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2,855,538

AMPLIFIER TUBE

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This invention relates to electron discharge tubes incorporating travelling wave systems.

A particular object of the invention is to provide an amplifying device for the continuous power amplification of signals having a wavelength in the range 1 mm. to 25 cms. although the invention is not necessarily limited to this range.

In British patent specification No. 680,794 there is disclosed an electron discharge tube comprising untuned input and output waveguides, an elongated cathode and anode and focussing means for directing a sheet like beam of electrons across both of said waveguides whereby the transverse field component of any unidirectional travelling electromagnetic wave in the input guide can modulate the electron beam by interaction with the beam over its whole width and the modulated beam can excite travelling electromagnetic waves in the output waveguide. For efficient working of an electron discharge tube of this type ratio of potential across the electron beam to the current in the beam must be equal to or less than the characteristic impedance of the waveguides. For example, assuming a cathode/anode potential of 20,000 volts and a characteristic impedance for the guides of 100 ohms, a beam current greater than 200 amps. and preferably of the order of 500 amps. is required. Apart from problems of power and heat dissipation, such a high current between electrodes of practicable size involve such a high current density that space charge effects become pronounced and the beam is difficult to utilise.

A "Klystron" amplifier tube of the conventional type consisting of means for passing an electron beam between two resonant cavities is limited in power output due to heat dissipation with cavity sizes predetermined according to wavelength and as the wavelength becomes shorter, the cavities become smaller and the maximum power output is further limited. In known commercial forms of "Klystron" tubes the power obtained is of the order of 10-25 watts. Apparatus according to the invention provides means of obtaining very much higher power outputs at millimetre and centimetre wavelengths.

According to one aspect of the invention an electron discharge tube comprises two re-entrant unidirectional travelling wave systems resonant at substantially the same or harmonic frequency and coupled by a sheet like electron beam directed across each system in turn in the direction of their transverse electric fields and with the plane of the sheet along the direction of wave propagation. An electron discharge tube in accordance with the invention may also be said to comprise resonant input and output re-entrant electromagnetic wave transmission paths, means for injecting unidirectional travelling electromagnetic waves at substantially the resonant frequency into said first path, means for ejecting electromagnetic waves from said second path and means for directing an electron beam across both of said paths whereby said beam is bunched by velocity modulation due to said injected waves in passing through the first path and excites travelling electromagnetic waves in said second path.

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The output transmission path may be resonant at the same frequency as the input path or at a harmonic frequency thereof.

The invention may also be regarded as a form of "Klystron" velocity modulated tube wherein the bunching of the electron beam is effected by a first electromagnetic wave travelling repetitively across said beam by circulation of the wave in a closed resonant path and energy is transferred from the bunched electron beam into a second electromagnetic wave also travelling in a closed resonant path.

From another aspect the invention provides an amplifying tube for signals in the range from one millimetre to twenty-five centimetres comprising an elongated cathode for emitting electrons from along its length, an accelerating electrode for said electrons to form them into a sheet like stream in transit from the cathode to the accelerating electrode a first re-entrant waveguide to carry a circulating electromagnetic wave to bunch said electron stream in passing across said waveguide between slots provided therein, a second re-entrant waveguide to carry a circulating electromagnetic wave generated by energy transfer from said bunched electron stream in passing across said second waveguide between slots provided therein, means for injecting unidirectional travelling electromagnetic waves to circulate in said first element and means for ejecting the electromagnetic waves generated in said second element.

By using resonant re-entrant paths for the wave transmission paths the characteristic impedance of the paths is effectively increased by a factor "Q" where "Q" is the ratio of reactance to effective resistance. In one designed form of apparatus according to the invention using waveguides of a characteristic impedance of 100 made re-entrant and resonant to have a "Q" factor of 100 and having a potential across the electron beam of 40,000 volts efficient working is obtained with an electron beam current as low as five amperes and this current can be spread over a cathode of such a length that it can readily be made to pass through a slot less than $\frac{1}{10}$ wavelength wide, which is about the maximum desirable width.

An efficiency of operation of 30% then provides 60,000 watts of output power. By loading the waveguides the "Q" factor is reduced and a larger bandwidth is obtained but to maintain the efficiency of working the density of the electron beam must then be increased.

