage tend to reduce harmonic radiation.

Crystal Unit.

The crystal unit is on the extreme left hand side of Fig. 2. For the first transmitter, eleven different frequencies were specified, and the unit was therefore designed to accommodate 12 crystals mounted on a small revolving turn-table. The crystal maintaining circuit (of the usual Pierce type) its valves and the crystals are in a common thermal chamber, which is maintained at a constant temperature through the usual devices. The isolator circuit is a single pentode stage, and takes the 3rd and 4th harmonic of the crystal frequency to give an output between 224 and 300 metres. Two identical crystal units are supplied complete with their own auxiliary supplies. The output of either can be switched through a common feeder system to the harmonic amplifiers.

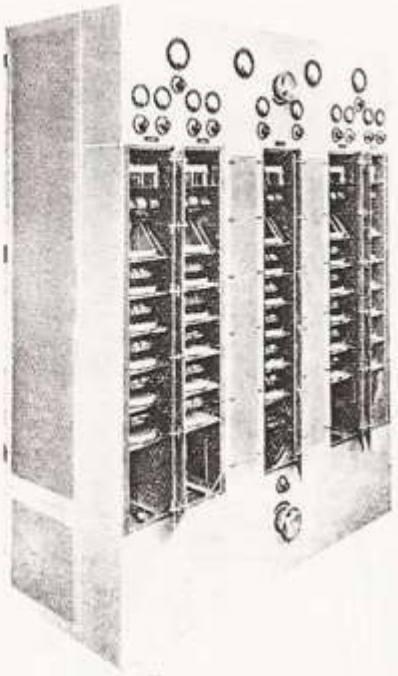


FIG. 3.

Harmonic Amplifier.

Fig. 3 shows a front view of this unit. It is divided into five racks, the four outside ones being driven from the crystal unit and the central one from a flexible valve oscillator. All five racks are otherwise identical. The first three stages use pentode valves, and may be used for frequency multiplication. The last three stages use triodes, and are purely amplifying stages, giving an output of about 120 watts, on the final frequency. The output from any rack can be supplied through a five-way switch and common feeder to the intermediate panel. All stages employ plug in coils, and are set up for the particular spot waves in use. Provision is made for metering all stages.

Flexible Master Oscillator.

The additional flexible master oscillator provides for any wavelength not determined by the crystals, and oscillates in a band from 1,340-1,000 mc/s. By selection of suitable harmonics this gives a continuous driving range from 13.5 to 80 metres. This oscillator is self-compensating for temperature changes, and has a stability better than ±1 in 20,000.

Intermediate Amplifier.

Adjustable plug in coils offer many advantages for quick wave changing. Losses due to idle end turns and switch contact troubles disappear, and by series parallel arrangements economical use is made of the conductors. But the manual handling of a number of large inductances in a limited time is difficult, and involves risk of breakage. It was, therefore, decided to mount the inductances for the intermediate and final amplifiers on trucks. The time for changing wave in the intermediate panel is reduced to less than 1 minute, and the risk of breakage is nil.

The panel contains two valve stages: the first, in the upper part of the panel, has two air-cooled triodes (type ACT. 9), while the second in the lower part has two water-cooled triodes (Type CAT. 9).

Figs. 4 and 5 are front and rear views of the panel, and show clearly the clean and symmetrical layout of the circuits. This effect is obtained by building each stage complete with its balancing condensers as a single composite unit, and mounting the valves directly on it.

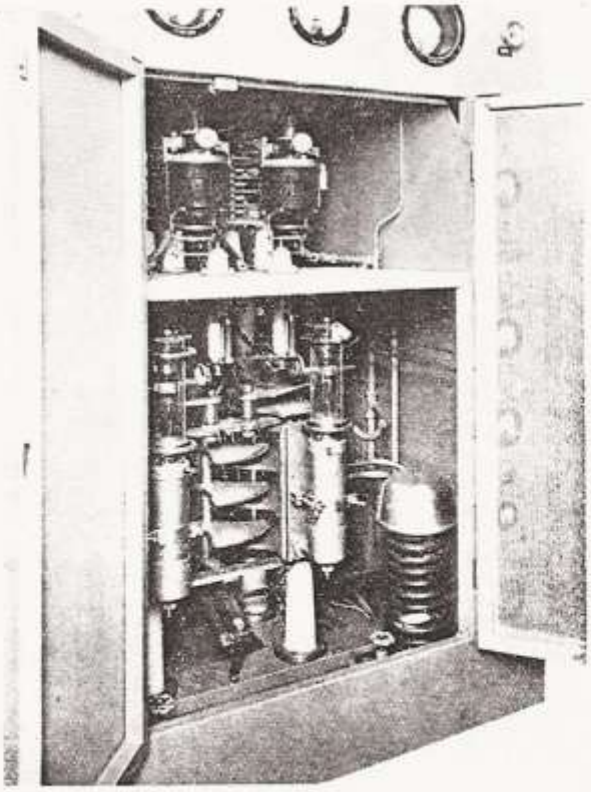


FIG. 4.

From Fig. 1 (c) it will be seen that four inductance units, in tuned circuits are involved. These are, the grid transformers L_1, L_2, the 1st stage anode coil L_3, the 2nd stage anode coil L_4 and the output coil L_5. All these units are mounted on the truck which is shown in Fig. 6.

The framework of the truck is of special aluminium alloy castings, bolted together to form a rigid support to the various inductances. The base casting is mounted on four ball bearing wheels, two of which are arranged to have a full swivelling action. The trucks can thus be easily manœuvered in a limited space for parking. The truck is picked up on a special rail system on entering the panel, which ensures correct alignment of all contacts and removes any risk of trouble due

to wear of the hard cork tyres. All inductance contacts are self-aligning and self-cleaning, and are particularly free from heating troubles. Low loss ceramic insulators are used where necessary. Interlocks are provided to ensure that the truck is fully engaged before the rear doors can be closed and power applied. After a truck is changed the output coupling and variable condensers are set to predetermined scale settings.

This panel can, if desired, be used as the final stage of a medium powered short wave transmitter, capable of an output of 13 to 17 kw. unmodulated carrier.

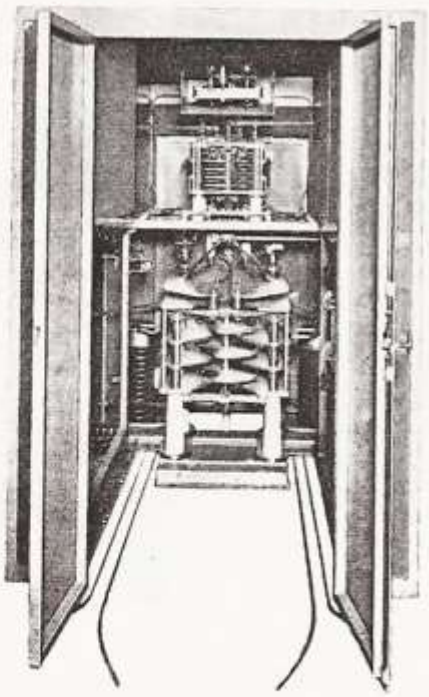


FIG. 5.

