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HIGH-POWER U.H.F TELEVISION TRANSMITTER SYSTEMS

In Europe and the United States there is a steadily rising demand for u.h.f television transmitters, capable of handling colour or monochrome signals as more channels are opened up by broadcasting concerns. As with all transmitting equipment, output power, reliability and running costs (maintenance and power consumption) are of prime interest to the user.

A colour television transmitter must have a high and stable performance if the colour information is not to be distorted. To satisfy these requirements, multi-cavity klystrons are used rather than tetrodes as final amplifiers, and the reasons for this choice have been discussed previously.[1]

SIMPLE U.H.F TRANSMITTER SYSTEMS

Currently available four-cavity klystrons have gains in the region of 40 dB, so that a driving power of a few watts is sufficient for an output of tens of kilowatts. A 10-W transmitter, such as the Marconi B7300, can be used to drive any of the Marconi u.h.f amplifiers whose outputs are in the range 5–40 kW. The amplifiers contain a variable attenuator to take up the range of klystron gains. The driving transmitter must contain a video correction unit which is used to compensate for the differential gain, differential phase and group delay errors introduced by the klystron. Fig. 1 shows the typical arrangement of a simple transmitting chain.

The amplifier accepts 10W peak synchronizing power vision signal (negative modulation) and 10W f.m sound signal from the driving transmitter. Identical klystrons are used as vision and sound amplifiers so that only one type of klystron is needed as a station spare. The two klystrons are operated from the same h.t supply, but the sound power is only one-fifth of the peak vision synchronizing power. So that the efficiency of the sound klystron is no less than that of the vision klystron, the beam power is reduced by reducing the beam current. This is achieved by applying a suitable bias to the sound klystron modulating anode.

The four cavities of the vision klystron are effectively stagger tuned to give the required vestigial sideband characteristic in conjunction with a suitable filter.

The sound klystron is tuned to give a comparatively narrow bandwidth, which may be broadened if necessary to reduce the gain. Thus there is no need for a variable attenuator before the sound klystron.

The high-power vision and sound signals are then combined in an external unit which will also contain resonators to absorb the colour subcarrier image which is generated by the klystron non-linearity. The v.s.b shaping which is needed beyond that given by the klystron may be done either at low level before the klystron, or at high level in the combining unit, in which case the combining unit is commonly referred to as a filterplexer.

The performance of such a transmitting chain can be adjusted to meet BBC, CCIR or FCC requirements, and can handle either NTSC, PAL or SECAM colour signals with imperceptible distortion. A 10-kW transmitter chain of this type has been supplied recently to Denmark, and the first phase of the Swedish Telecommunications Administration's expansion into u.h.f will use Marconi 10-kW and 40-kW transmitters.

RELIABILITY

Over a large number of equipment running hours it is possible to establish a certain failure rate, usually expressed as a mean time between failures (MTBF). A failure may be defined as an event which places the transmitter performance out of specification, the simplest case being an event which produces zero output power. The MTBF can be estimated at the design stage from a knowledge of individual component failure rates and their stress level. As with any statistical exercise, the accuracy of the prediction can only be increased by accumulating a history of all failures and their circumstances. A consistent pattern of failures will locate any hidden design shortcomings which can then be eradicated. If the user co-operates with the manufacturer by reporting all failures in as much detail as possible, valuable information is gained which can be used to increase the reliability of future designs.

The reliability of a single transmitting chain such as that described above can be not better than the reliability of the weakest link, i.e the component with the highest failure rate, often a pump or some other piece of moving machinery.

It has long been known, and indeed proven, that the reliability of a system is significantly increased by building in redundancy, the simplest example being where the weakest link is duplicated. If there is a 10% chance that one of a pair will fail over a given period, the chance that both will fail in the same period is simply 10% of 10%, i.e 1%. If this 1% corresponds to a failure rate comparable with that of the unavoidable common parts of a duplicated system, then the duplication increases the system reliability. Full duplication is somewhat expensive and most broadcasting authorities specify a system which will radiate at reduced power in the event of a fault in one half of the system. Any number of schemes is possible, but three recent ones will be discussed.

PARALLELED AMPLIFIERS WITH WORKING AND STANDBY C.W DRIVES

The first generation of Marconi u.h.f transmitters (as supplied to the BBC in 1963) used a pair of B7300 transmitters followed by a pair of B7301 water-cooled 25-kW amplifiers at each station. The details of these stations have been fully described in a previous issue,[2] but the reasons for the system configuration will be discussed briefly.

When transmitters and amplifiers are run in parallel, they must of course radiate on precisely the same frequency, so at any one time the c.w drive for both transmitters is derived from one crystal oscillator. Two crystal oscillators are provided, which are buffered by cross-coupled muting amplifiers and thence to a hybrid giving one output for each transmitter. Should one crystal oscillator fail, the other is automatically allowed to take over via its muting amplifier. Fig. 2 shows the arrangement of crystal oscillators, transmitters and amplifiers. Following the hybrid splitter, each chain is fully duplicated. Each klystron amplifier is preceded by its own modulator and video correction unit so the same high performance can be had from either chain if the individual klystron performances differ somewhat. The klystron amplifiers are obvious candidates for duplication since they contain motors, adjustable high-power tuned circuits, heavy currents and high voltages. Each amplifier has its own combining unit for the vision and sound signals, and the v.s.b shaping may be done at high or

