A High Power Travelling Wave tube for Satellite Communications*

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This paper describes the CW travelling wave tube used by the General Post Office in their ground transmitter for Project Telstar. It operates in the 6000 Mc/s band with a maximum power output of about 5 kw and a bandwidth of great than 100 Mc/s. The factors influencing the design of the valve and its performance are discussed in some detail.

AUTHOR

The experimental communication satellite Telstar requires a ground transmitter at 6390 Mc/s giving a power of more than 2 kW with a bandwidth of about 50 Mc/s. The valve used by the General Post Office to produce this power in their station at Goonhilly Downs is a travelling-wave amplifier using a 'clover leaf' slow-wave structure[1] to interact with the electron beam. Amplifiers of this type have been the subject of much research in recent years[2, 3, 4, 5, 6] which showed that the requirements for Telstar could probably be best satisfied by a similar device. This valve has already been briefly described in the Press[7]. In the present paper the most important factors influencing the design and performance are described in more detail and the potential capability of clover leaf travelling wave amplifiers for CW operation is discussed. Fig. 1 shows the main features of the valve which will be described in the following paragraphs.

REASONS FOR CHOOSING A CLOVER LEAF TRAVELLING WAVE TUBE

For a CW output power of several kilowatts at centimetre wavelengths travelling wave tubes with the familiar helical wire circuit are impracticable at present because their thermal dissipation is too low. If a travelling wave tube is to be used it must have a more massive circuit, such as a periodically-loaded waveguide. Stagger-tuned

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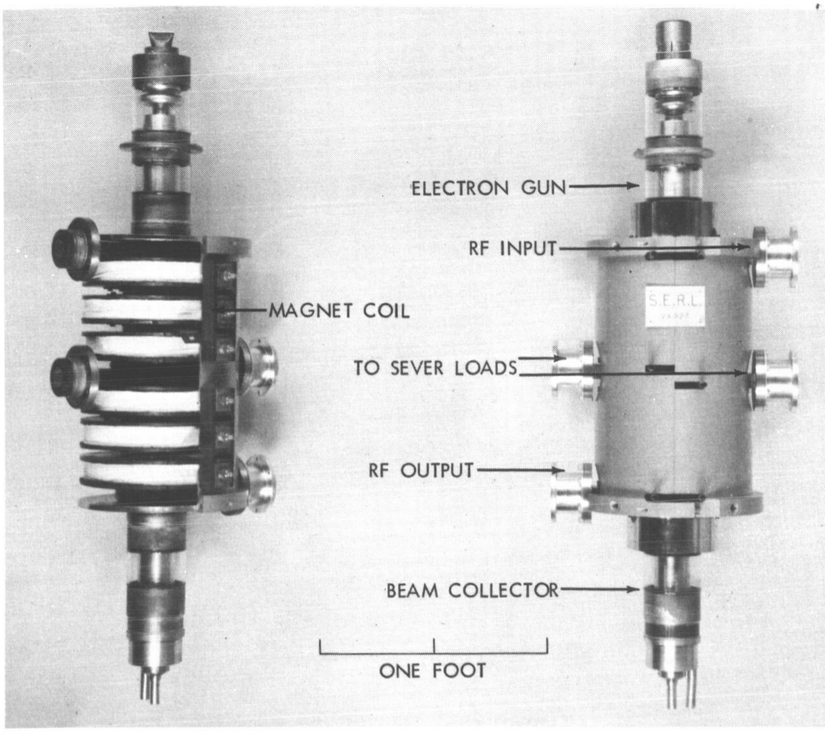

Fig. 1 — The C-band travelling wave tube. The valve on the left has the protection covers removed to show more detail.

multicavity klystron amplifiers might also be considered. These are capable of very high CW output powers,[8] but the bandwidth obtainable at kilowatt power levels is barely 1%[9]—and that only at relatively poor efficiency. Furthermore, in any communication system it is desirable that the transmitter be tunable over a large fraction of the allocated frequency range in order to avoid a multiplicity of frequency variants. Although klystrons can be mechanically tuned by a few percent it is very difficult to maintain the stagger-tuning of the cavities required for maximum bandwidth.

Travelling wave tubes with periodically-loaded wave guide circuits have greater bandwidth and in our experience are much easier and more reliable to make. There are several types of circuit which might be considered. The choice between them is a rather complicated one and has been elaborated elsewhere[2,3]. The clover leaf structure is considered to be the best available at present because of its very high power handling capacity, relative freedom from instabilities and high gain per unit length. At kilowatt powers its bandwidth is rather limited, but more than adequate for the amount of traffic likely to be handled by one transmitter, and it can be voltage-tuned over a frequency range of about 5%.

