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 H 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.
- Wavetrain ... 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 r cycle per second with 80 per cent. modulation.

(1)
100 kw. Short Wave Broadcasting Transmitter. Type S.W.R. 14 & 18.

Fig. 1.

(e)
Fig. 1.

(a)

ELEVEN CRYSTAL DRIVES IN DUPLICATE AND ASSOCIATED APPARATUS

(b) 1 VALVE DRIVE

TO AMPOLE SUPPLY

TO AMPOLE SUPPLY

TO AMPOLE SUPPLY

TO AMPOLE SUPPLY

TO AMPOLE SUPPLY

TO AMPOLE SUPPLY

TO AMPOLE SUPPLY

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TO AMPOLE SUPPLY

TO AMPOLE SUPPLY

TO AMPOLE SUPPLY

FINAL STAGE ONLY

FREQUENCY MULTIPLYING AND AMPLIFYING UNITS AS SHOWN ABOVE

LT SUPPLY

NE

NE2
The design of the transmitter, to be known later as the S.W.B.14 High Power Short Wave Transmitter, was commenced in 1930. 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 neutral 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 fixed 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) has 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.

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 to 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.

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 especial 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 manoeuvred 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 tires. 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 input 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.

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 insidious 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 realignment.

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 skillful 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 L1, L2, Fig. 1 (a), tuned by a condenser, the anode inductance L3 tuned by its condenser and the balancing condensers C4.
Various additional refinements have been added to improve the performance, the chief among which are the following:—$C_3$, are grid reactance condensers for neutralising the inductance of the grid leads; $C_{14}$, $C_{15}$, and $C_{16}$, 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 $R_5$ 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 "squelch." $R_5$ 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 $L_7$ 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:—

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filament Volts</td>
<td>32.5 volts</td>
</tr>
<tr>
<td>Filament Amperes</td>
<td>400.0 amperes</td>
</tr>
<tr>
<td>Emission at 90 per cent. saturation</td>
<td>100.0 amperes</td>
</tr>
<tr>
<td>Anode volts for telephony</td>
<td>11,000 volts</td>
</tr>
<tr>
<td>Maximum anode dead loss</td>
<td>150.0 kw.</td>
</tr>
<tr>
<td>Grid anode capacity</td>
<td>70.0 mmf.</td>
</tr>
<tr>
<td>Grid filament capacity</td>
<td>100.0 mmf.</td>
</tr>
<tr>
<td>Anode filament capacity</td>
<td>24.0 mmf.</td>
</tr>
<tr>
<td>Filament earthed</td>
<td></td>
</tr>
</tbody>
</table>

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.

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 track 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.

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 over-heating 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 wave range (13.5-80 metres). Where necessary grid resistance 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 manoeuvre 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:

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.

<table>
<thead>
<tr>
<th>Metres</th>
<th>Kw. Input</th>
<th>% Efficiency</th>
<th>Kw. Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>150</td>
<td>66</td>
<td>100</td>
</tr>
<tr>
<td>50</td>
<td>150</td>
<td>70</td>
<td>105</td>
</tr>
<tr>
<td>30</td>
<td>150</td>
<td>79</td>
<td>105</td>
</tr>
<tr>
<td>25</td>
<td>150</td>
<td>66</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
<td>150</td>
<td>64</td>
<td>95</td>
</tr>
<tr>
<td>15</td>
<td>140</td>
<td>61</td>
<td>85</td>
</tr>
<tr>
<td>13.5</td>
<td>135</td>
<td>60</td>
<td>80</td>
</tr>
</tbody>
</table>
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.](image)

In the series modulation system used on long and medium waves, the filaments of the modulator valves 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 (b).

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 $V_1$ (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 $V_2$ and $V_3$. 

(13)
V₂ is the valve that provides the floating carrier control. It is operated as an anode bend rectifier, its alternating grid voltage being supplied from V₂.