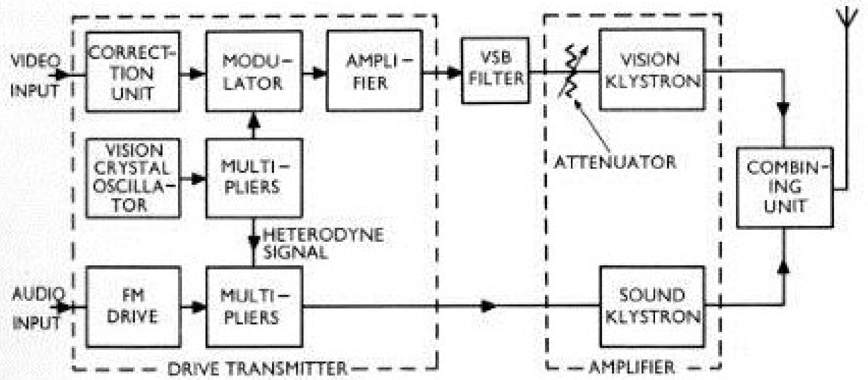

Fig. 1. A typical single transmitting chain.

low level. The two combined vision and sound signals are fed to a duplexer. Automatic equipment controls the relative phases of the A and B chains, so that the two contributions add and pass on to the antenna.

The action of a diplexer has been described previously in this journal,[2] where it is shown that if the power to one input of the diplexer disappears, the remaining input power splits equally between the antenna and the balancing load. Thus if one transmitter or amplifier fails, the radiated power falls to quarter of its normal value, unless steps are taken to bypass the diplexer when the reduced power will only be half of its normal value.

The unavoidable common parts of the system are the vision and sound drive splitters, the diplexer and the phasing gear. Four klystrons are used altogether

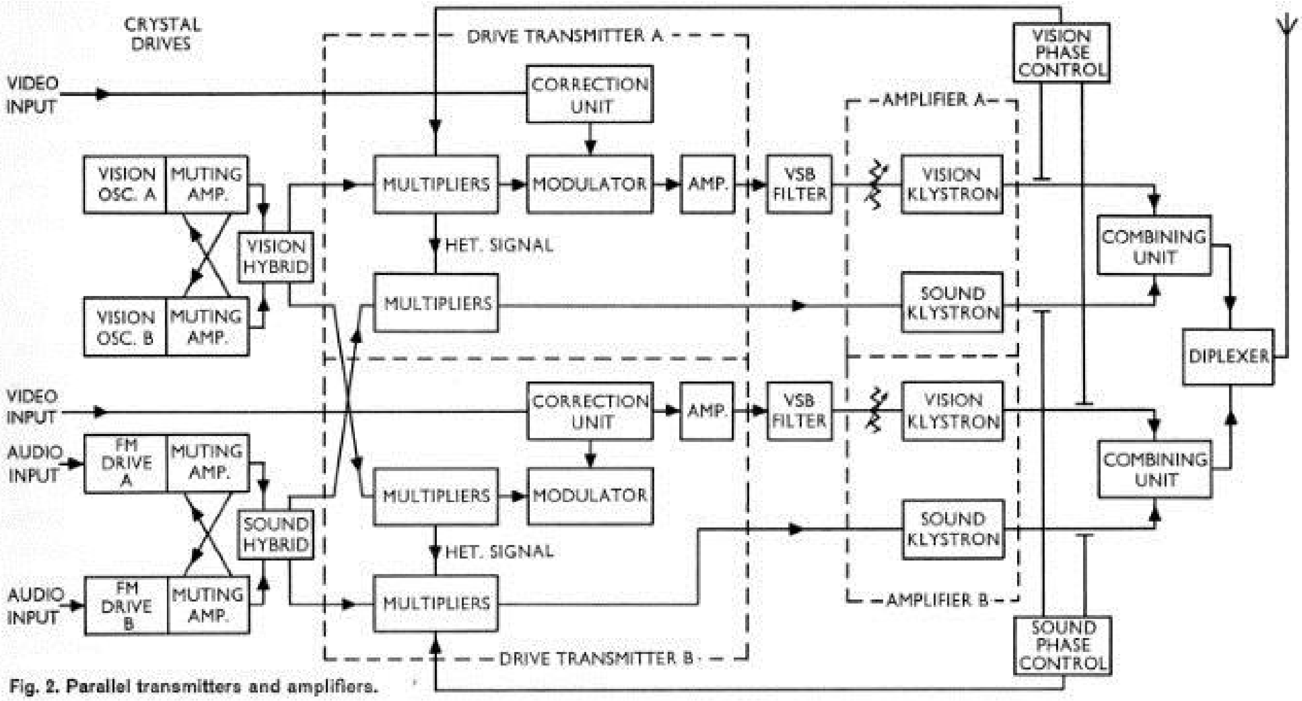

Fig. 2. Parallel transmitters and amplifiers.

