The Output Stage for the Ground Transmitter at Goonhilly*

A. R. PETHERHAM

ASSOCIATED ELECTRICAL INDUSTRIES LIMITED

The power output amplifier of the transmitter for the Goonhilly project uses a travelling tube, type VX527 delivering 4 kW at 6,390 Mc/s, with a bandwidth of about 100 Mc/s. This amplifier, together with its power supplies and driver stage is located in a cabin, situated on the turntable underneath the aerial. Input signals for the transmitter are received in the cabin from the main control room at a frequency of 70 Mc/s; they are converted to the nominal 6,390 Mc/s before being amplified to about 3 watts by the driver TWT and fed via a waveguide link to the output stage.

The output stage, described below, was designed and manufactured by A.E.I. Electronic Apparatus Division, Leicester, England, during the first half of 1962.

THE TRAVELLING WAVE AMPLIFIER

The travelling wave tube, which was designed and built for the Goonhilly Station by the Services Electronics Research Laboratory, at Harlow, England is illustrated in Fig. 1. Fig. 2 is a schematic diagram of its power supply, based on SERL recommendations, and Fig. 3, the associated RF circuitry.

The tube is of the type in which an electron beam passes firstly through a hole in the anode and then through the centre of a cloverleaf slow wave structure before striking the collector. Amplification takes place due to the interaction between the beam and the fields associated with the structure, which has input and output waveguide windows at its ends and is at earth potential. The dc power supplies are therefore required for three electrodes and for the focusing magnet, while water and air are required for cooling.

Table I lists the characteristics of the tube at different frequencies and, as may be seen from Fig. 2, voltages are available from the power

* First published in *British Communications and Electronics,* August 1962.

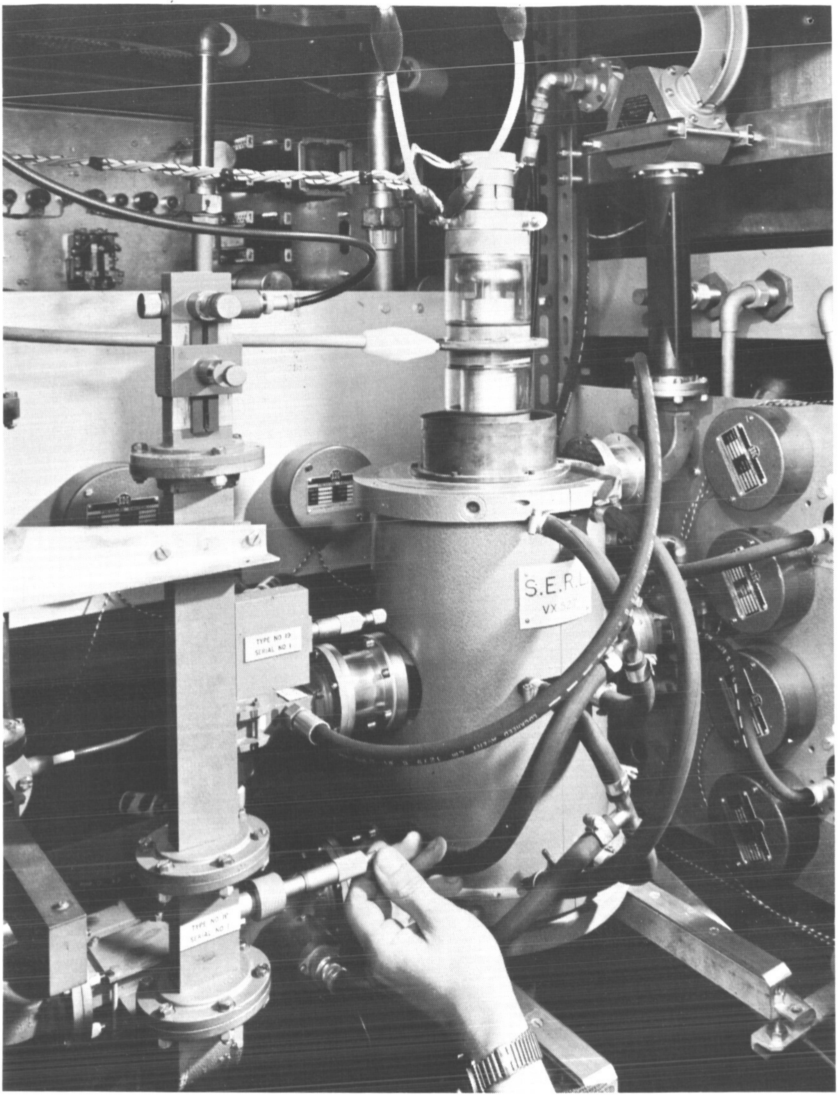

Fig. 1 — The SERI travelling wave amplifier.

supplies to tune the tube for maximum power over the full range of 6,275 Mc/s to 6,550 Mc/s.