Final Amplifier.

The difficulties in designing circuits for large valves at such high frequencies, have driven some designers to the use of abnormal circuits, such as the so-called series amplifier, and claims for higher efficiencies have been made which cannot be substantiated. The system has certain definite disadvantages. The filaments of the final stage are isolated from earth, and A.C. lighting is not practicable, because of phase modulation. The hum due to A.C. lighting might be reduced by feedback, but the more insiduous phase modulation would not be affected.

D.C. lighting from earthed generators requires a tuned circuit of some kind to carry the filament current and adjustable over the wave ranges as the penultimate and final amplifier are working in series.

Secondly, any variation of loading on the final stage due to coupling adjustment, or change in aerial conditions, directly affects the loading on the penultimate stage and necessitates readjustment.

On the other hand, with the normal amplifier the filaments are at earth potential, and the load on the final amplifier does not affect the previous stage. The initial adjustment of the circuits are, therefore, easy, and can proceed stage by stage; and once made, will cover a considerable variation in loading.

It is, therefore, worth while maintaining the use of normal circuits by a skilful combination of electrical and mechanical design.

The final amplifier is therefore a single stage Class "C" amplifier employing CAT.17 water cooled valves and again making use of the balanced bridge circuit as used in the previous two stages. The circuit consists of the grid input transformer L_1 L_2, Fig. 1 (D), tuned by a condenser, the anode inductance L_3 tuned by its condenser and the balancing condensers C_4.

Various additional refinements have been added to improve the performance, the chief among which are the following:—C_2, are grid reactance condensers for neutralising the inductance of the grid leads; CH_4, C_{10} and C_{11} are respectively the filament reactance chokes and condensers which are used for the same purpose as regards the filament leads and so reducing the H.F. voltage of the filaments with respect to earth. The resistances R_3 and R_4 are H.F. chokes, whilst R_2 is provided for the purpose of obtaining automatic bias. The resistances R_5 and R_{5A} are damping resistances on the grid circuit, for improving stability and suppressing any tendency for the circuit to "Squigger." R_5 has a semi-fixed capacity to earth whilst R_{5A} rely on their self capacity to earth to control the amount of damping.

The output circuit is inductively coupled to the anode circuit L_3 by L_4 and tuned by the capacities C_7, C_8 and C_9.

In the case of short wave transmitters the behaviour as regards efficiency and stability depends entirely on the detailed mechanical design.

If the circuits are to function normally and efficiently at the shortest waves, the valves and circuits must be so grouped together, as to make the circuit symmetrical. Idle stray capacities, and the inductances of connecting leads must be reduced to a minimum. Stray coupling between grid and anode circuits must be avoided. All surfaces at high radio frequency potential must be well rounded and high frequency connectors and conductors must be adequate.

The valves must be first considered, as around these the whole circuit is designed. A photograph of the CAT.17 valve mounted in its special transporting carriage is shown in Fig. 7. The robust nature of the grid seal will be noticed. It consists of a complete copper ring which has ample capacity for the 120 amperes or more of high frequency current which must pass through the seal at 13.5 metres. It also ensures that the inductance of the connections can be kept down to a minimum.

Brief data of this valve is as follows:—

Filament Volts	32.5 volts.
Filament Amperes	460.0 amperes.
Emission at 90 per cent. saturation ..	100.0 amperes.
Anode volts for telephony	11,000 volts.
Maximum anode dead loss	150.0 kw.
Grid anode capacity	70.0 mmf.
Grid filament capacity	100.0 mmf.
Anode filament capacity } Filament earthed .. }	24.0 mmf.

The figures of 100.0 amperes emission of the valve is a generous allowance for a mean feed of 7.0 amperes, the normal anode feed for this transmitter. This is borne out by the fact that the filament can be run about 1.5 volts below the marked value, which ensures a long life.

The total of the capacities measured across the anode diagonal of the bridge is 120 mmf., which for the active capacities involved is remarkably small. This requires 0.4 microhenries to tune to 13.0 metres, which is represented by a single turn 7 in. in diameter of 0.25 in. diameter material. It is clear that not much inductance can be allowed for connecting leads.

The reactance of the total anode circuit capacities at 13.5 metres is approximately 60 ohms. The peak high frequency voltage on carrier across the circuit is about 20,000 volts. Hence the R.M.S. current in the circuit is 240 amps. and

100 per cent. modulation will increase this to 300 amps. The area of connectors and of the conductors must be adequate for such currents.

The following description shows how the principles specified have been carried out in practice. The whole of the active circuits are contained in a cubicle constructed of brass angle and brass sheet liberally perforated for ventilation.

Fig. 8 shows a view of the interior from the front, and Fig. 9 from the back of the unit.

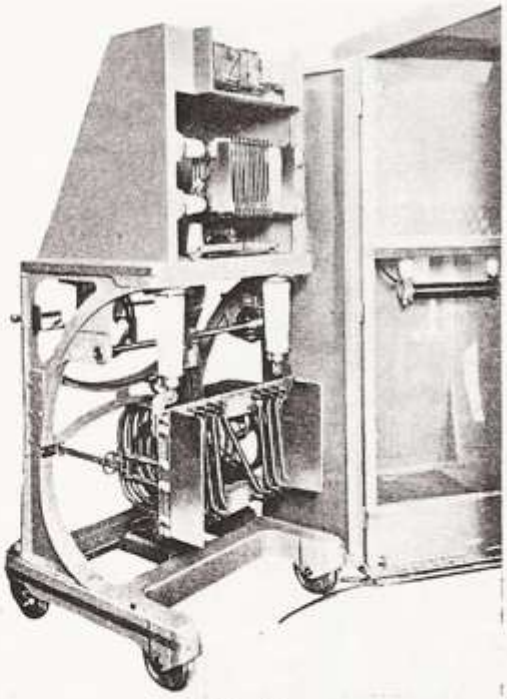


FIG. 6.

Central Assembly.

The two CAT.17 valves are mounted towards the front of the cubicle the base of their water jackets being mounted on two machined bronze plates insulated from the floor by a box-like structure of mycalex. To the inner edge of these mounting plates are bolted massive aluminium U-shaped plates which form one electrode of the balancing and anode circuit condensers. The single flat plate in front is the other side of the anode circuit condenser, which can be moved by the hydraulic ram controlled by the handwheel on the front of the transmitter. The other sides of the balancing condensers are enclosed inside the U-shaped plates. They each consist of a central column supported on mycalex insulators and on the column are pivoted two thick oblong shaped plates with well rounded edges. These plates can be moved by the same handle via a selector switch and a second hydraulic ram.

The cross-over of the balancing arms comes directly from the columns which also provide support for the grid platform on which the grid transformer is placed inside the screening box. Inside the box also is the grid circuit tuning condenser which provides further support for the grid platform. In Fig. 9 showing the rear view of the panel can be seen the back section of the U-shaped plate, on which is mounted the long vice grip which connects to the anode inductance busbar when the circuit truck is in place.

This completes the central assembly.

The arrangement is symmetrical and all surfaces of the U-shaped plates are in active use so that stray capacities on the anode side are reduced to a minimum.