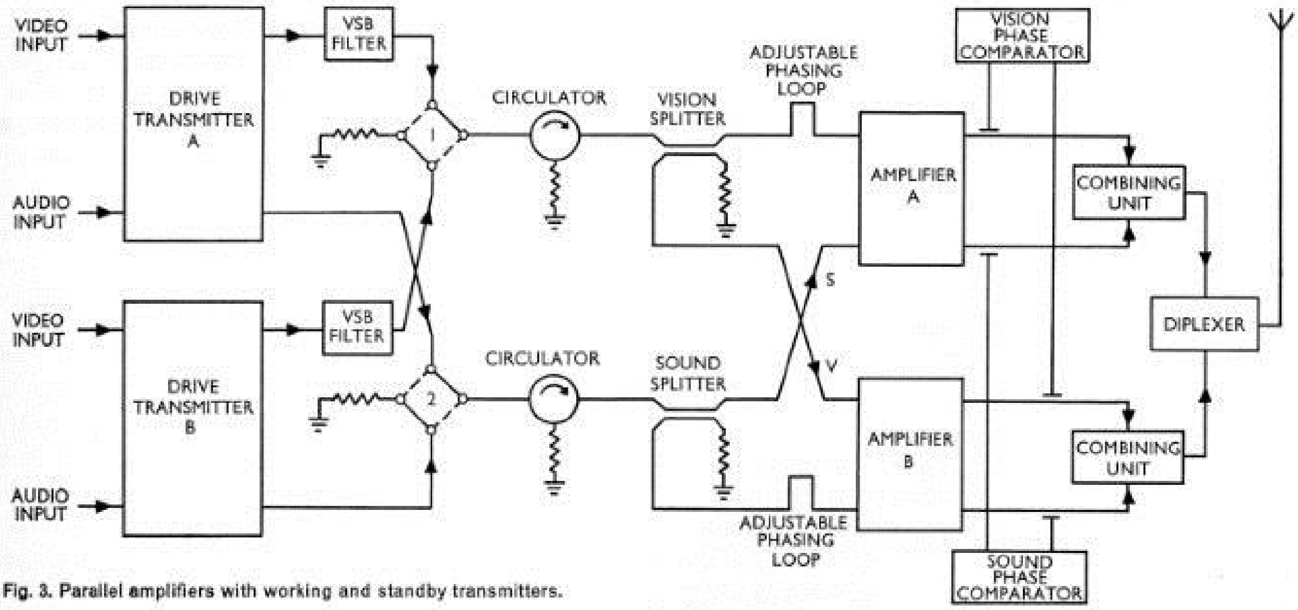

Fig. 3. Parallel amplifiers with working and standby transmitters.

and as much of the equipment as possible is normally in service all the time, so the performance can be monitored continuously, by vertical interval testing for example, and speedily corrected if necessary.

PARALLELED AMPLIFIERS WITH WORKING AND STANDBY TRANSMITTERS

An alternative arrangement is to drive both amplifiers from one driving transmitter, keeping the second transmitter in reserve, as shown in Fig. 3. The vision and sound signals are each split by a 3-dB quarter-wave stripline coupler. In each path there is an adjustable phasing loop, and the relative phase is indicated by separate comparators on the vision and sound feeders. The functions of the A and B transmitters can be interchanged by operating switches 1 and 2. If one transmitter fails the other can be brought into service with no loss of output power, but if one amplifier fails the power will be reduced to one-quarter of its normal value as in the first system. The advantage is that one transmitter can be serviced without reduction of power or interruption of service. There are two disadvantages. The performance of the standby transmitter is not known until it is put into service unless additional monitoring equipment is laid on. Alternatively, the two transmitters could be interchanged daily using a time clock. Also, each transmitter has to provide rather more than twice the normal power to drive the two amplifiers simultaneously.

KLYSTRON MULTIPLEX SYSTEM

This is probably the most unusual system and it has brought to light an unsuspected property of the klystron, which will be described later.

One klystron can handle both vision and sound signals simultaneously, provided that the demanded output power is much reduced.

Marconi 1-kW transposer amplifiers type B7310, use what is basically a 10-kW vapour-cooled klystron to provide 1-kW peak vision power and 200 W f.m sound power. The klystron has to be run on the very linear lower portion of its transfer characteristic, otherwise intermodulation products of an unacceptable amplitude are formed. The most objectionable of these is formed by the interaction of the colour sub-carrier and the sound carrier signals, whose difference frequency fails in the video passband and which would be very evident on a displayed picture if the klystron were working anywhere near its full output capability. It is the permissible amplitude of this intermodulation product which dictates the level at which the klystron may operate. About a 10 : 1 reduction in output power gives a good performance.

The essence of the klystron multiplex system is the use of separately powered sound and vision amplifiers each of which can be used as a standby for the other by carrying combined sound and vision signals at reduced power in the same way as described above in the transposer application.

Some of the second generation u.h.f stations in this country will use the multiplex system. Two amplifiers, type B7308 are to be used, which each contain only one 40-kW klystron. The amplifiers are designated A and B with A normally for vision and B normally for sound. Should amplifier A fail, vision and sound are routed through amplifier B, and vice versa. Both klystrons are tuned identically, i.e with sufficient bandwidth to carry vision and sound simultaneously. The changeover from one condition to another has to be fully automatic, so there can be no question of retuning the klystrons for different conditions. A setting has to be found which is good for all conditions.

It will be recalled that in an amplifier containing vision and sound klystrons, the sound klystron is tuned narrow band, and runs off the same h.t supply as the vision klystron, and its beam current is reduced by modulating anode bias, the object being to equalize vision and sound amplifier efficiencies. To use the same technique in the multiplex system, the B amplifier would have to be biased back when handling sound only, and the bias would have to be removed to allow full beam current when handling both sound and vision in the standby condition. There is, however, a serious disadvantage, due to the properties of the klystron.

It has been found that if a broad-band tuned klystron has its beam current reduced while the h.t is held constant, the frequency response sags severely at the higher-frequency end, i.e exactly where the sound-carrier frequency lies (Fig. 4). The result is that at the sound-carrier frequency, both the gain and the efficiency deteriorate.

Fortunately in this system the normal vision and sound amplifiers have independent h.t supplies and so the h.t voltage of the B amplifier can be reduced. Then of course the saturated output power falls, but the gain and the efficiency are maintained at sound-carrier frequency. It is not quite true to say that the A and B amplifiers are identical, the klystrons are tuned identically, but the B amplifier has to have this provision for altering the h.t voltage by remote control.

Fig. 5 shows the arrangement of the driving transmitters, amplifiers and the input and output switching.