It will also be seen from Fig. 2 that the collector is not connected to the slow wave structure at earth potential, but is held negative by the collector bias supply.

Table I — Characteristics of Travelling Wave Tube VX527

Frequency	Minimum 6,275 Mc/s	TELSTAR 6,390 Mc/s	Maximum 6,550 Mc/s
Beam Voltage (Cathode to Slow-Wave Structure)	32kv	25kv	20kv
Beam Current	0.8 amps	1.1 amps	1.4 amps
Collector Voltage	21.5kV	17kV	13.5kV
Collector Bias Voltage	10.5kV	8kV	6.5kV
Anode Current	<1mA	<1mA	<1mA
Magnet (Hot)	Voltage 40V Current 40A		
Heater	Voltage 6.5V ac Current 8.5A		

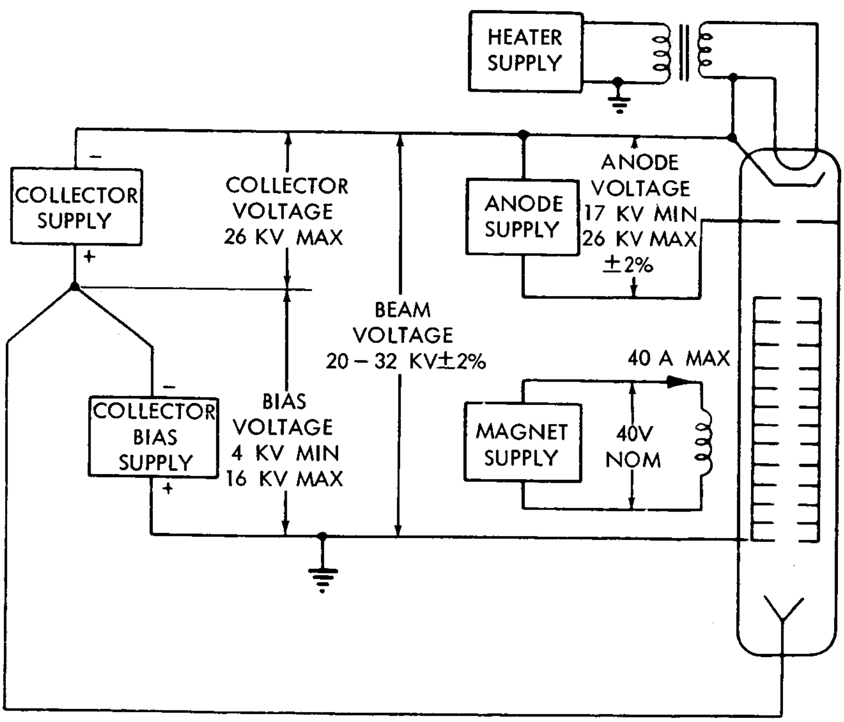

Fig. 2 — Schematic diagram of Telstar output stage power supply.