The shape of the various members are simple so that well rounded edges are easily provided. The cross-over arms of the bridge are short and their inductance

is practically equal to that of the valve arms. This makes for stability, and the variation in balancing capacity over the wave range is slight. The connections between the anode of the valve and the anode tuning condenser, and more particularly the anode coil are of ample area and minimum inductance.

Circuit Truck.

Fig. 9 gives a good view of a circuit truck coming into position in the panel. The truck itself consists of a skeleton gun-metal base with four swivelling wheels which run in guide rails. At the front, the vertical busbars of the anode inductance are mounted on rigid box structures of mycalex. The anode inductance is made up of horizontal tubes supported from the vertical busbars with mycalex where necessary. The sizes of the individual turns are easily adjusted, by quick-locking sliding members. The number of active turns can be varied and turns can be used in series or parallel. The type shown has a continuous wave range of 25 to 80 metres. A short wave type using thicker tubes is shown in Fig. 10 and covers the wave range 13.5 to 40 metres. The complete absence of bolts and nuts or other sharp projections should be noted.

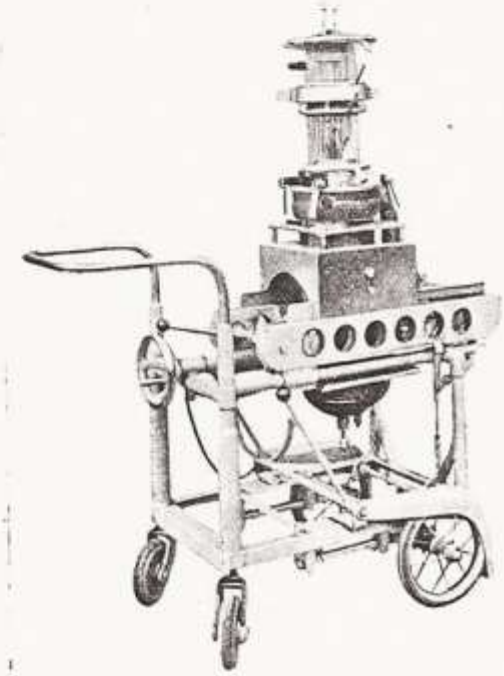


FIG. 7.

Attached to the front of each busbar is a long flexible strip which is gripped in the vice grip previously mentioned when the truck is pushed home. This allows for even distribution of currents which prevents overheating and minimises the internal inductance of the structure.

From the top of each busbar project two curved mycalex insulators which support the grid transformer. This is also constructed of tubes, and by series and parallel arrangements covers the complete waverange (13.5-80 metres). Where necessary grid reactance condensers appropriate for the wavelength are mounted with the grid inductance.

The box with hinged door into which the grid transformer goes when the truck is pushed home is clearly visible.

The grid connections wedge against special spring contacts with ample current capacity.

At the rear of the truck the variable tuning condenser of the output circuit is mounted on mycalex slabs from a subsidiary sliding carriage. The coupling coil

is supported directly from the condenser. Extra parallel condensers can be mounted on top of the variable condenser. There are also two nests of tubular condensers fixed in the panel which can be connected as required for the longer waves by detachable switches. The outgoing feeders are mounted at the top of these units, and go through ammeters outside the panel. These ammeters being situated towards the back of the top panel, would be difficult to read, but by an ingenious

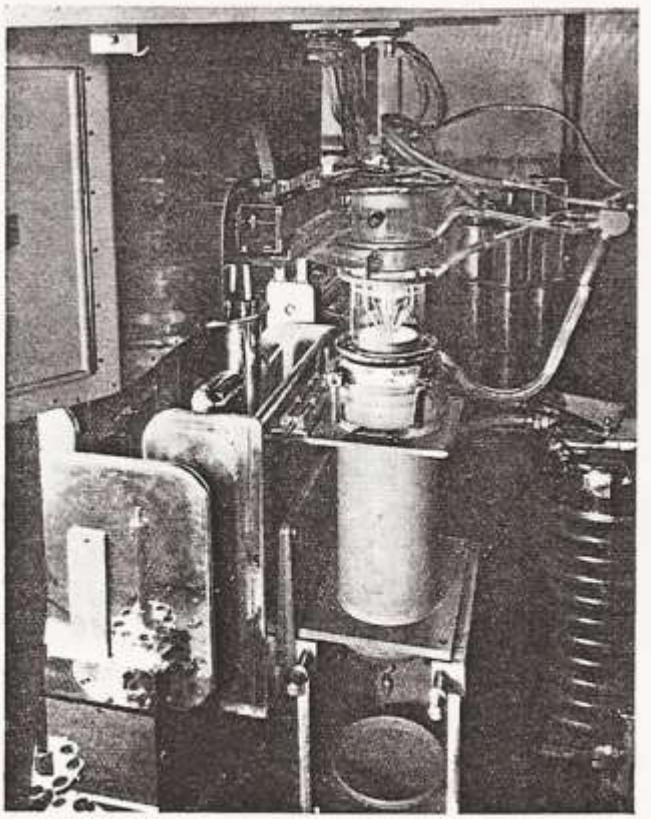


FIG. 8.

system of lenses and periscopes an enlarged picture of both ammeters is brought to a viewing position at eye level immediately above the main control handle.

When the truck is in position the sliding carriage carrying the output circuit can be controlled from the common handle by hydraulic ram. Fig. 10 shows how the rail system extends over the whole parking area with four positions of rest for the trucks.

All manual effort in steering is therefore eliminated and it is merely necessary to set the points at the junctions to their correct position. By this means the amount of physical effort required to manœuvre these trucks is reduced to a minimum and speed of wave-change increased.

Various interlocking arrangements are provided, operated by the two pedals placed either side at the rear of the truck. These two pedals, one on the left and one on the right hand side, are marked respectively, "FREE," and "LOCK." The "Free" pedal is depressed before removing a truck from the panel, and remains so during the whole time the truck is being moved. The "Lock" pedal is depressed when the truck is in position in the panel, and performs the following operations :—

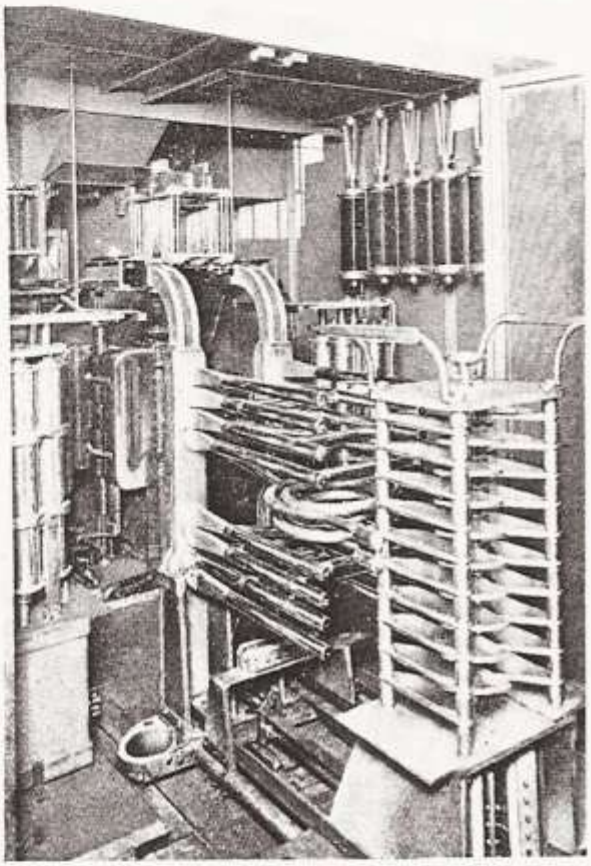


FIG. 9.