With the solid links as drawn, driving transmitter A supplies the appropriately corrected normal drive signals and transmitter B is set up for the standby conditions. Low-level v.s.b shaping is used. In the standby condition, vision and sound are combined in the stripline coupler. The circulators are necessary to isolate the vision and sound transmitter output stages and variable attenuators are used to set up the reduced drive levels needed.

The roles of transmitters A and B can be interchanged by moving all the solid links to the dotted positions.

Detectors on the output feeders of each amplifier sense whether or not the levels are normal and send signals to the changeover equipment. The changeover equipment is a solid-state logic unit whose outputs operate the relays and feeder switches to the standby arrangement in the event of a fault. Switches 1 and 2 are coaxial transfer relays which connect the amplifiers to the appropriate inputs. Switches 3, 4 and 5 are motorized feeder switches which bypass the combining unit and connect either amplifier directly to the antenna if need be. Switch 6 is manually operated when it is necessary to connect the B amplifier directly to the test load.

The great advantage of the system is that only two klystrons rather than four are needed to provide normal service and reduced standby power. For equal normal and standby performance the power reduction would have to be about 10 : 1, but if a slightly inferior performance can be tolerated for the standby period, a power reduction of 5 : 1 will suffice. The unavoidable common components are the motorized feeder switches and the relatively complicated solid-state control unit, but the reliability of the common components is likely to be significantly higher than that of the klystron amplifiers alone.

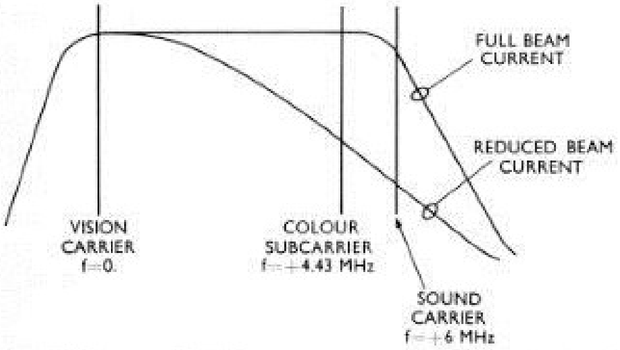

Fig. 4. Klystron amplitude/frequency response with full and reduced beam current.

10-kW KLYSTRON AMPLIFIERS, TYPES B7314 AND B7315

The 10-kW amplifiers use English Electric Valve Company's K370 series klystrons, which have four external tuning cavities and vapour-cooled collector. The numerous advantages of vapour cooling have been discussed recently in a previous issue.[3] The amplifiers consist of one cabinet per klystron with its associated heater and focus current supply (Figs. 6 and 7) and one control and h.t power supply cabinet. The B7314 has only one klystron for multiplex

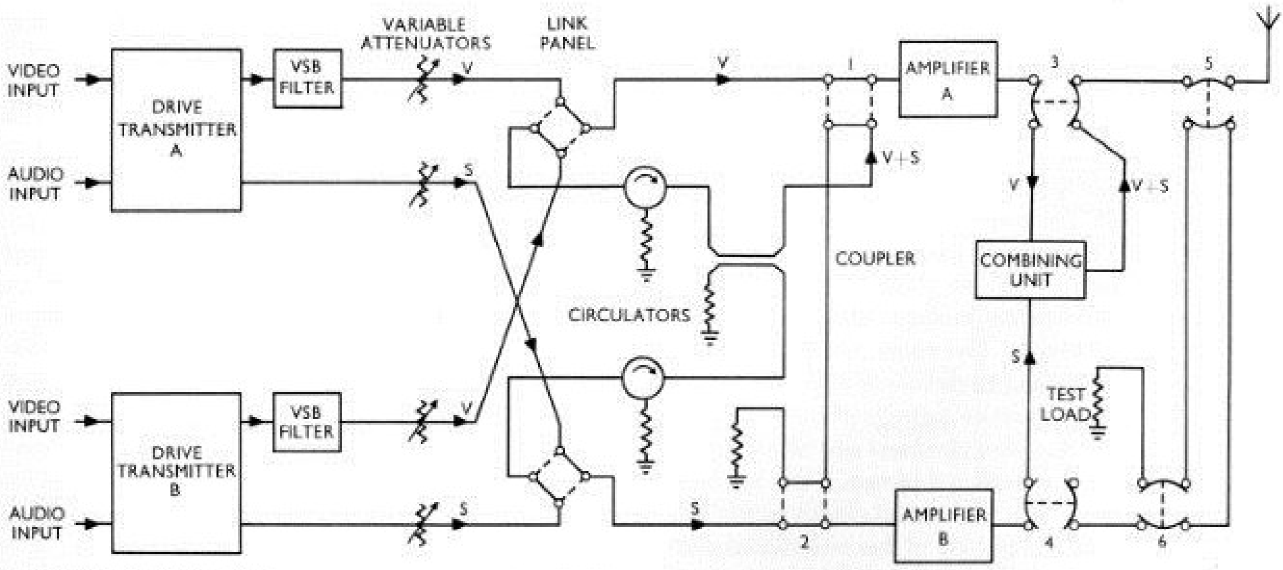

Fig. 5 Klystron multiplex system.

