HIGH-POWER MILLIMETER-WAVE TUBES

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ABSTRACT

This paper discusses 8 mm and 3 mm high-power tubes which have been developed at ISTOK. At 8 mm wavelengths two systems are representative of ISTOK capabilities: (1) a medium power (10's of kW) TWT chain using ppm focusing and a low-gain "see-through" final stage and (2) a three-beam 50 W cw klystron. Also, a 2 kW cw TWT was developed for industrial heating. For higher powers an Orotron-TWT (3 MW peak, 3 kW average power) has been developed. At 3 mm wavelength, a pulsed klystron with 1.5 kW power output and 300 MHz bandwidth has been developed, and a 25 W cw TWT with an 800 MHz bandwidth was produced. For frequency ranges 36-1500 GHz there are multiple-beam oscillator BWO's with ribbon-like beams which produce 40-2 mW.

DUAL-MODE AMPLIFIERS

One approach to the design of compact millimeter wave amplifiers with pulse power of tens of kilowatts and average power of several kilowatts is the amplifying chain concept shown in Figure 1. The chain consists of

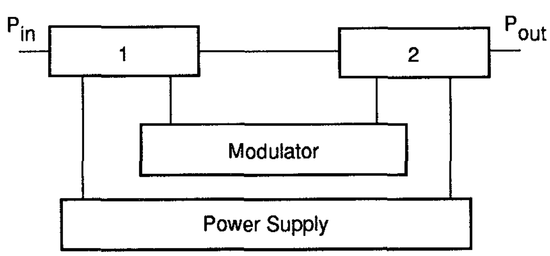

Figure 1. TWT Amplifying Chain. 1-Driver PPM TWT, 2-High Power See-Through PM TWT.

two tubes (1) a preamplifying TWT with a PPM focusing system, low beam current, and high gain, and (2) a "see-through" power TWT with high current, and low gain, and packaged with permanent magnet focusing. For the millimeter wave range such design provides two main advantages when compared to the standard design of a power TWT with a focusing solenoid. First, the focusing solenoid is replaced by a system of permanent magnets, which reduces weight and eliminates the solenoid power supply. Second, dual-mode operation is available so that power may be matched to the system requirements. A typical diagram of output power characteristics is given as Figure 2.

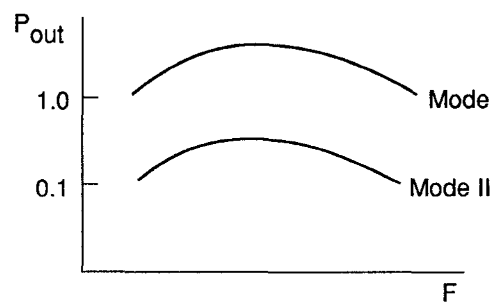

Figure 2. Power Output For Two Modes Of TWT Amplifying Chain.

It should be noted that the output one-section TWT increases the stability of the amplifying chain. The output TWT dampens instability of the driver stage due to variations in its operating conditions. This is because it possesses low sensitivity to the change of slow wave structure voltage U_{sw}, beam current I_o, and input microwave power P_I.

The amplifying chain as a rule is designed for the same voltage U_{sw} for both TWT 1 and TWT 2. In this case the most optimal design for the output "see-through" TWT is a multiple-beam design; such tubes are discussed in a comparison paper. Such solution has been successfully realized in centimeter-wave chains, and millimeter-wave chain using a multiple-beam design is currently under development.

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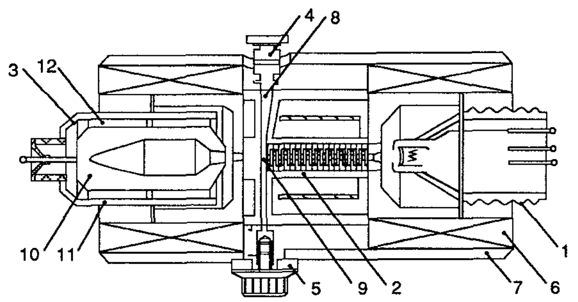
For industrial installations of ceramics, sintering oscillators based on one-section ("see-through") TWT's with intrinsic feedback have been developed. One such device is shown as Figure 3. Referring to Figure 3, this



1 Electron Gun
2 High-frequency Unit
3 Collector
4 Output Window
5 Adjusting Unit
6 Magnetic Rings
7 Magnetic Screen
8 Waveguide Transformer
9 Plunger
10 Collector Electrode
11 Water Jacket
12 Ceramic Bushing

Figure 3. TWT Oscillator - see text for details.

oscillator consists of the electron gun 1, high frequency unit 2, collector 3, microwave power output window 4, adjusting unit 5, and magnetic focusing system comprising of two radially magnetized magnetic rings 6, and magnetic shield 7.

The resonance TWT oscillator which was developed provides 1.5 kW cw power at 34 GHz. The device voltage and beam current are 18 kV and 0.7 A respectively. Collector voltage is 9 kV. The oscillator can also operate in a pulsed mode. While not as powerful as the gyrotrons, oscillators of the resonance TWT type can be used in applications requiring several kilowatts of rf power.

HIGHER POWER TUBES

Earlier research programs at ISTOK (conducted in the 1970's) developed an amplifying chain which consisted of a 3-beam four-resonator amplifying klystron driver tube (packaged with a permanent magnet) and a final stage amplifying gyrotron shown as Figure 4. The output cw power was greater than 10 kW at 35 GHz.

