DEVELOPMENT OF 12GHz TWT FOR BROADCASTING SATELLITES

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Summary. This paper describes the basic development of a 100W travelling-wave tube in 12GHz band for broadcasting satellites. This tube incorporates the impregnated cathode, helix slow wave circuit with velocity taper, and four stage depressed collector.

Introduction

Broadcasting satellites in Japan, following BSE "Yuri" which is now in its mission, are to be operated in accordance with the channel assignment (channel 1, 3, ...,15) agreed upon at WARC-BS-77, or in the frequency range of 11.7 to 12.2GHz for space to earth transmission.

Basic development of the TWT aimed for application to such future broadcasting satellites has been initiated by NHK (Japan Broadcasting Corporation), with a 100W helix type TWT in 12GHz band. In this development, NHK has conducted electrical design, measurement, and analysis of the measured data; while, ordered by NHK, manufacturers (Toshiba and NEC) have independently fabricated test models of the TWT based on their own technologies.

The development is now in the second phase where, from the analysis of TWTs built in the first phase, design was modified, and TWTs are under fabrication. The first phase was mainly devoted to obtaining fundamental knowledge to design the objective TWT. The key objective characteristics are summarized in Table 1.

Table 1 Objective characteristics

Operating frequency range	11.7 to 12.2GHz
Saturated output power	100W min.
Saturated gain	40dB min.
Overall efficiency	50% min.
Cooling - body	conduction
- collector	radiation

Phase I Development

Design Consideration and Fabrication

Electron Gun. The electron gun is of Pierce type with area-convergence ratio of approximately 30:1, and the perveance is 0.24×10^{-6} $A/V^{\frac{3}{2}}$. The impregnated cathode with current density of 0.78 A/cm^2 is used to ensure long life operation. The anode voltage, which is raised by about 100V over the helix voltage to protect the cathode from ion bombardment, is 5.6kV to draw beam current of 100mA.

Slow Wave Circuit. The helix is chosen at this power level, instead of the coupled cavity, to save the tube weight and to cover any available channel with single kind of TWT due to its wide band nature.

The helix circuit is composed of two sections: the input and output sections, and has a mean radius of 0.7 mm. The pitch of standard section of 0.65mm is so chosen as to obtain the maximum small signal gain at the operating helix voltage of 5.5kV. The γa is 1.23 which is rather small compared with typical value of 1.5 to get stronger coupling between the RF field and electron beam.

Resyncronization technique between the circuit wave and electron beam to increase the interaction efficiency is utilized by tapering the helix pitch at the end portion of the output section. It is known that the nonlinearity of the TWT is increased when the interaction efficiency is increased by velocity taper[1]. In the broadcasting satellite, however, the degradation of the signal due to the nonlinearity will not be significant because the TWT is anticipated to amplify single carrier of frequency modulation. A single taper reducing the velocity by 15% at maximum is, therefore, applied.

The helix made from tungsten / molybdenum wire is supported by three beryllium oxide (BeO) rods. The helix assembly is held within the vaccum envelope of stainless steel / copper by force fitting.

Beam Focusing. The PPM of Samarium-cobalt is used, and the peak magnetic flux density on the axis is 0.224 Tesla.

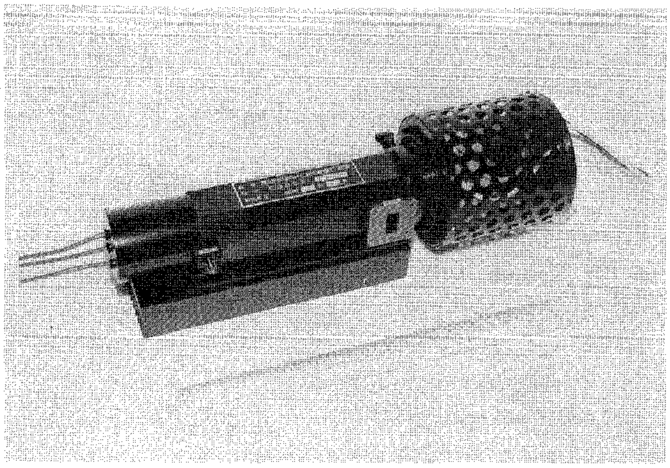
Collector. The multi-depressed collector to improve the overall efficiency comprises three conical horn-shaped electrodes and a Faraday cage type electrode as the final stage. These electrodes made from copper are supported in position by ceramic insulators which are parts of the vaccum envelope, or by ceramic insulators and a metal vaccum envelope which radiates dissipated power into deep space.