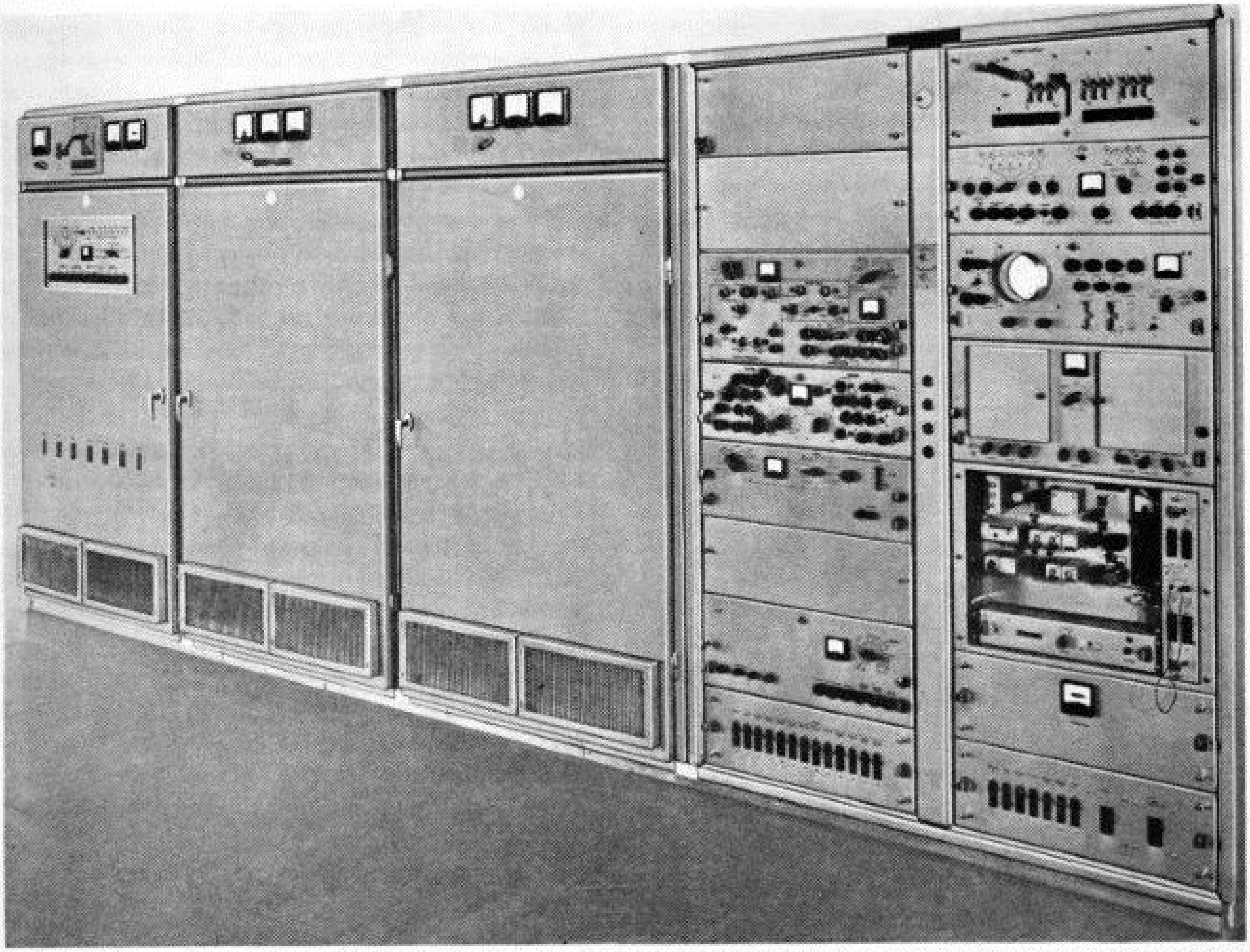

Fig. 6. A B7300 transmitter with B7315 10-kW amplifier. From left to right may be seen the control and h.t supply cabinet, the sound klystron cabinet, the vision klystron cabinet and 10-W driving transmitter. *Picture:* Danish P & T Administration.

applications, and the B7315 two klystrons for sound and vision.

It is a very simple matter to add on or take away the second klystron cabinet, so orders for either type can be met rapidly from stock.

The cabinet form of construction has been used to minimize erection time on site. They are 3 ft 9 in square by 7 ft high, and are intended to be transported without dismantling, apart from the heavy iron-cored components, the main smoothing capacitor and the klystron magnetic circuit assemblies. On installation the cabinets merely have to be bolted together on their plinth and the intercabinet wiring 'comb' inserted.

The vapour-cooled klystron collectors are near the floor (collector down) and are supplied with demineralized water from an internal constant-level tank. The steam produced is taken via the boiler side-arm to an external heat exchanger and the condensate returns to the constant-level tank under gravity. Fig. 8 shows the arrangement. A pressure-equalizing pipe and an overflow siphon ensure that the levels in the boiler and tank are independent of any back pressure developed in the steam pipe. The cooling system has the great advantage of having no water pump.

The output tuning cavity, final drift tube section and the electron gun of the klystron are cooled by an internal high-pressure blower, and the cabinets are cooled by an external exhaust fan in the ducting to the amplifier. Washable air filters forestall any damage due to accumulating dust.

An electro-mechanical interlock system ensures the safety of the operating personnel, and comprehensive control and recycling overload circuits apply the supplies to the klystrons in the correct sequence, removing the h.t voltage if certain limits are exceeded.

Silicon rectifiers are used in all the d.c supplies for long life and reliability and are protected from switching surges, short circuits and mains-borne transients. Miniature circuit breakers are used as far as possible in preference to replaceable fuses.

The normal cathode heating time of these klystrons is about 5 min, during which the h.t voltage must not be applied. In an emergency, the heater can be temporarily overrun and 90% of full r.f output power is available after 2 min. This is the 'quick start' sequence which can be initiated either locally by pressing a button or by closing a circuit remotely.

The whole amplifier can be stopped or started remotely by opening or closing a single circuit, and after a mains failure of limited duration all the supplies are reapplied without waiting for the full heater delay.