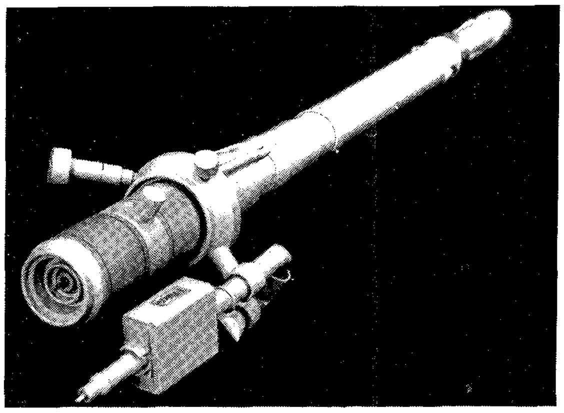


Figure 4. 8mm Amplifying Gyrotron.

If higher pulsed power levels (tens of MW) are required in the millimeter region other approaches are required. Although these power levels are not as high as achieved by relativistic devices, (3-5 GW in oscillation mode, 1-2 GW in amplification mode), nevertheless, many difficulties have to be overcome to obtain the required power levels. The difficulties can be both fundamental problems (self-excitation of parasitic modes, high-frequency breakdown of electrodynamic structure) and implementation problems such as cooling of electrodynamic structure, and providing an optimal collector, to mention only a few.

The gyrotron is an example of the successful solution of some of the problems mentioned above. However, for many applications, the superconducting solenoid magnets which produce the large magnetic fields required for gyrotrons may not be allowed. For some applications, O-type devices are attractive since the conditions for handling the electron beam are easily established without the use of strong magnetic fields.

A cross-sectional view of one such O-type device is shown as Figure 5. The device consists of a circular gun

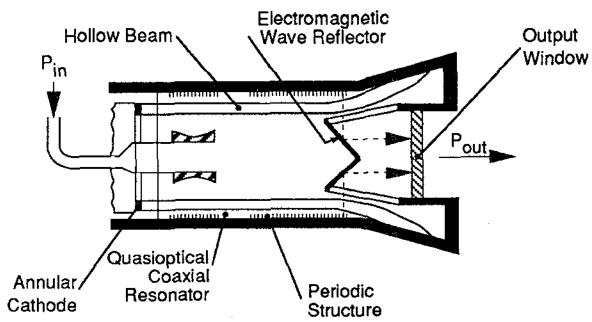


Figure 5. Cross-Section Of 8mm "O-Type" Power Device.

with a large diameter which forms a thin hollow electron beam with 1 mm thick wall. Beam transmission is realized in a homogeneous magnetic field with intensity of about 2000 Oe. The device electron-optical system allows beam currents limited only by cathode emissive capability. The superdimensional electrodynamic structure of the device consists of two sections: a "modulating" first section and an output section where energy extraction from the beam takes place. The first section is designed as a quasioptical coaxial resonator, the outer reflective surface of which is coated with a periodic structure. The beam interacts with resonator transversal oscillations here, and physical processes are similar to those ones which take place in the orotron. The second section provides power exchange with a surface wave of the superdimensional periodic structure. Due to different types of interaction in these two sections they are well "decoupled" as far as the device self-excitation is concerned. The large size (transversal dimensions are 10-15 wavelengths at the operating frequency) significantly simplifies the device cooling which gives the hope for obtaining considerable average power.

Theoretical analyses were performed based on linear and nonlinear models. Some possible side effects, for example, diocotronic instabilities were also investigated. Based on these calculations, the device design was optimized to provide maximum efficiency at the required amplification. Using relatively simple device modifications an efficiency of 10-15% and gain of about 20 dB can be realized.

Sealed-off experimental samples of the device have been developed which were used to refine path of current flow, to control beam modulation efficiency by the first section, and to receive an amplification mode with 13 dB gain.

An investigation of experimental optimization of coupling coefficient of the beam and electrodynamic structure is currently underway. About 500 kW power was achieved in the amplification mode in the 8-mm wavelength range. The obtained results on the whole are in agreement with a physical picture, developed by numeric modelling methods. Currently investigations are being carried out in order to obtain calculated values of output power, efficiency and gain.

3mm WAVELENGTH TUBES

The five-resonator pulsed amplifying klystron shown as Figure 6 was developed for operation in the 3mm region, with 1.5 kW output pulse power over a 300 MHz frequency range, 40 dB klystron gain, and 24 kV cathode voltage. The tube has a control electrode which swings from -1 to 6 kV relative to the cathode as the tube is turned off and on. The weight is 8 kg, and overall dimensions are 125 x 125 x 80 mm.

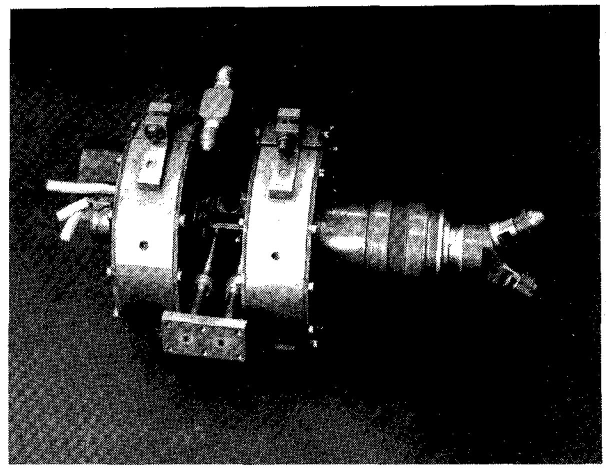


Figure 6. 3mm Klystron Amplifier.

A TWT with 25 W output cw power over an 800 MHz bandwidth has also been developed.

MM-WAVE LOW POWER DEVICES

In 36-1500 GHz region a unique series of multiple beam BWO oscillators with ribbon-like beams have been developed which produce from 40 to 2 mW of output power. In the 36-178 GHz frequency range the devices are packaged with permanent magnets, but in 179-1500 GHz frequency range the devices require an external magnet. Details of these devices are given in a companion paper.