Computer simulation technique was fully utilized to determine electrode configuration, where various inclinations of spent beam trajectories as well as velocity spread were taken into account. The maximum electrode temperature is estimated to be less than 300°C without RF input, and less than 310°C with RF driven.

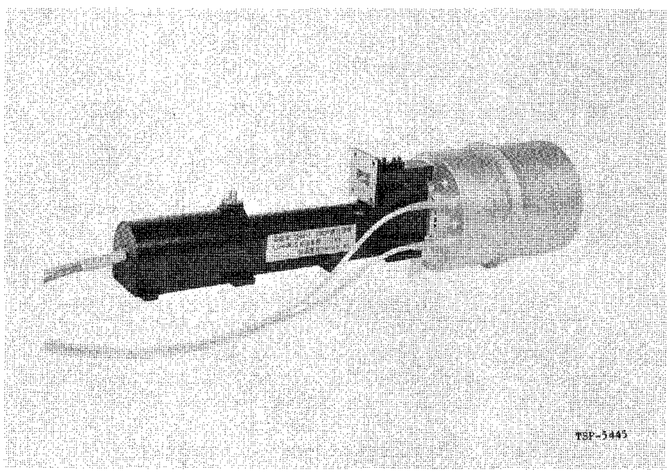
Results

Photographs of the TWT are shown in Fig. 1. These TWTs are 349/393 mm long, and weigh 2.0/2.7 kg.

Measured data of the electrical performance are summarized in Table 2. Major problem here is a large amount of the helix current which obviously leads to a low overall efficiency.



(a) E3822



(b) LD4365

Fig.1 Photographs of test model TWT

Phase II Development

Analysis of Phase I Results

Helix Current. A large amount of the helix current is mainly due to back-streaming electrons from the potential depressed collector. The back-streaming electrons are caused by the secondary emission of collector electrodes and the reflection of primary electrons in the collector space. It was clarified that the back-streaming electrons, in this case, were mostly due to the reflection of the primary electrons, from the measurements on the TWT in which the pyrolytic graphite instead of copper was used for the electrodes. Extensive computer analysis also indicated that the back-streaming by the reflection is possible when there exist greater inclinations of the spent beam trajectories.

Table 2 Measured data at 12GHz

Heater voltage/current	4.8 V/0.95A
Cathode current	107.5mA
Helix voltage/current	5.6 kV/18mA
Collector 1 voltage/current	2.74kV/20mA
Collector 2 voltage/current	2.39kV/20.5mA
Collector 3 voltage/current	1.86kv/16mA
Collector 4 voltage/current	0.78kV/33mA
Gain	41.4dB
Output power	72.4W
Efficiency	28%
Collector efficienty	80%

As a consequence, it was conceived that some means to improve the trajectories of spent beam must be provided at the collector entrance, as Kosmahl proposed[2].

Interaction Efficiency. The output power of 72.4W corresponds to the interaction efficiency of 12%. On the other hand, the interaction efficiency without velocity taper was investigated on the TWT built with the same design except the taper section, and was measured to be 9.1% at the similar operating condition. Using these data, the large signal analysis program was carefully checked.

Design Modification

Slow Wave Circuit. The helix pitch of standard section was increased to raise the operating helix voltage to 6.5kV. In addition, the velocity reduction in tapered section was changed to 23% at maximum based on the large signal analysis. These will allow to obtain the output power of more than 100W using the same fabrication technique.

Spent Beam Refocusing. A new spent beam refocusing method[3] was provided with. This method makes use of the space charge force and the magnetic lens to optimize the spent beam at the entrance of the multi-depressed collector. Design of the refocusing section was performed by computer simulation to suppress back-streaming electrons and to obtain good velocity sorting. Trajectories of the spent beam in the four stage potential depressed collector with the refocusing section applied is shown in Fig. 2.