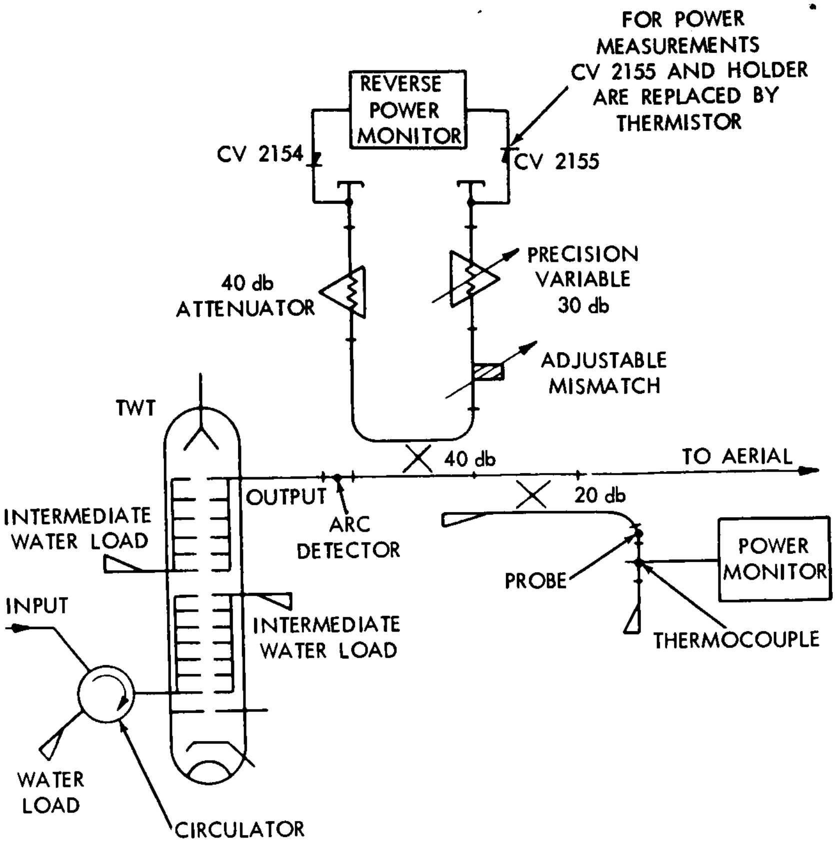

Fig. 3 — Telstar output stage waveguide system.

Operation of the tube is controlled by the cathode-slow wave structure voltage, called the beam voltage, and if the collector bias supply is omitted, the beam current must be supplied at this voltage. This is not necessary however, since the electrons may be allowed to slow down by the action of the collector bias before striking the collector. It will be seen that at the Telstar frequency, a collector voltage of only 17 kV is required compared with a beam voltage of 25 kV, giving a saving of over 8 kW, since the bias power is small in comparison.

This form of bias is also known as collector depression and when used gives a tube efficiency of 22% with a collector input of 18 kW

Part of the electron beam is, however, intercepted by the slow wave structure due to imperfect focusing and other causes and this forms a load on the collector bias supply, which increases with drive power and may reach 15mA. The leakage current flowing from earth to collector in the cooling water must also come from the collector bias supply and it is in the order of 20 mA when distilled water is used.

Interception of the electron beam also occurs at the anode to some extent but the current is usually less than 1ma.

The electron beam is focused by an electromagent wound with aluminum strip directly on to the outside of the slow wave structure.

STABILIZATION OF ELECTRICAL SUPPLIES

To keep the travelling wave tube operating correctly, the beam and anode voltages must be stabilized against variations of the mains supply and against voltage drift due to component warm-up. Failure to do this results in loss of gain and therefore of power output, but also causes the gain to depend on frequency, resulting in distortion of the transmitted signals. Similarly ripple voltages must be limited to .25% peak in order to keep phase modulation of the output at an acceptable level in the transmission of, for example, colour television.

Since neither side of the collector supply is at earth potential when depression is used and since the bias current is less than 5% of the collector current, it is convenient to stabilize the beam voltage by controlling only the bias voltage. Stabilization against slow changes is carried out by varying the ac input voltage to the bias supply using a motor driven variable ratio transformer, while faster transients and ripple are reduced by means of a dc coupled series valve and LC filters. A conventional system is used in which a small fraction of the beam voltage is compared with a neon reference and the difference amplified to supply the grid of the series valve. If low frequency drifts make the operating point of the series valve wander too far from the optimum, a voltage discriminator across the valve causes the variable transformer to re-adjust the input voltage.

The anode voltage is stabilized in a similar manner, although neither side of the anode supply is at earth potential. Since the supply is fed from the mains some method of transferring power and monitoring and protection signals between earth and anode circuit potential is required. The solution chosen involves having the variable ratio transformer and its motor control circuits at earth potential and all the other stabilizer components including the rectifiers and smoothing at anode potential. Connection between the two is by means of transformers insulated for the high voltage, and the control circuits as well as the power circuit use mains frequency. This system requires only a small number of components and has been proved to be reliable.

During the turning on procedure, bias, collector and anode supplies are controlled without stabilization by raise and lower switches working in the motor drive circuits, and at the correct working point, indicated by a lamp, the operator switches the stabilizer into circuit.

The magnet supply is stabilized to prevent the current from falling during the initial warming-up period, and to hold it to within ± 1 amp of the nominal 40 amps. However, it has been shown that the VX527 is very tolerant to changes of magnet current and will work satisfactorily over a range of more than 10 amps.

The TWT cathode heater is energized from a constant voltage transformer. The heater is run up to full power over a period of 5 minutes and then allowed to settle for a further 5 minutes before the electrode voltages are applied. A protection circuit prevents application of the e.h.t. to the tube before the correct operating voltage is reached.

COOLING OF THE TRAVELLING WAVE TUBE

In addition to the input and output waveguide windows, the TWT has two intermediate windows fitted with water cooled loads to absorb reverse power. The output window is supplied with 2 ft^2/min. of free air to cool it while the other three windows are connected in a series air circuit and supplied with 1 ft^2/min. This air is obtained from a single cylinder compressor providing oil free air at 100 psi. In order to dry the air, it is cooled so that the excess water condenses and can be removed. The pressure is then reduced to 10 psi at which point the relative humidity has been reduced to less than 35%. Carbon piston rings with a life of over 5000 hours are fitted in the compressor to remove the need for lubrication of the bore.