(1) Tightens Anode vice clamping contact to the main inductance.

(2) Releases output circuit carriage on chassis.

(3) Allows jaws of hydraulic control on coupling circuit to close.

(4) Releases interlock on back doors allowing these to be closed.

The reverse of these operations takes place when the "Free" pedal is depressed.

Output Power.

The maximum nominal unmodulated carrier output from the Final Amplifier varies with frequency, and is a maximum around 40 metres when an output of 105 kw. is obtainable.

The following table gives the input and output kw. over the wave range of the transmitter.

Metres.	Kw. Input.	% Efficiency	Kw. Output.
80	150	66	100
50	150	70	105
30	150	70	105
25	150	66	100
20	150	64	95
15	140	61	85
13.5	135	60	80

Modulation Circuits.

The Transmitter may be supplied either for Class B. modulation or for Series modulation, modulators for both systems having been developed and designed.

(a) Series Modulator.

It is well known that by the use of series modulation in combination with floating carrier a large amount of power can be saved during periods of weak modulation. Stresses on transmitter, feeder and aerial system are minimised, and excess voltages due to over modulation cannot occur.

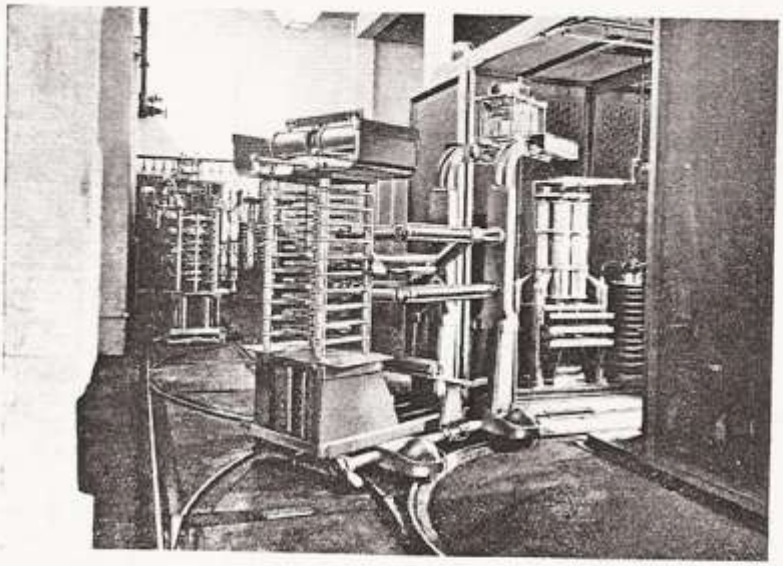


FIG. 10.

In the series modulation system used on long and medium waves, the filaments of the modulator valve are kept at earth potential while the whole of the high frequency circuits are insulated from earth. On short waves this would greatly increase the difficulties of design of the high frequency currents, and a series modulation system was designed in which the modulator valves were at the high potential end of the system, and the high frequency circuits were normal. This arrangement is shown schematically on the theoretical diagram Fig. 1 (E).

The anodes of the main modulator valves (4 CAM. 5) are connected directly to the positive of the 22,000 volts supply while their filaments are connected to the + supply terminal of the H.F. load. The filaments are lit by transformers in a Scott connection, the secondaries being highly insulated and having a low capacity to earth. The grids are connected directly to the anode of an input valve V_3 (CAM. 4) used as a resistance amplifier. The filament of this valve is lit by D.C., and maintained at a steady —ve potential of about 5,500 volts to earth. Normal modulation is applied to the grid of this valve by the usual resistance capacity amplifier containing V_1 and V_2.

V_5 is the valve that provides the floating carrier control. It is operated as an anode bend rectifier, its alternating grid voltage being supplied from V_2.

The rise in carrier level takes about .05 seconds, while the decay time is adjusted between ½ and 1 second.

The modern trend is towards High Level Class B anode modulation systems, as described later, but the special features of this type of series modulation are of interest and a full description is given in Appendix 1. For one particular transmitter the float was arranged to reduce the H.T. on the final amplifier to half value at zero modulation, and to increase it linearly with the degree of modulation so that full H.T. giving 100 kw. carrier was reached with 100 per cent. modulation. The total input to the transmitter was as under:—

Modulation.	With Floating Carrier.		Without Floating Carrier.	
	Total Input A.C. Mains.	Distortion. 400 ∿	Total Input A.C. Mains.	Distortion. 400 ∿
0%	310 kw.	—	470 kw.	—
30%	358 ,,	1%	470 ,,	1%
60%	407 ,,	3·7%	470 ,,	1.2%
90%	454 ,,	4.0%	470 ,,	3.6%
100%	470 ,,	6%	470 ,,	6%

Frequency Response.

50	.. .. ..	1.5 D.B.
1,000	.. .. ..	0
10,000	.. .. ..	1.0 D.B.

(b) Modulator (Class B).

The stages included under this section are the two audio frequency or signal frequency amplifiers, and the Class B modulator itself, a schematic of which is given in Fig. 11.

(*a*) *Signal Frequency Amplifiers.*

The first stage consists of two PX. 25 valves connected in push-pull, the incoming signal from the line being connected to their grid through a loading attenuator and input transformer to ensure correct circuit matching.

The stage is quite distortionless, and consists of a normal resistance capacity voltage amplifier, the anode voltage being about 250 volts, and the feed about 100 milliamperes. The gain of the stages can be arranged to suit the input level delivered from the average line amplifier into 600 ohms., an attenuator usually being incorporated between line and the input to the stage.

The second amplifier uses 2 type MT. 14 valves with an anode voltage of 4,000 volts, and a feed of 100 milliamps. per valve. This stage is also a normal resistance capacity amplifier similar to the first but of higher power.