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 I. 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:—

<table>
<thead>
<tr>
<th>Modulation</th>
<th>With Floating Carrier</th>
<th>Without Floating Carrier</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Input</td>
<td>Distortion.</td>
</tr>
<tr>
<td></td>
<td>A.C. Mains.</td>
<td>400 ̊V</td>
</tr>
<tr>
<td>0%</td>
<td>310 kw.</td>
<td>—</td>
</tr>
<tr>
<td>30%</td>
<td>385 ..</td>
<td>1%</td>
</tr>
<tr>
<td>60%</td>
<td>407 ..</td>
<td>3.7%</td>
</tr>
<tr>
<td>90%</td>
<td>454 ..</td>
<td>4.6%</td>
</tr>
<tr>
<td>100%</td>
<td>470 ..</td>
<td>6%</td>
</tr>
</tbody>
</table>

**Frequency Response.**

<table>
<thead>
<tr>
<th>Frequency (kHz)</th>
<th>Response (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>1.5</td>
</tr>
<tr>
<td>1,000</td>
<td>0</td>
</tr>
<tr>
<td>10,000</td>
<td>1.0</td>
</tr>
</tbody>
</table>

(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.

(14)
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.
(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.

<table>
<thead>
<tr>
<th>% Modulation</th>
<th>Total Input from A.C. Mains</th>
<th>Distortion at 400 %</th>
<th>Distortion at 8,000 % 2nd harmonic only</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>311 kw.</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>30%</td>
<td>324 &quot;</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>—</td>
<td>1.5%</td>
<td></td>
</tr>
<tr>
<td>90%</td>
<td>411 kw.</td>
<td>3.4%</td>
<td>2.4%</td>
</tr>
<tr>
<td>100%</td>
<td>444 &quot;</td>
<td>3.5%</td>
<td></td>
</tr>
</tbody>
</table>

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

Frequency Response.

39 ... ... ... ... ... -2.0 dB.
59 ... ... ... ... ... -0.7 dB.
1,000 ... ... ... ... ... 0 dB.
10,000 ... ... ... ... ... 1.8 dB.

( 16 )
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 16 kW, by reducing the static feed on the main modulators, with slightly reduced distortion and improved frequency response.

**Performance with 5dB Feed-back.**

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Total Input From A.C. Mains.</th>
<th>Distortion at 400 cycles.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>300 kw.</td>
<td>0</td>
</tr>
<tr>
<td>30%</td>
<td>314</td>
<td>0.5%</td>
</tr>
<tr>
<td>90%</td>
<td>400</td>
<td>2.6%</td>
</tr>
</tbody>
</table>

**Frequency Response.**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Response</th>
<th>30 cycles</th>
<th>1,000</th>
<th>10,000</th>
<th>Overall Efficiency on Carrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 dB</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>33 per cent.</td>
</tr>
<tr>
<td>0 dB</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>33 per cent.</td>
</tr>
<tr>
<td>0 dB</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>33 per cent.</td>
</tr>
</tbody>
</table>

**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 Unscrened Transformers.**

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

<table>
<thead>
<tr>
<th>Transformer</th>
<th>Type A (Unscreened)</th>
<th>Type B (Screened)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Inductance Whole winding</td>
<td>10 henries</td>
<td>24 henries</td>
</tr>
<tr>
<td>Secondary leakage Inductance</td>
<td>8.5 m.h.</td>
<td>24 m.h.</td>
</tr>
<tr>
<td>Self capacity referred to half primary</td>
<td>2,500 m.mf.</td>
<td>6,000 m.mf.</td>
</tr>
</tbody>
</table>

**Comparative Distortion Factor.**

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

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Input</th>
<th>Output</th>
<th>Input</th>
<th>Output</th>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 dB</td>
<td>1,000 cycles</td>
<td>34%</td>
<td>5%</td>
<td>1,2%</td>
<td>1.12%</td>
<td></td>
</tr>
<tr>
<td>0 dB</td>
<td>1,000</td>
<td>33%</td>
<td>1.0%</td>
<td>1.74%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 dB</td>
<td>2,050</td>
<td>58%</td>
<td>52%</td>
<td>2.23%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 dB</td>
<td>4,000</td>
<td>39%</td>
<td>2.23%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(17)
Frequency Response.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Unscrened</th>
<th>Screened</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 cycles</td>
<td>-0.5 dB</td>
<td>-0.88 dB</td>
</tr>
<tr>
<td>50</td>
<td>-0.14 dB</td>
<td>-0.36 dB</td>
</tr>
<tr>
<td>100</td>
<td>+0.07 dB</td>
<td>-0.12 dB</td>
</tr>
<tr>
<td>1,000</td>
<td>0 dB</td>
<td>0 dB</td>
</tr>
<tr>
<td>4,000</td>
<td>+0.17 dB</td>
<td>-0.06 dB</td>
</tr>
<tr>
<td>10,000</td>
<td>+0.08 dB</td>
<td>-0.85 dB</td>
</tr>
</tbody>
</table>

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.