An embodiment of the invention will now be described with reference to the single figure of the accompanying drawing which is arranged to show the essential parts of an electron tube in accordance with the invention and omits such features as water cooling and the connections to the electrodes of the tube.

An evacuated envelope 1 contains a strip-like electron emitting cathode 2, as inclined electron collector 3, a first waveguide element 4 and a second waveguide element 5. The electron beam 6 between cathode and collector, shown by the shaded area, passes through slots, such as slots 7, 8 in the guide elements 4, 5. Waveguide elements 9, 10 are attached to the elements 4, 5 respectively to form resonant re-entrant waveguides (rat-races). A wave injector device 11 is provided in the element 9 for the input travelling wave and a similar device 12, acting as an ejector for the amplified wave, is provided in element 10. The guide element 4 carrying the input travelling wave acts as a "buncher" for the electron beam passing through it and the guide element 5 acts as a "catcher" and amplified electromagnetic waves are generated in it from the energy given up from the electron beam.

This collector 3 is preferably inclined so that the electrons are collected over a larger area to simplify problems

of heat dissipation. Phase shifting devices 13, 14 are provided in elements 9 and 10 respectively for tuning purposes.

Alternative configuration of the waveguides is possible, for example, they may be circular in outline or of a "race-track" form, that is having circular ends with straight side pieces.

The electron tube of the invention may be used as an oscillator device by feeding back a part of the power and may be operated continuously or may be pulsed.

Other modifications to the structure may include an intermediate wave guide of substantially the same dimensions as the "buncher" and "catcher" guides to improve the efficiency by modifying the bunching in the manner of a three cavity "Klystron."

Frequency multiplication may also be used in modified arrangements of the invention by arranging for the output system to be resonant at a harmonic of the input system and by making appropriate adjustments to the relative phase velocities in the guides.

In the example shown, rectangular section waveguides are used. It will be appreciated, however, that waveguides of any section capable of transmitting a mode having a transverse component of electric field may be employed.

Coaxial transmission lines are adaptable as re-entrant travelling wave systems for the purposes of the invention by, for example, making the inner conductors hollow to contain the filament and collector respectively and by providing slots in the inner and outer conductors for the passage of the electron beam. Such an arrangement, however, would probably be unsuitable at wavelengths less than about 25 cms.

I claim:

1. An amplifying tube comprising resonant input and output endless electromagnetic wave transmission paths each of an electrical length equal to an integral number of wave-lengths at the operating frequency, means for injecting unidirectional travelling electromagnetic waves unidirectionally into said first path, means for ejecting electromagnetic waves from said second path and means for directing a sheet-like electron beam across both of said paths with the plane of the sheet along the direction of wave propagation whereby said beam is bunched by

velocity modulation due to said injected waves in passing through the first path and excites travelling electromagnetic waves in said second path.

2. An amplifying tube comprising an elongated cathode for emitting electrons from along its length, an accelerating electrode for said electrons to form them into a sheet like stream in transit from the cathode to the accelerating electrode a first slotted waveguide arranged as a closed loop of resonant electrical length to carry a circulating electromagnetic wave to bunch said electron stream in passing across said waveguide between the slots provided therein, a second slotted waveguide arranged as a closed loop of resonant electrical length to carry a circulating electromagnetic wave generated by energy transfer from said bunched electron stream in passing across said second waveguide between the slots provided therein, means for injecting unidirectionally a travelling electromagnetic wave to circulate in said first waveguide and means for ejecting the electromagnetic waves generated in said second waveguide.

3. An amplifying tube comprising two tubular waveguides each bent to form a closed loop wave transmission path of resonant length, means for injecting a transverse electric wave into one of said paths so as to travel in one direction therearound, means for ejecting a transverse electric unidirectional wave from the other of said paths, and means for directing a sheet-like electron beam across at least part of each path in turn in the direction of the electric fields with the plane of the sheet along the direction of wave propagation, whereby said beam is bunched by velocity modulation due to said injected waves in crossing said one path and excited travelling transverse electric waves in said other path.

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