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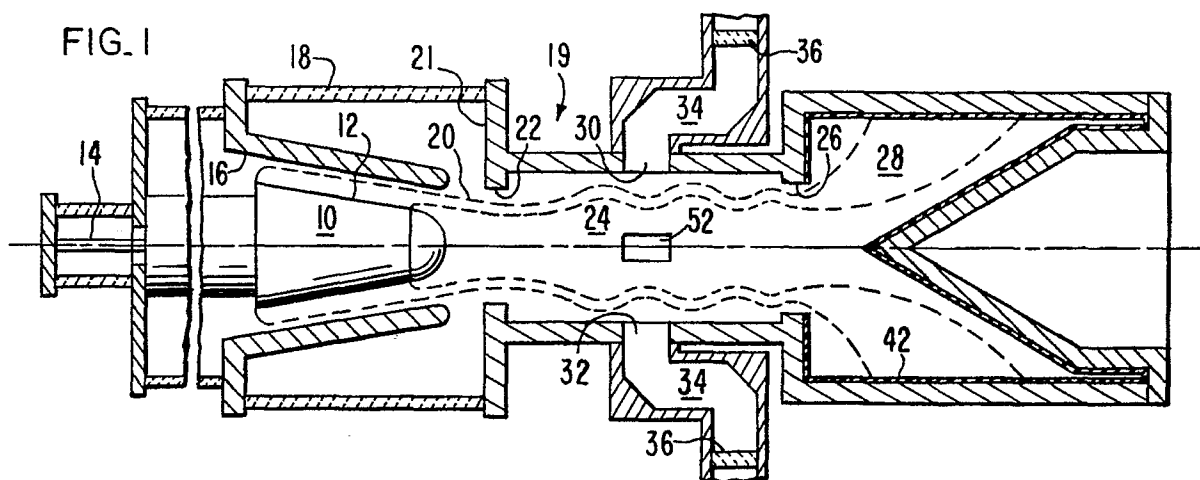
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(54) **Gyrotron.**

(57) In a gyrotron with a hollow interaction circuit (24) the generated microwave in a higher-order mode is extracted transversely into a lower-order waveguide while the spent beam passes axially into a hollow

collector (28). Wave energy leaking into the collector is absorbed by lossy walls (42). The loss is increased by tapering down a transverse dimension to increase the wave fields.



EP 0 411 890 A1

## GYROTRON

The invention pertains to gyrotron electron tubes for generating microwave power.

The conventional gyrotron is usually operated in a mode with a transverse electric field. The power is extracted through the collector cavity maintaining a circular symmetry through an output window, the beam being diverted outward into the inner surface of a cylindrical collector so that no beam reaches the output window. The rf energy through it is in the same mode as in the interaction cavity which in general is a higher order mode.

The symmetry of the higher order modes can be used to extract energy from the interaction cavity directly into waveguides in a fundamental mode such as the TE<sub>11</sub> in a circular guide or the TE<sub>10</sub> in a rectangular guide. However, there may be some residual coupling into lower order modes which then can propagate into the collector region because the output aperture may not be cut off for the low order modes.

Many attempts have been made for methods of extracting energy in a fundamental mode. For example, US-A-4,200,820 issued April 29, 1980 to Robert S. Symons describes a quasi-optical minor for deflecting the wave. This was not completely successful due to local fields of the output aperture. The problem of unwanted energy entering the collector has not arisen in the previous prior art because the collector was used as the output waveguide. Wave energy reflected in the collector, however, could re-enter the interaction cavity, distorting the desired field pattern, causing oscillation in a competing mode, or disrupting the beam focussing in the region between cathode and interaction circuit.

### Summary of the Invention

The object of the invention is to provide a gyrotron with output energy coupled transversely from the tube such that harmful energy of whatever mode entering the collector is absorbed rather than being reflected. This is achieved by coating the downstream end of the collector, preferably past the beam-impact area, with a lossy, resistive layer. To increase loss, a transverse dimension of the collector is tapered down to be near or even beyond waveguide cutoff for the mode of the undesired wave.

### Brief Description of the Drawings

FIG. 1 is an axial cross-section of a gyrotron

embodying the invention.

FIG. 2 is an axial cross-section of an alternative arrangement of the collector.