The facility to switch from full to half power can be provided, by means of a motorized tap changing switch mounted directly on the main h.t transformer. Exactly the same method is used to alter the h.t voltage when an amplifier is used as the B amplifier of a multiplex system.

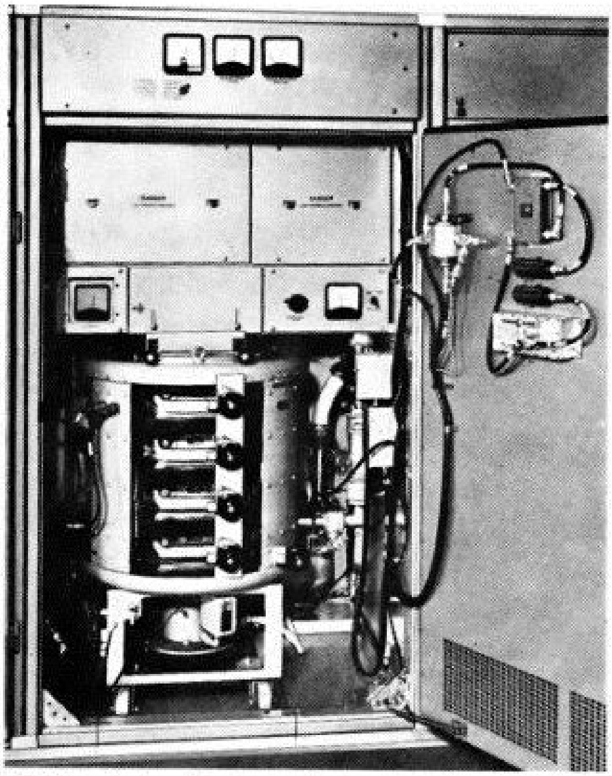

Fig. 7. Internal view of the vision 10 kW klystron in its cabinet. *Picture:* Danish P & T Administration.

40-kW U.H.F AMPLIFIERS, TYPES B7308 AND B7309

The 40-kW amplifiers use English Electric Valve Company's K3017 series klystrons, which also have four external tuning cavities and are vapour cooled. Again there is a control cabinet, in this instance housing all the auxiliary supplies, and a cabinet for each klystron (Figs. 9, 10 and 11). In addition there is a rear enclosure, 8 ft square which surrounds all the components of the h.t supply. The large iron-cored components (main h.t transformer, autotransformer, smoothing reactor and capacitor) all wheel into the enclosure, while the main isolator/earthing switch assembly, contactors and rectifiers are mounted in an angle-iron framework which forms the rear boundary of the enclosure. The framework is taken to site in one piece, and on installation is joined to the cabinets by a door assembly and side-wall which complete the enclosure, which may be right or left handed as required. A preformed cable harness links all the units.

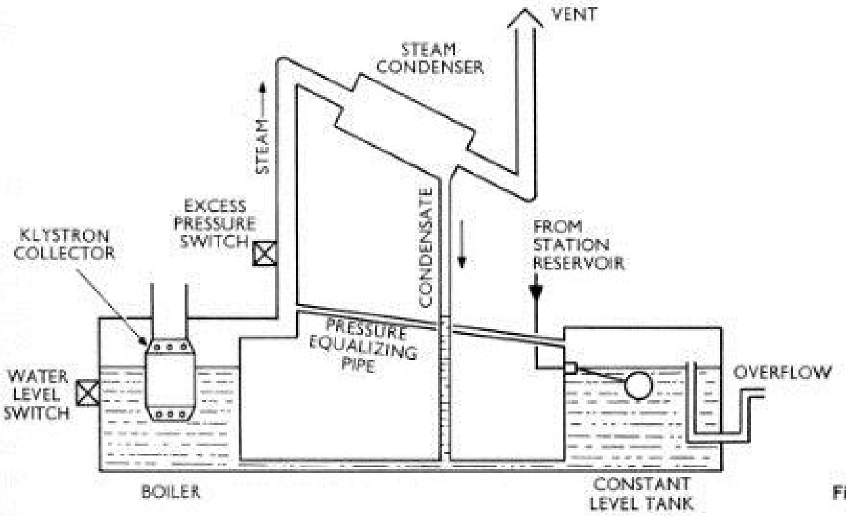

Fig. 8. 10-kW vapour-cooling system.

The K3017 series klystrons have their electron guns near the floor and the steam-cooled collectors on top. The steam exit pipe is axial with the klystron and the uniform heat distribution thus obtained makes the boiler relatively compact for the high dissipation (130 kW max.).

The drift tube sections are water cooled and the same water is eventually boiled off at the collector. Fig. 12 shows the arrangement. The cooling system is still very straightforward, but in this case requires a small circulating pump. Water enters the drift-tube cooling passages at the electron gun end of the klystron and is pumped up through all the passages until it enters the boiler via the external weir.[4] Two gallons per minute are needed to cool the drift tubes, but even at full dissipation (no r.f drive) less than 1 gallon per minute is boiled at the collector. The great merit of the external weir system is that the resulting overflow from the level-controlling weir is only a little warmer than the inlet, so no water sub-cooler is needed in spite of the boiling water at the collector. The steam produced goes to an external heat exchanger and the condensate returns to the sump tank under gravity.

An internal blower cools the gun, the penultimate and the final cavities, with the cabinets scavenged in the same way as in the 10-kW amplifier.

Interlock, control and overload circuits perform similar functions to those in the 10-kW amplifier, but no fuses are used anywhere in the equipment, miniature circuit breakers being used throughout.