A diagram of the clover leaf structure is shown in Fig. 2. It consists essentially of a circular waveguide, operating in the TM_{01} mode, which is periodically loaded by thin irises. Alternatively it may be regarded as a series of coupled cavities forming a band pass filter. The cavities are inductively coupled by radial slots and there is also a small amount of capacitive coupling through the beam hole. The structure is very simply made from two varieties of copper stampings which are stacked and brazed together inside a copper shell forming the vacuum envelope.

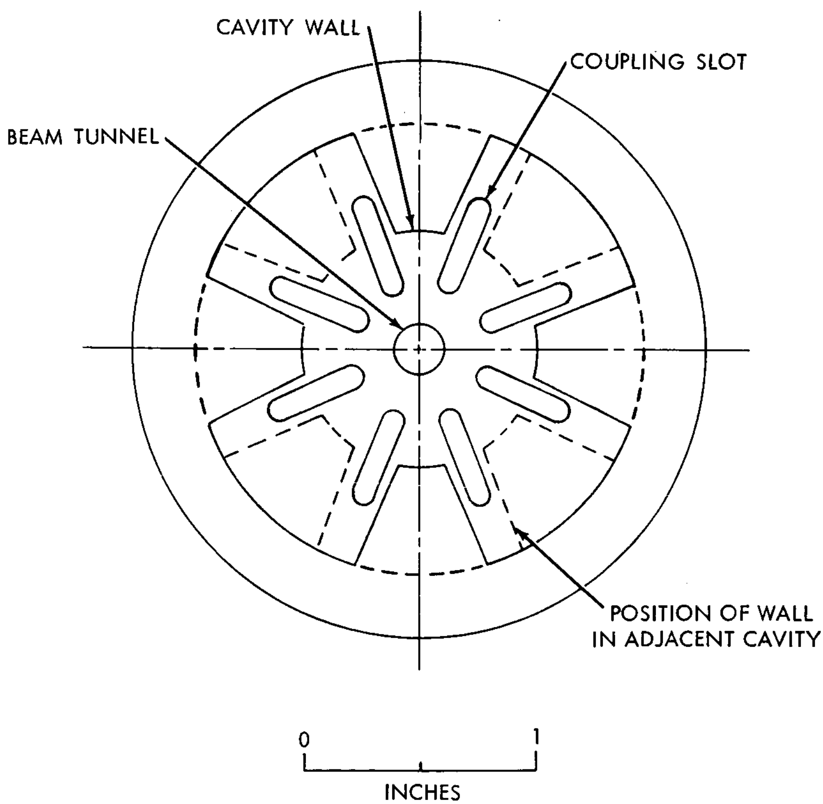

Fig. 2 — The clover leaf structure.

OPERATING PARAMETERS AND PERFORMANCE

At output powers of a few kilowatts the clover leaf structure offers a bandwidth at fixed beam voltage of 1-2%, with a tuning range of about 5% for a beam voltage variation of less than 2:1. The best choice of voltage and current for a particular valve is governed by a number of factors. One of the most important of these is that the maximum space charge density in the beam shall not be too high. Excessive space charge prevents the formation and maintenance of the very sharp electron bunches necessary for high gain and efficiency. In the present case the choice was dictated by the performance of an existing electron gun which had been developed for another valve but was used in order to carry out this development in the very short time available.

This gun gives a constant dc beam power of about 28 kW over a voltage range of 20-32 kV, the beam current being controlled independently by a separate electrode. At the high voltage end of this range a much higher beam power can be reached, the maximum of 32 kV being about 46 kW. Fig. 3 shows the output power of the valve for four beam voltages at a constant beam power of 28 kW. At each beam voltage the R.F. drive power is kept constant at the value giving maximum bandwidth. An output of greater than 3 kW is obtained from 6290 Mc/s to 6660 Mc/s, a range slightly greater than 5%. The gain and efficiency are reduced at the high frequency end of the tuning range, largely as a result of the high space charge density in the beam at low voltages. A rather small variation of gain and power output with voltage would be obtained if the operating range were somewhat higher, say 25 kV-40 kV.

The power handling capacity of the clover leaf structure is very much greater than can be achieved with the present gun. Using a beam power of 46 kW at the high voltage end of the tuning range a CW output of 10 kW has been obtained without difficulty with a gain of 30 db. With a new electron gun operating at higher voltage the dc power input to the tube could be even further increased, with a corresponding increase in power output.