### Description of the Preferred Embodiments

FIG. 1 shows very schematically the construction of a gyrotron embodying the invention. A cathode structure 10 has a truncated electron-emissive surface 12 heated by an interior radiant heater (not shown) fed through an insulated lead-in 14. A hollow conical anode 16 supported by a hollow dielectric cylinder 18 from the metallic vacuum envelope 19 draws a hollow beam of electrons 20 from emitter 12. An axial magnetic field deflects beam 20 to produce an azimuthal motion component and limits its radial motion. Anode 16 may have a greater taper than emitter 12 to improve focusing of hollow beam 20 and give it an axial motion component. After leaving anode 16, beam 20 may be further accelerated by axial electric field to an apertured end-plate 21 of vacuum envelope 19. In this region, the axial magnetic field increases to reduce the beam diameter and increase the transverse velocity at the expense of axial velocity. Beam passes through an input iris 22, preferably of diameter to be cut off as a waveguide for the operating frequency. Beyond iris 22, beam 20 passes through an interaction chamber 24 and leaves through an output iris into an enlarged beam collector 28. In collector 28, the axial magnetic field decreases rapidly so the beam expands under magnetic and space-charge forces before being dissipated on the walls of collector 28, which are in contact with a fluid coolant.

Cavity 24 is resonant in a higher-order mode such as TE<sub>01</sub> or T<sub>21</sub> to interact with terse components of electron motion. In this configuration, the generated electromagnetic wave energy is extracted through apertures 30, 32 leading via waveguides 34 and dielectric vacuum windows 36 to useful loads (not shown).

The proper symmetrical arrangement of output ports 30 can balance out the excitation of lower order modes in interaction cavity 24. However, such neutralization is never perfect and some residual energy in lower order modes may result. Aperture 26 through which beam 20 leaves interaction cavity 24 to enter collector cavity 28 is normally small enough to be cut off for the high-order desired interaction mode. However, the lower-order unwanted modes accidentally excited, having much lower cut off frequencies, can be readily transmitted through aperture 26 into collector 28.

In higher order mode gyrotrons, it is required to provide sufficient rf loading of the lower order modes such that these will not oscillate instead of the desired mode. For gyrotrons with transverse power extraction, this loading is typically provided by allowing the wave to propagate into the collector region where the power is absorbed. Rf loss must be provided to prevent reflection of this energy back into the interaction circuit.

In the prior art, collectors have been made of low-loss material such as copper because they served also as output waveguides. Any lower-order modes excited by transverse output coupling apertures of the above application could then resonate in a number of field patterns in the enlarged collector 28 and build up high fields which can be retransmitted through aperture 26 back into interaction cavity 24 and also through input aperture 22 into the cathode region where they can disrupt both the beam flow and the desired electronic interaction. The present invention includes means 42 for absorbing the energy from these low order modes directly inside collector 28. Prior-art means for absorbing unwanted wave energy involve wave-absorptive materials. In some cases, lossy dielectrics such as alumina or beryllia ceramics loaded with particles of metallic carbides have been used, but the heat dissipation available in such materials is insufficient for the high powers involved in gyrotrons. Another means for absorbing energy has been to coat the surface of the conductors with a material having a high resistance to the flow of high-frequency currents associated with the electromagnetic resonance. However, the total loss available is usually insufficient to reduce the energy reflected from the collector to a satisfactory value. According to the invention, this loss is increased many fold by shaping the collector to concentrate the microwave fields and hence increase the surface currents which dissipate the energy. To do this, transverse dimensions of the collector are tapered down to smaller values such that as the wave energy flows away from the interaction region and down the collector, it becomes concentrated in a smaller volume, with associated higher circulating currents. Additional enhancement of loss is produced by the characteristics of the collector as a waveguide in that as the dimensions are decreased, the waveguide becomes closer and closer to its cut-off frequency, accompanied by a large increase in stored energy and electromagnetic fields. At the exact waveguide cut-off point, energy is no longer propagated axially and theoretically the loss will approach infinity. In the embodiment shown in FIG. 1 the farther end of collector 28 has a reentrant conical element at its center such that as the wave flows down the collector its energy becomes compressed into a smaller and

smaller distance. In the case of FIG. 1 the cone terminates, leaving a coaxial cylindrical space at the very end in which the distance between the coaxial conducting cylinders is very small, thus forming a coaxial line of extremely low impedance, which means high circulating currents and high losses. This particular section of waveguide will be cut off for some of the possible resonant modes. Alternatively, the spacing could be decreased smoothly and gradually and until the point where all modes except the fundamental TEM coaxial line mode are cut off.