V3 and V4 work in opposite phase. At the peak of modulation the grids of V1 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 V3. At the trough of modulation, there should be no voltage across the load, the filaments of V4 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 \( V_3 \) 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 \( V_a \). This is shown in the lower portion of Fig. 12. The total voltage across \( V_4 \) and resistance \( R_{in} \) 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 (\( V_m \)) and this should be used in plotting the characteristics. \( V_m \) is the resistance drop across \( R_{in} \), and if the CAM. 4 valve is set at a, 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 \( V_m \) 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 \( V_m \) axis for \( V_a = 22 \) K.V., and entering the positive grid region

\( (10) \)
at C. The scale for $V_m$ in the upper figure should be the same as that for $V_m$ 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 correspond. $V_m = 0$ 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 $V_m$ 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

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the centre of this line. Hence the CAM. 4 valve must be set at " b " a grid bias of nearly 1,500 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 valve, 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 $V_e$ on the CAM. 5 to give cut off (25,000 V) + 2 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 o will be o'r, and the curve for $V_e = -200$ becomes that for $V_e = 0$, and so on, so that " b " move to b' and B to B', so that the carrier level has increased. The lower limits of the modulation swing are now a' and A', 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'n 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 8a per cent.

On the other hand, if the filament bias were increased by a similar amount, a'n would be the new zero axis, a'n 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'n, 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'C. The carrier level B will be vertically above " b " and the voltage on the load is practically unchanged. The modulation conditions are unchanged except that C' 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 across the panel, but the voltage across it will only increase very slightly.

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Removal of One Modulator Valve.

If working on 3 valves instead of 4, the working line at full load would be AB'C'M, 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 PQ, and if no grid current flowed, the static setting would be at Q. Grid current, however, produces a voltage drop in R₉, 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 001 111. The characteristic marked V₈ = 2,000 will correspond to V₇ = 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 950 volts. The load line on the CAM. 5 characteristic is WXY, central setting X. The CAM. 4 setting is X, and the required zero axis is 001 111. 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 (12 power) at zero modulation R₆ will be the CAM. 5 setting and be 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 12 to 1 second). This is done by V₇ (DA 100 valve) and its associated circuits shown in (b) Fig. 1. This valve is lit in parallel with the CAM. 4, and its anode feed is supplied through R₆ from the filament bias supply.

This valve V₇ is operated as an anode bend rectifier, by high level audio frequency power. This is supplied to the grid of V₇ from the anode of the sub-modulator.
valve $V_3$ through condenser $C_4$, potentiometer $R_3$ and resistance $R_6$. The condenser $C_4$ 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 $V_3$ is made sufficiently negative to filament, to cut off anode feed. The voltage across $C_3$ is high, and the tapping for the grid bias of $V_3$ on $R_4$ is adjusted to suit. When modulation is applied, $V_3$ will conduct on the positive swing and reduce the voltage across $C_3$. 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 $V_3$ goes positive to filament, and grid current flows through the high resistance $R_6$. This limits the anode current and the minimum voltage across $C_3$. This is set to coincide with the carrier level required for full modulation. Further, increase of modulation will only change the voltage across $C_3$ very slightly.

The adjustment of the floating carrier to any desired value is a simple matter. The filament bias and $R_4$ are normally fixed, so that the degree of float is entirely governed by $R_7$. From the characteristics on Fig. III we saw that to reduce to 1/2 power at zero modulation, we require a change of 580 volts on CAM. 4 grid bias. The minimum volts across $V_3$ are about 150, hence the maximum volts must be $580 + 150 = 730$ approximately. $R_3$ 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 DA 100 just shows grid current. The input level at which this occurs is noted, and the tapping on $R_3$ 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. (9500 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 filament generator produced 30V at 2000 Amps and was still running in the early 1970s.

The filament generator of the SWB 18 transmitter at BBC Daventry in 1970.