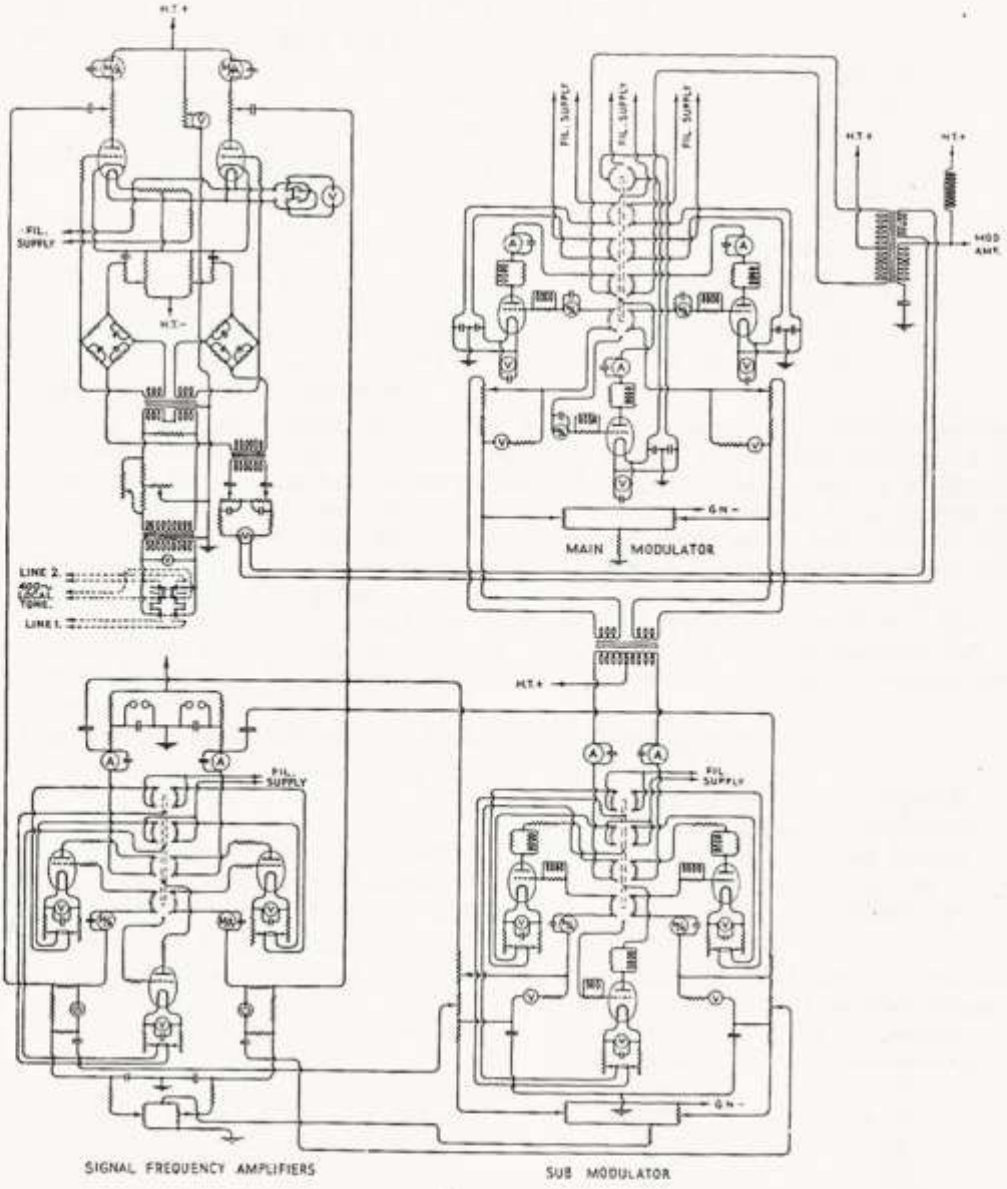


FIG. 11.

(*b*) *Sub Modulator.*

The L.F. amplifier stage is resistance capacity coupled to the succeeding sub-modulator stage, using 2 type CAM. 2 water-cooled anode valves in Class A push-pull.

The coupling between the sub and main modulator stages is through an input transformer with split primary and secondary windings.

(*c*) *Main Modulator.*

The main modulator unit consists of two water-cooled high-power modulators mounted in push-pull. The grid input circuits contain the bias potentiometers, and are arranged with a compensating device so that the valves may be exactly matched. The valves used are of the CAT. 20 type with an anode voltage of 11 kilovolts.

The stage is equipped with all necessary indicating meters and protection devices, both for the electrical and water circuits, in common with all other sections of the transmitter.

A neon tube limiter is fitted on the grid of the sub sub modulator valves to prevent excessive voltages on over modulation. Feed-back can be fitted between the main transformer and the input to the PX. 25 valves, but the distortion of the normal chain is so low that it is not required. With the exception of the harmonic amplifiers and 1st signal frequency amplifier all H.T. power supplies are from a single 11,000 volt source, giving both efficiency and simplicity. Performance figures for 100 kw. carrier are given below.

% Modulation.	Total Input from A.C. Mains.	Distortion at 400 ∿	Distortion at 8,000 ∿ 2nd harmonic only.
0	311 kw.	0	—
30%	324 ,,	1%	—
50%	—	1.5%	—
90%	411 kw.	3.4%	2.4%
100%	424 ,,	3.5%	—

Overall efficiency on Carrier .. .. .. 32 per cent.
Overall efficiency on 100 per cent. Modulation 35.4 per cent.

Frequency Response.

30 —	—2.0 dB.
50 —	— .7 dB.
1,000 —	0 dB.
10,000 —	1.8 dB.

The loss at high and low frequencies is not due to transformer characteristic, but to extraneous sources.

By the application of 5 dBs. of feed-back the total input to the transmitter can be reduced by 10 kw., by reducing the static feed on the main modulators, with slightly reduced distortion and improved frequency response.

Performance with 5dB Feed-back.

% Modulation.	Total Input From A.C. Mains.	Distortion at 400 cycles.
0	300 kw.	0
30%	314 ,, ...	0.5%
90%	400 ,, ...	2.6%

Frequency Response.

30 cycles	0 dB.
1,000 ,, ...	0 dB.
10,000 ,, ...	0 dB.
Overall Efficiency on Carrier	33 per cent.
,, ,, ,, 100 per cent. Modulation	36.5 per cent.

Main Modulation Transformer.

The main modulation transformer merits more detailed consideration. It has been claimed by other manufacturers that to avoid high second harmonic it is essential to have an earthed screen between the primary and secondary windings. Such a screen increases both the size and cost of the transformer, while making it more liable to break down. Thus the manufacturers of screened transformers will only allow full power to be taken from the transformer at frequencies above 200 cycles for a very short period.

We have consistently maintained and recently proved that with our design of transformer no screen is required, and that its presence is a disadvantage and a source of weakness as previously stated. The following comparative figures are of great interest.

Comparison of Screened and Unscreened Transformers.

Each transformer was for 75 K.V.A. output.

	Type A. (Unscreened).	Type B. (Screened).
Primary Inductance Whole winding..	10 henries	24 henries
Secondary leakage Inductance ..	8.5 m.h.	24 m.h.
Self capacity referred to half primary..	2,500 mmf.	6,000 mmf.

Comparative Distortion Factor.

(measured at a level equal to 60 per cent. modulation of 140 kw. carrier.

	Frequency.	Distortion Factor Unscreened Transformer.	Distortion Factor Screened Transformer.
Input	1,000 cycles	.34%	.5%
Output	1,000 ,,	1.2%	1.12%
Input	2,050 ,,	.33%	.64%
Output	2,050 ,,	1.07%	1.7%
Input	4,000 ,,	.58%	.52%
Output	4,000 ,,	1.39%	2.23%

Frequency Response.