The portion of the collector surface actually bombarded by electron beam 20 may be coated with lossy material or, if the power densities are too high, it can be left bare and the lossy material applied only to the unbombarded areas. The outer surface of the central cone can be coated, or the central element can be designed to actually intercept some of the electrons.

FIG. 2 is an axial cross-section sketch of a slightly different embodiment. Here the outer diameter of collector 28 is simply tapered gradually to a point. At the axial position where any certain mode reaches its cut off point the loss for that mode will be exceedingly high. For this construction the overall length of the collector will be somewhat longer than that shown in FIG. 1, which may be a disadvantage in a gyrotron in which the overall length of the tube can become very large.

### Claims

#### 1. A gyrotron comprising:

a hollow circuit for interaction of the electron beam with a higher-order electromagnetic mode of said circuit;

means for coupling the generated wave energy from said interaction circuit directly into a useful load;

an aperture for passing the spent electron beam from said circuit into a hollow collector, said aperture being cut off for transmission of said higher-order mode and transmissive for at least one lower-mode having lower cut-off frequency than said higher-order mode;

said collector containing lossy material for absorbing energy transmitted from said lower-order mode; said collector being tapered to at least one smaller transverse dimension with increasing distance from said aperture, whereby fields of said transmitted energy are concentrated to provide higher absorption of said transmitted energy.

2. A gyrotron as claimed in Claim 1 wherein said collector tapers to a value at which such lower-order modes becomes cut off.

3. The gyrotron of claim 1 wherein said collector is

a figure of revolution about the axis of said beam.

4. The gyrotron of claim 3 wherein said tapered dimension is the radial opening of said collector.

5. The gyrotron of claim 3 wherein said collector has a reentrant conical section inside its outer wall and said tapered dimension is a radial separation between said conical section and said outer wall.

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6. The gyrotron of claim 1 wherein said lossy material is a high-resistance coating on an inside wall of said collector.

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7. The gyrotron of claim 3 wherein said tapered dimension is the diameter of a non-reentrant collector.