To alter the h.t voltage for power switching or multiplex purposes an auto transformer is used on the primary side of the main h.t transformer. It is inadvisable to have taps on a transformer of such a high voltage rating (19 kV r.m.s).

CONCLUSION

Three schemes to improve upon the reliability of a single transmitting chain have been discussed. The first scheme is close to full redundancy, with nearly all the equipment operational under normal conditions. A failure of either one transmitter or one amplifier will reduce the radiated power to one-quarter of its normal value. The performance of all the equipment may be monitored while it is carrying programme material.

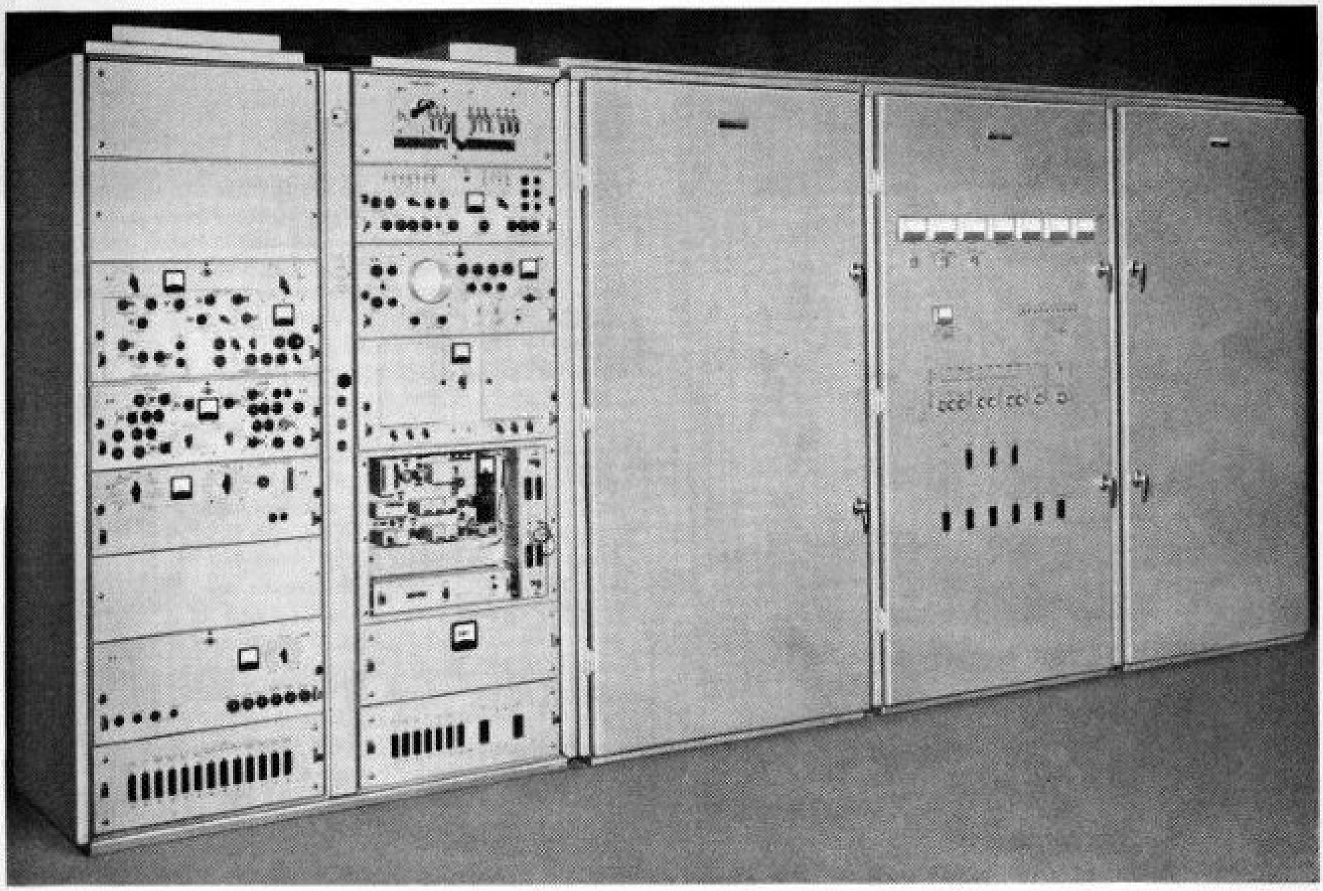

Fig. 9. A B7300 transmitter with the B7309 40-kW amplifier. From left to right the transmitter, the sound cabinet, the control cabinet and the vision cabinet.