Frequency.	Unscreened.	Screened.
25 cycles	—0.5 dB.	—0.88 dB.
50 ,,	—0.14 dB.	—0.36 dB.
100 ,,	+0.07 dB.	—0.12 dB.
1,000 ,,	0 dB.	0 dB.
4,000 ,,	+0.17 dB.	—0.06 dB.
10,000 ,,	+0.08 dB.	—0.85 dB.

The conclusion must be that excellent results are obtained from an unscreened transformer of good design, and that there is no justification for adopting the more expensive and larger screened type.

Auxiliary Panels.

In addition to the panels already described, there are three other units forming part of the transmitter as a whole, namely, the Potentiometer Control Panel, the E.H.T. Cubicle and the Control Table.

The former as its name implies, houses the potentiometers and resistances for breaking down the main 500 volt grid negative supply, to the various voltages required for each individual panel, it also contains various smoothing units for grid bias and harmonic amplifier filament and H.T. supplies. All relays associated with the interlock and control circuits are also mounted on this panel.

The E.H.T. Cubicle contains the H.T. Switchgear for isolating all panels and earthing all dangerous supplies before access to the panels can be obtained. Mounted on the front is the mechanical interlock control. This operates the mechanical bolt preventing any of the doors giving access to the panels, and transmitter enclosure, from being opened when power is on. It also operates the H.T. switchgear, breaking supplies to the panels and earthing the latter. By means of an auxiliary switch coupled to the main interlock handle, the main electrical interlock line is broken on moving this handle to the off position, thereby tripping the circuit breakers in any supply that has inadvertently been left on. It is, therefore, clear that admittance to the transmitter or its enclosure is impossible whilst power is still on.

Control Table.

Complete monitoring and control of all power supplies is done on the control table. On the front panel of the table are fitted switches operating remote controlled starters, for various motor generator sets. These generators usually being in duplicate, selection is made by means of these switches. Voltage regulation is again performed by remote controlled motor driven field regulators, operated by conveniently placed handles on the desk of the table.

APPENDIX.

Series Modulation System.

Referring to Fig. 1 (E), the following points are clear by inspection.

V_3 and V_4 work in opposite phase. At the peak of modulation the grids of V_4 will be at the same potential as the filament (and load) and the volts drop across the valves will be small. This corresponds to minimum feed in V_3. At the trough of modulation, there should be no voltage across the load, the filaments of V_4 will

be at earth potential and the grids must be sufficiently negative to give cut off. Hence the voltage swing on the grids of V_4 is greater than that across the load by this amount. Cut off on the CAM. 5 valves requires that their grids and CAM. 4 anode shall be approximately 3,200 volts negative to filament or earth. The CAM. 4 anode cannot be less than 2,400 volts +ve to its filament. Hence the CAM. 4 filament should be 3,200+2,400=5,600 volts negative to earth.

Owing to the D.C. connection between the anode of V_3 and the grids of V_4, the carrier level can be varied by a varying voltage on the grid of V_3. This is provided by valve V_5, and its network in a manner to be described later. It will be noticed that the valves V_4 and the high frequency load form a cathode follower system, having numerous advantages as summarized below :—

(1) Non-linearity of the characteristics of V_4 has only a secondary effect on the linearity of the output provided the grid swing is linear.

(2) The hum due to the A.C. lighting of V_4 is very small as no voltage magnification occurs in V_4. With single phase lighting the hum level is about 55 dB. down, and the Scott arrangement reduces it to 70 dB.

(3) With a non-linear load the voltage swings across the load are still almost linear.

(4) If the load resistance is varied over wide limits, the voltage across the load only varies slightly, and the modulator settings are still O.K. Such a variation in load resistance occurs in practice when the output coupling is varied.

(5) If one modulator valve burns out or is removed from service, the remaining three take up the load automatically.

(6) Variation in H.T. voltage produces a small variation in load voltage so that the noise due to H.T. ripple is reduced.

(7) When the valves have been adjusted to take equal D.C. loads, the A.C. loads will also be approximately equal.

We can examine the working of the system best by combining the characteristics of the two valve stages in a particular way.

For V_3 (the CAM. 4 valve) we use the normal I_a V_a characteristics plotted for various values of V_{gf}. This is shown in the lower portion of Fig. 12. The total voltage across V_4 and resistance R_{11} is 22,000+5,500=27,500 V. The load line for the anode resistance of 25,000 ohms. will be abc, and starts from the base line at 27.5 K.V.

The controlling variable for V_4 the CAM. 5 valves is not grid to filament voltage, but grid to anode voltage (V_{ga}) and this should be used in plotting the characteristics. V_{ga} is the resistance drop across R_{11}, and if the CAM. 4 valve is set at b, is measured by mx the projection of bx on the V_a axis.

We therefore plot the characteristics of the CAM. 5 valves at various anode voltages directly above those of the CAM 4. taking V_{ga} for the horizontal axis and I_a for vertical axis, as shown in the upper curve. These characteristics are easily derived from the normal I_a V_a characteristics. The load line for 9,500 volts 15.7 amps. is ABC, cutting the V_{ga} axis for V_a = 22 K.V., and entering the positive grid region

at C. The scale for V_{g4} in the upper figure should be the same as that for V_a in the lower figure. Then if the two sets of characteristics are correctly positioned relative to each other, the working point on the upper diagram will always be vertically above the working point on the lower diagram. Thus the carrier settings B and b