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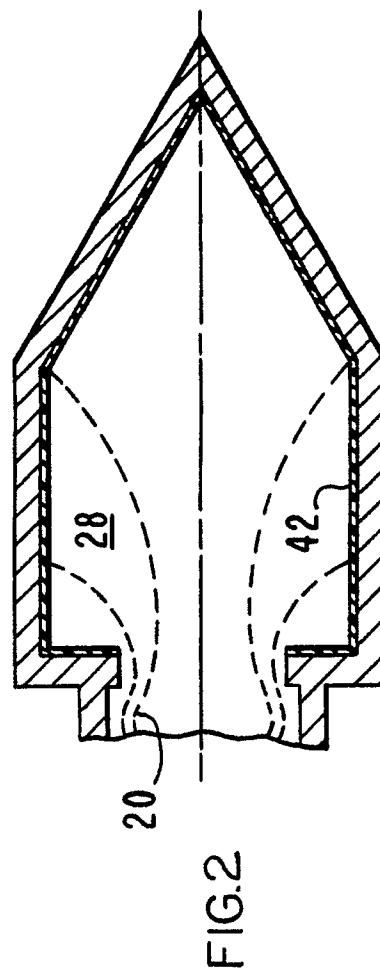
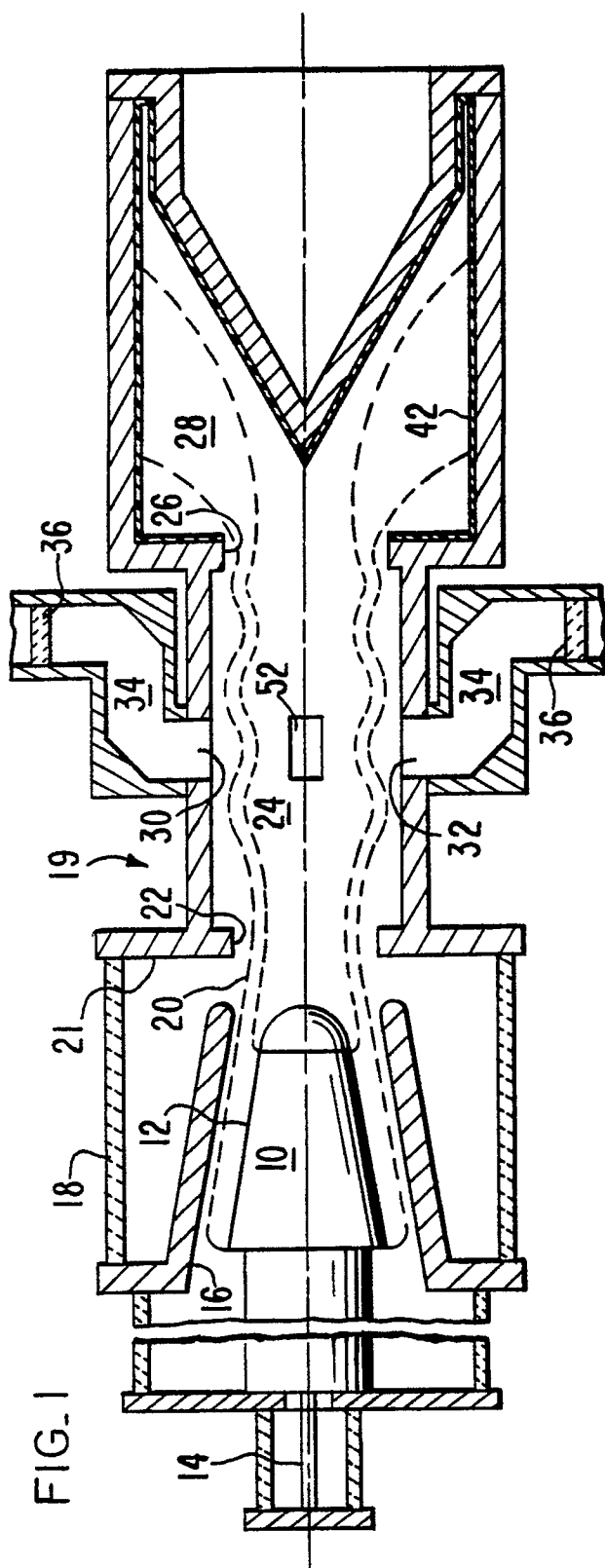
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## EUROPEAN SEARCH REPORT

Application Number

EP 90308395.4

| DOCUMENTS CONSIDERED TO BE RELEVANT                                                                                                                                                                                                                                                   |                                                                                                                                                                                                            |                                         |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|
| Category                                                                                                                                                                                                                                                                              | Citation of document with indication, where appropriate, of relevant passages                                                                                                                              | Relevant to claim                       |
| A                                                                                                                                                                                                                                                                                     | <u>US - A - 4 513 223</u><br>(CHODOROW)<br>* Fig. 3A; abstract; column 4, lines 36-45 *                                                                                                                    | 1                                       |
| A                                                                                                                                                                                                                                                                                     | PATENT ABSTRACTS OF JAPAN,<br>unexamined applications,<br>E field, vol. 10, no. 69,<br>March 18, 1986<br>THE PATENT OFFICE JAPANESE<br>GOVERNMENT<br>page 39 E 389<br>* Kokai-no. 60-218 739<br>(NIPPON) * |                                         |
|                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                            | TECHNICAL FIELDS<br>SEARCHED (Int. CL5) |
|                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                            | H 01 J 25/00<br>H 01 J 23/00            |
| The present search report has been drawn up for all claims                                                                                                                                                                                                                            |                                                                                                                                                                                                            |                                         |
| Place of search<br>VIENNA                                                                                                                                                                                                                                                             | Date of completion of the search<br>06-11-1990                                                                                                                                                             | Examiner<br>BRUNNER                     |
| CATEGORY OF CITED DOCUMENTS                                                                                                                                                                                                                                                           |                                                                                                                                                                                                            |                                         |
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