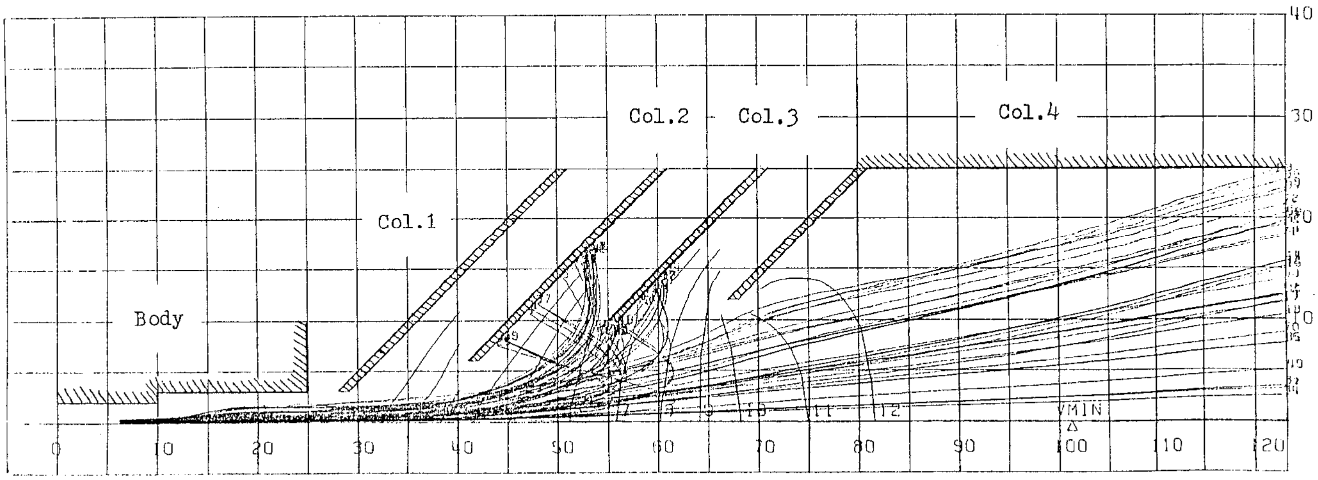


Fig.2 Trajectories of spent beam in the collector with spent beam refocusing

In this figure, the body means the helix and short drift tube sections. The collector electrodes 1 to 3 are of conical horn type with progressively lowered potentials with reference to the body. The collector 4 is of Faraday cage type with the lowest potential.

The spent beam passed through the helix section starts to expand in the drift tube section due to the space charge force, where if there exist electrons having radial velocity component directed to the beam center, they are gradually converted to those having radial velocity directed outward. The magnetic lens is, then, placed at an appropriate position to let the spent beam enter the collector region with reduced radial velocity.

In the figure, 90 trajectories representing various initial radii, velocities, and inclinations are shown together with equi-potential lines. It is seen that each trajectory reflected in the collector space is terminated on one of collector 1 to 3 electrodes and no electron is streaming back to the helix section. The collector efficiency, which is defined by the ratio of energy recovered in the collector to energy conveyed at the collector entrance regarding the spent beam, is estimated to be 86.4% in this simulation.

Design Parameters

Major design parameters for phase II development are summarized in Table 3.

Conclusion

In the basic development of 12GHz TWT for broadcasting satellites, the first phase was completed giving information on the interaction efficiency and the problem area concerning back-streaming electrons from the potential depressed collector. Making use of the information obtained, the design for the second phase has been established. Measured data of the second phase TWT will be presented in detail at the symposium.

Table 3 Design parameters for phase II

Helix voltage	6.5 kV
Col.1 voltage/current	3.24 kV/∿ 0
Col.2 voltage/current	2.82 kV/50.5 mA
Col.3 voltage/current	2.2 kV/22.8 mA
Col.4 voltage/current	0.93 kV/36.7 mA
Collector efficiency	86.4 %
Spent beam refocusing section	
- length	13.3 mm
- peak magnetic flux density	0.09∿0.1 Tesla

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