THE ELECTRON BEAM

The diameter of the electron beam is about 3 mm. and the maximum current 1.4 amp, corresponding to a current density of 20 amp/cm^2. This is well beyond the capability of existing cathodes and the beam is therefore formed from a cathode with about ten times the beam area. The beam is converged electrostatically and then introduced into

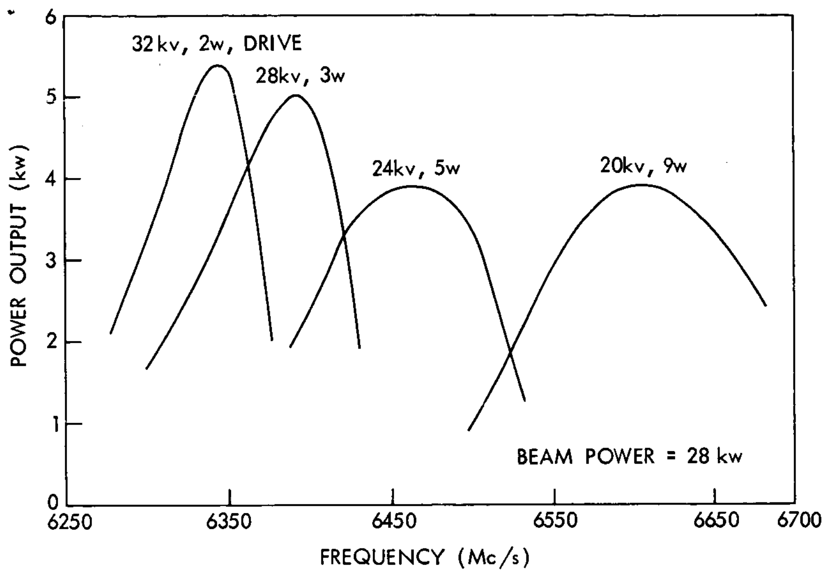

Fig. 3 — Output power of the valve.

an axial magnetic field of 1100 gauss which prevents it from spreading until it has travelled through the R.F. circuit. In a valve of this power it is essential to minimize heat input to the circuit from electron bombardment and the design of the focusing system requires great care. In the present case less than 1% of the dc beam current is intercepted on the slow-wave structure at maximum RF output. Considerable assistance in reaching this low figure is obtained by using an electromagnet whose coils are wound directly on the body of the valve thus ensuring very good alignment of the magnetic field with the beam. The virtue of this type of magnet has been demonstrated with previous valves,[4] but a new technique for making the coils has now been adopted.[10] They are wound from 1 in. $\times$ 0.01 in. O.F.H.C. copper tape, interleaved with 0.003 in. glass fibre tape and impregnated with a self-setting porcelain cement. This method of construction gives very good heat dissipation and also allows the coils to be baked on the tube at up to 450°C. during outgassing on the pumps. Thus the magnet is available for focusing the electron beam while the valve is on the pump, which is a great advantage. It also permits valves to be rebuilt and processed, thereby effecting worthwhile economies. For a field of 1100 gauss the coils require a current of 40 amp and consume a power of 1600 W.

STABILITY

In order to avoid excessive feedback in high gain travelling wave tubes, caused by internal reflections, some form of isolation in the slow-wave structure is needed. In high power tubes such isolation is provided by introducing one or more breaks, or severs, in the structure. At these severs any power on the circuit is dissipated in resistive loads and the RF signal is propagated solely as current and velocity modulations on the electron beam, which act in the forward direction only. In this tube the gain is such that only one sever is necessary. Because the mean power is so high the sever terminations are not placed inside the valve, but the structure is matched through waveguide transitions into loads outside the vacuum envelope. These loads are required to dissipate up to 200 watts, depending on the power output and the proportion reflected.

COLLECTOR DEPRESSION

In a travelling wave tube only a small proportion of the dc beam energy can be converted into RF and the remainder is wasted in heating the collector cooling water. This situation can be improved by holding the collector at a negative potential with respect to the RF circuit. By this means electrons are slowed down before hitting the collector and hence the power wasted and the amount of cooling water needed are reduced. In practice, the extent to which the collector potential can be depressed is limited by the number of electrons accelerated back into the slow-wave structure by the biasing field. This problem becomes more acute the higher the mean power in the electron beam but even if only a modest amount of collector depression can be used it may effect an economy in dc power of many kilowatts. With the present design[5] the maximum depression that can be used is about 40% of the cathode potential. At a beam power of 28 kW this depression reduces the collector power by about 12kW giving a maximum efficiency of dc to RF conversion of 34%.

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