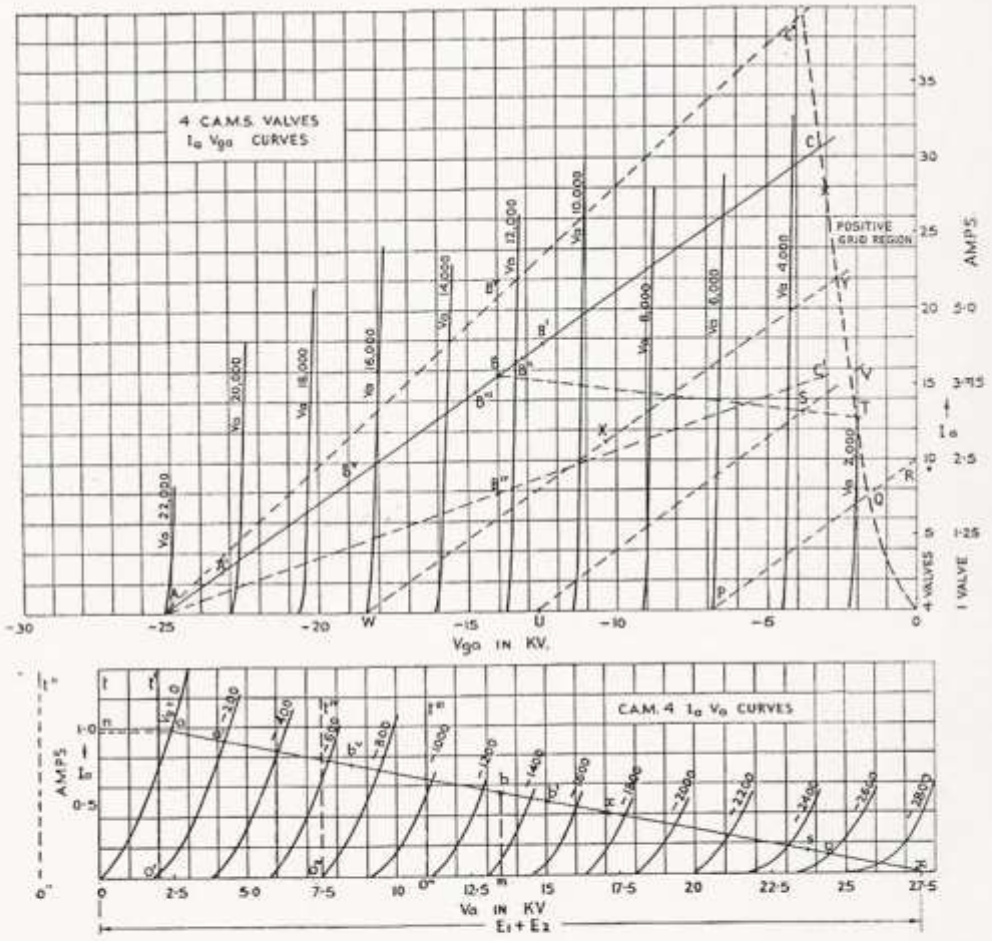


FIG. 12.

correspond. $V_{g4} = O$ when there is no current in R_{11}. Hence this axis must be directly above the point x where the R_{11} load line crosses the V_a axis, and this remains true for any variation of voltages on the system. These derived characteristics of the CAM. 5 valves are far more linear than the normal ones so that distortion due to this cause should be much less than normal.

The available voltage swing from the CAM. 5 is from A to C, where the positive grid region begins and grid current will flow. This is almost 19,000 volts equivalent to 100 per cent. modulation on a mean voltage of 9,500. The carrier setting B is at

the centre of this line. Hence the CAM. 4 valve must be set at " b " a grid bias of nearly 1,300 volts. At one end of the modulation swing the CAM. 4 valve swings into the region of grid current at " a " just before cut off on the CAM. 5 valves, while at the other end of the swing the CAM. 5's swing into grid current at C. The normal method of setting the carrier level is to apply modulation, and adjust the CAM. 4 grid bias until both CAM. 4 and CAM. 5 valves just touch grid current at the same level of modulation. The cut off point on the CAM. 5 valves should lie vertically above " a " or slightly to the left for optimum working conditions, as shown in the figure. This setting is determined by the total voltage across the CAM. 4 and its resistance. This must be equal to the value of V_{g1} on the CAM. 5 to give cut off (25,000 V.) + n.a, the minimum voltage drop across the CAM. 4 (2,400 V.) = 27,400. (27,500 is used in figure). The main H.T. is 22,000, hence the filament bias voltage must be 27,400 — 22,000 = 5,400 V.

We can now determine what happens when various settings are altered.

Alteration of Filament Bias.

The load line remains fixed in position on the diagram while the zero axis " ot " and the characteristic curves move bodily to the left (increase) or right (decrease) by the amount of the change. As the grid bias is unchanged, the point " b " slides along the load line retaining its relative position among the characteristic curves. Thus suppose the filament bias is reduced by 2,000 volts. The new position of ot will be $o^{1}t^{1}$, and the curve for V_g = —200 becomes that for V_g = O, and so on, so that " b " move to b^{1} and B to B^{1}, so that the carrier level has increased. The lower limits of the modulation swing are now a^{1} and A^{1}, so that the possible swing has been reduced by about 1,800 volts. To bring the carrier setting to the centre of the modulating swing b^{11} we must reduce the CAM. 4 grid bias by 100 volts. The final result is a higher carrier level (load volts 10,400) and a modulation swing reduced to 17,000 corresponding to a maximum modulation of 82 per cent.

On the other hand, if the filament bias were increased by a similar amount, $o^{11}t^{11}$ would be the new zero axis, a^{11} would be well to the left of A, where the CAM. 5 valves cut off.

If the carrier level were set central by the grid current method to B^{111}, distortion would result due to CAM. 5 cut off.

The carrier could be restored to its old level at B by 200 volt increase of CAM. 4 grid bias, and the full modulation swing would be available. The grid current limit would only show on the CAM. 5's.

Variation of Load on H.F. Output Stage.

This is equivalent to altering the load resistance on the CAM. 5's. Thus, if the H.F. output were halved, the effective load resistance would be approximately doubled. This gives the load line $AB^{iv}C^{1}$. The carrier level B^{iv} will be vertically above " b," and the voltage on the load is practically unchanged. The modulation conditions are unchanged except that C^{1} is well clear of the grid current region. The efficiency of working could be increased by reducing the H.T. supply by 1,000 volts, and resetting the carrier level slightly.

If the drive fails on the H.F. panel, the load resistance will be increased to that of the voltmeter acrosss the panel, but the voltage across it will only increase very slightly.

Removal of One Modulator Valve.

If working on 3 valves instead of 4, the working line at full load would be AB^vC^{11}, and the load voltage would be almost unchanged. A slight adjustment of CAM. 4 grid bias would be required to maintain a central setting. To avoid overload it would be advisable to reduce the feed to the modulated H.F. amplifier.

Variation of H.T. Voltage.

The conditions during the running up of H.T. voltage can also be analysed, assuming all other supplies set to their normal values. The CAM. 4 valve will not commence to take current until the total voltage across it is 11,500 volts, *i.e.*, H.T. = 11,500 — 5,500 = 6,000. The load line on the CAM. 5 valves for this voltage is PQR, and if no grid current flowed, the static setting would be at R. Grid current, however, produces a voltage drop in R_{11}, and the static setting moves nearly to Q on the boundary of the positive grid region.

For H.T. voltage of 11,000, the voltage on the CAM. 4 is 16,500, so that the zero axis moves to $o^{iii}\ t^{iii}$. The characteristic marked V_g = 1,200 will correspond to V_g = 0 so that the static setting moves to " s." The load line for the CAM. 5's is USV, S vertically above " s " being the static setting, and so on. The locus of the static setting as the H.T. is varied is therefore OQTSB. Up to point T, where CAM. 5 grid current ceases, there is only a small voltage drop across the modulators, most of the voltage appearing across the H.F. panel. Beyond T the voltage across the modulators increases rapidly, and that across the H.T. panel slowly. So that at the normal carrier setting, variation in H.T. voltage produces about 1/8 of the variation in load voltage. Any noise on the H.T. supply will be greatly reduced on the load.

Adjustment to work at a lower H.T. Voltage.

Providing H.T., CAM. 4 filament bias and grid bias are reduced in the same proportion, the static settings will be substantially correct. This follows from the linearity of the various characteristics, but has been checked out on the diagram for the case where the main H.T. is reduced to 16,000, the proportionate values of filament and grid bias being 4,000 and 930 volts. The load line on the CAM. 5 characteristics is WXY, central setting X. The CAM. 4 setting is x, and the required zero axis is $o^{iv}t^{iv}$. This gives a total voltage on the CAM. 4 of 20,000, leaving filament bias at 20,000 — 16,000 = 4,000. Grid bias at x = 1,750 — 800 = 950.

The line input should also be reduced in proportion.

Floating Carrier Circuits and Adjustments.