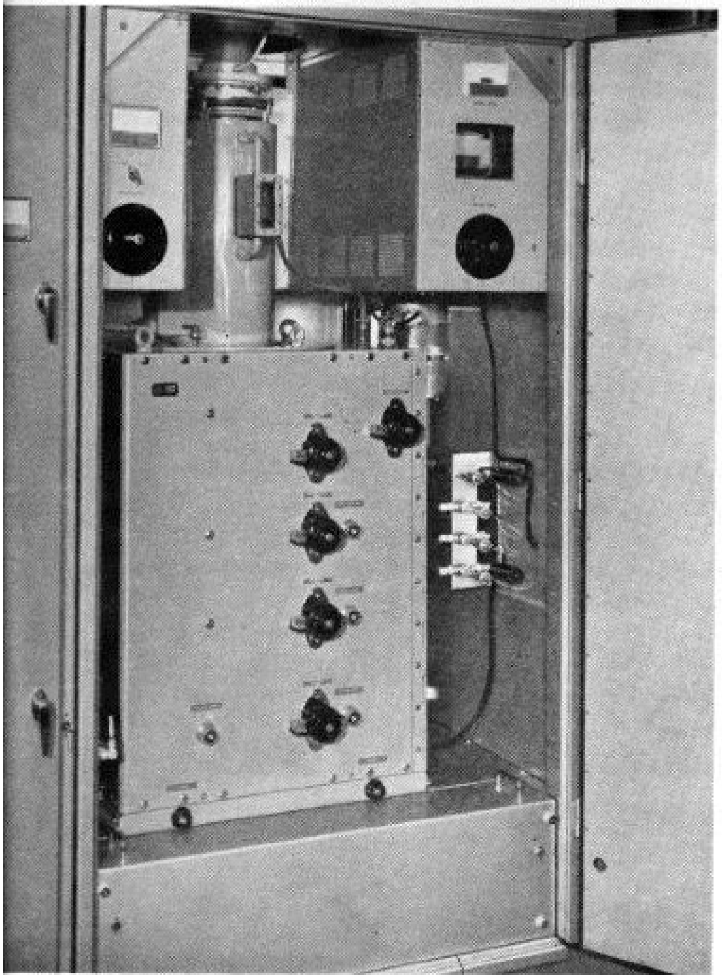

Fig. 10. A view of the 40-kW vision klystron in its cabinet.

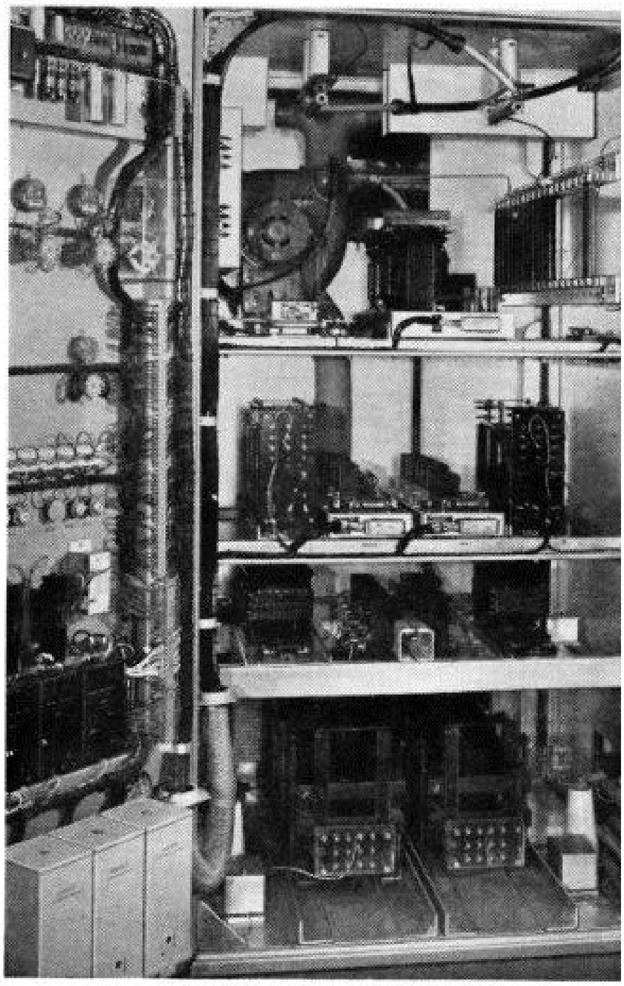

Fig. 11. The interior of the 40-kW control and auxiliary supplies cabinet. Meters, circuit breakers, relay boxes, etc. are mounted on the control door with the heavier components on shelves within the cabinet.

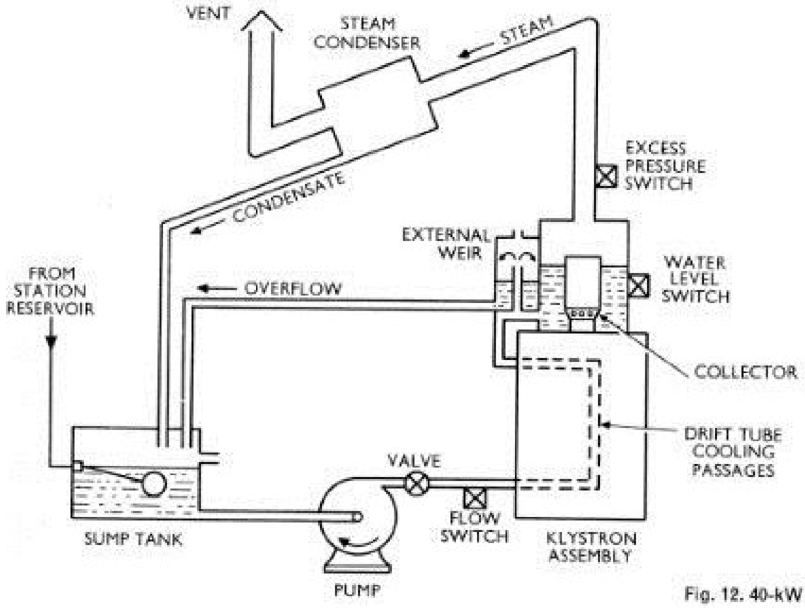

Fig. 12. 40-kW vapour-cooling system.

The second scheme uses no less equipment and an amplifier failure will have the same effect. A transmitter failure will not result in reduced output power provided that the standby transmitter is working.

The third scheme uses only two klystrons, but any failure leads to one-fifth normal power being radiated with reduced performance. All the schemes are intended for unattended operation with remote supervision, so that repair action can be started quickly should a fault occur.

Clearly the choice lies with the user who knows what resources are available, but it is hoped that this article will assist him in his choice, or at any rate to draw his attention to the features of the various systems currently in use.

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