The TWT also requires liquid cooling, both for the collector and for the slow wave structure/magnet assembly. Distilled water is used in a closed cycle system lessen corrosion and to reduce the leakage current flowing from earth to the collector and it is pumped at 120 psi with a flow of 14 gallons per minute through the TWT cooling system to a forced-air-cooled heat exchanger mounted on the cabin roof. Separate pressure switches and flow meters are fitted in four parallel flow paths supplying the collector, the structure, the intermediate window loads and an RF dummy load which can be connected to the output window.

To prevent the water from freezing in the heat exchanger in cold weather, it is continually circulated via a 6 kW immersion heater when the transmitter is off.

RF POWER MEASUREMENT

For single way working between two ground stations via Telstar it is normal practice to run the transmitter at its full power. However when two way working experiments are in progress, using two closely spaced frequencies in the satellite pass band, it is necessary to ensure that the single strength at the satellite is approximately the same for both signals. This means that the transmitted power must be continuously reduced during passes in which the satellite approaches the transmitter and to cope with these requirements, two methods of power measurement are provided. As may be seen in Fig. 3, one method uses a 20 db coupler feeding a thermocouple, the output of which is amplified by a magnetic amplifier to drive a meter with a scale linear from 1 to 5 kW. This is satisfactory for general use, but below 500 watts it is not accurate enough for two way working.

A second method of measuring power is to meter the crystal current in the forward arm of the reverse power monitor. The crystal current is calibrated against the thermocouple at full power and a decibel scale may then be considered linear to at least 15 db below 4 kW with an accuracy of better than 1 db. The basic calibration for both systems is obtained from a thermistor bridge.

FAULT PROTECTION

The TWT is expensive and care must be taken to prevent damage caused by any faults occurring in the system. Failure of the water and air cooling is detected by pressure and flow switches, and failure of the magnet or heater excitation by no-volt relays, while overload relays detect excessive electrode currents. All these trips bring out the contactor supplying the electrode voltages as well as the contactor supplying the circuit causing the trip. However, this system is not necessarily adequate when the fault results in excessive interception of the beam current by the anode or slow wave structure since there may be sufficient energy stored in the components of the smoothing circuits to damage these electrodes even if the main supply could be removed instantaneously. This condition is dealt with in a few microseconds by a pulse circuit operated from the rapid increase in electrode current which causes the e.h.t. supplies to be short-circuited through ignitron and thyratron crowbars. In each case the stored energy is diverted into resistors which dissipate it until the normal overload relays open the contactor to clear the fault currents produced.

If arcing should occur in the output waveguide, it will either start at, or run towards the output window where an arc detector is fitted. This is a photoelectric relay whose photocell looks into the waveguide through a slot so that an arc passing the slot causes the relay to operate and fire the crowbars.

Fig. 4 — A general view of the Telstar ground transmitter at Goonhilly.

Protection against mismatches in the output guide is given by a reverse power monitor. Forward power is measured by a crystal fed through a variable attenuator and a variable mismatch used for setting the sensitivity, and reverse power is measured by a crystal fed through a fixed attenuator. The ratio of the RF fields feeding the two crystals is proportional to the reflection coefficient in the main waveguide and the crystals are connected in a circuit driving a dc amplifier which operates a relay to switch off the drive to the TWT. The use of two crystals in this way reduces the effect of transmitter power variations on the tripping point.

MECHANICAL ARRANGEMENT

The equipment is fitted into six cubicles, three of which are on a common baseplate for convenience of interconnection (Fig. 4). All cubicles are 7 ft. 6 in. high but are of varying plan dimensions to fit the available space in the transmitter cabin.

Components at a high potential to earth are mounted in boxes made from proprietary extruded aluminium sections, which is a convenient way of ensuring well-rounded corners to prevent corona. Other electronic components are mounted on swing frames inside the cubicles, which have doors front and back, and trays fitted on these frames may be repaired in situ or removed for servicing, although for safety of personnel it is not possible to close the main supply isolator when any of the cubicle doors are open. Fault location is simplified by a comprehensive system of lamps which indicate the part of the circuit that has initiated a shut down.

The cubicles are cooled by extractor fans mounted near the roof feeding an external common duct which is led outside the cabin through a diverter which permits the hot air to be fed into the cabin to economize on heating in cold weather. The larger transformers are filled with non-inflammable oil and are sealed and fitted with bursting diaphragms which have separate vents leading directly to the outside of the cabin. The cabin is air conditioned to avoid difficulties due to condensation on high voltage insulators.

REFERENCE

1. Bryant, M. O., Thomas, A., and Wells, P. W., A High Power CW Travelling Wave Tube, *J. Electronics and Control* 12(1), January 1962.