If for the floating carrier condition we wish to move to half feed ($\frac{1}{4}$ power) at zero modulation B^v will be the CAM. 5 setting and b^v that of the CAM. 4. This requires a reduction in CAM, 4 grid bias to 700 volts, a change of 1,280 — 700 = 580 volts approximately, and provision must be made to vary this bias linearly with modulation so that full bias and carrier are restored at full modulation. The increase in bias must be rapid to cover rapid increase in modulation, and the return relatively slow (period $\frac{1}{2}$ to 1 second). This is done by V_5 (DA. 100 valve) and its associated circuits shown in (E) Fig. 1. This valve is lit in parallel with the CAM. 4, and its anode feed is supplied through R_8 from the filament bias supply.

This valve V_5 is operated as an anode bend rectifier, by high level audio frequency power. This is supplied to the grid of V_5 from the anode of the sub-modulator

valve V_4 through condensor C_4, potentiometer R_5 and resistance R_9. The condenser C_8 is a by-pass for high audio frequencies to maintain the frequency response of the floating carrier at a uniform level.

In the quiescent state the grid of V_5 is made sufficiently negative to filament, to cut off anode feed. The voltage across C_5 is high, and the tapping for the grid bias of V_3 on R_6 is adjusted to suit. When modulation is applied, V_5 will conduct on the positive swing and reduce the voltage across C_5. This increases the grid bias on V_3, and increases the carrier level as required. If the audio swing is sufficiently great, the grid of V_5 goes positive to filament, and grid current flows through the high resistance R_9. This limits the anode current and the minimum voltage across C_5. This is set to coincide with the carrier level required for full modulation. Further, increase of modulation will only change the voltage across C_5 very slightly.

The adjustment of the floating carrier to any desired value is a simple matter. The filament bias and R_8 are normally fixed, so that the degree of float is entirely governed by R_7. From the characteristics on Fig. 11 we saw that to reduce to $\frac{1}{4}$ power at zero modulation, we require a change of 580 volts on CAM. 4 grid bias. The minimum volts across V_5 are about 150, hence the maximum volts must be $580 + 150 = 730$ approximately. R_7 is set to the calculated value to give this voltage drop. Then with all supplies normal but main H.T. off, the grid bias on the DA. 100 is adjusted so that with no modulation the valve is just clear of anode feed. Then tone is applied, and gradually increased until the D.A. 100 just shows grid current. The input level at which this occurs is noted, and the tapping on R_5 is adjusted so that it occurs at the input level corresponding to 90 per cent. modulation. Main H.T. is now applied, and with 90 per cent. modulation the bias of the CAM. 4 is adjusted so that H.F. stage is at normal H.T. (9,500 volts). Modulation is reduced to zero, and the carrier level checked. If it is not correct, R_7 must be altered in the direction indicated and the process repeated.

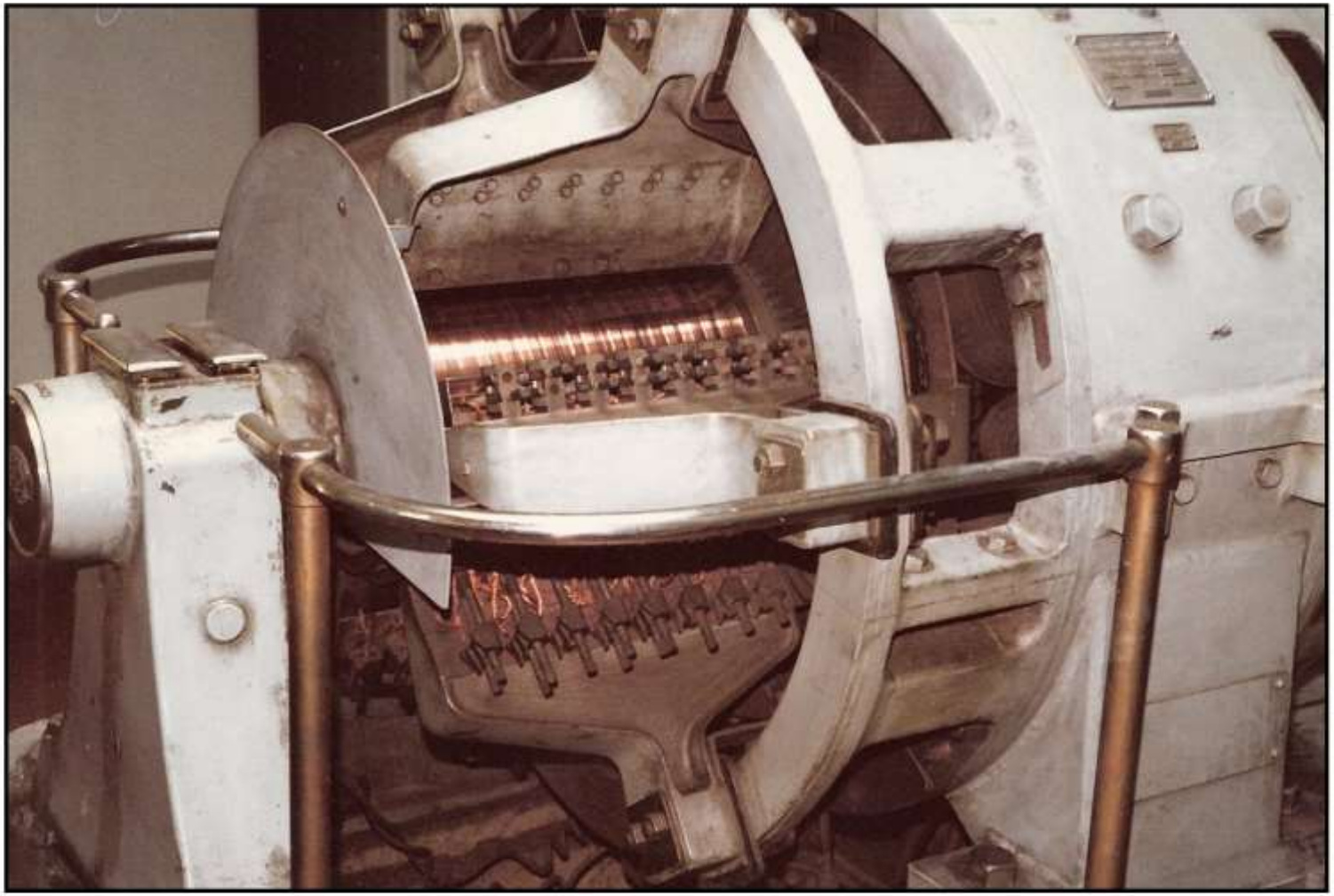
E. GREEN.
L. T. MOODY.

THE SWB 18 TRANSMITTER AT THE BBC IN DAVENTRY PRIOR TO THE B6126 BEING INSTALLED ~1970

L to R: Ewan Fenn and Basil Francis of Marconi, ? and Brian Slater of the BBC

Photo courtesy Ewan Fenn

THE FILIAMENT GENERATOR OF THE SWB 18 TRANSMITTER AT BBC DAVENTRY ~1970



The filament generator produced 30V at 2000 Amperes and was still running in the early 1970s!

Photo courtesy Ewan Fenn