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Description

The invention pertains to linear-beam electron tubes in which the beam is density-modulated by a control grid. Such tubes have been found useful for generating amplitude-modulated ultra-high-frequency radio waves such as television broadcast transmission, with efficiency superior to klystrons.

Radio transmitters have generally used grid-controlled electron tubes such as tetrodes. When frequencies increased to the ultra-high frequency range (UHF), the gridded tubes reached their performance limits of power or frequency due to the transit times of electrons across the gaps between electrodes becoming comparable to the period of the generated wave. The first development to overcome these limits was the UHF klystron in which transit time is taken advantage of rather than being unwanted. However, the klystron is very inefficient for amplifying an amplitude-modulated wave such as the standard TV signal where amplitude corresponds to brightness. The klystron has to have enough power in the beam to generate the signal peaks, such as black and the still stronger synchronization pulses. The average power needed for an average signal is several times smaller, but the unused beam power is wasted as heat in the spent-beam collector.

Various proposals have been made to improve the average klystron efficiency. One is to modulate the beam current to follow the envelope of generated power. This has not been successful due to the complicated circuitry needed to correct problems with linearity and amplitude-to-phase distortion and to the power needed to modulate the beam.

The first successful attempt to improve efficiency is the "Klystrode®" described in U.S. Patent US-A-4,480,210 issued October 30, 1984 to Donald H. Preist and Merrald B. Shrader. This followed the much older "Inductive Output Tube" described by A.V. Haeff in *Electronics*, February 1939, in that the beam of electrons was amplitude modulated by a control grid, and the output circuit was a non-intercepting resonator as in a klystron. Haeff's tube was a low-power device following the close-spaced grid art of that day. Preist and Shrader made a high-power tube using klystron beam technology and a much larger carbon grid to which the rf signal was applied in class B or class C modulation. The video-frequency power envelope of the beam is thus just what is needed to generate the instantaneous signal amplitude. The power efficiency in TV transmission was increased greatly.

A proposed improvement on the Preist-Shrader "Klystrode" is described in U.S. Patent US-A-4,611,149 issued September 9, 1986 to Richard B. Nelson. One disadvantage of the "Klystrode" is that the rf bunches of current leaving the modulating grid as approximately half sine-waves in class B modulation are spread out somewhat by the time they reach

the output resonator by the repulsive space-charge forces between electrons. In the Nelson tube, a second resonator is inserted between the grid and the output. It is resonant at a frequency above the signal band to provide an inductive impedance to the beam which rebunches the beam current by velocity modulation as in a multi-cavity klystron amplifier. The bunches are even narrower than those leaving the grid, so the efficiency lost by space-charge spreading is more than recovered.

US-A-4611149 can be taken to describe a linear-beam frequency-multiplier electron vacuum tube comprising an electron emissive cathode; an electron-permeable control grid closely spaced from the emissive surface of said cathode; means for supplying a high-frequency signal voltage between said cathode and said grid; an anode spaced from said grid and facing said emissive surface, apertured for passage of an electron beam from said cathode; a hollow conductive drift tube for transmitting said beam beyond said anode, the drift tube being formed with a first and a second gap, the second gap being on one side of the first gap near the anode; a first hollow cavity located around the first gap in said drift tube to form a re-entrant cavity resonant at a frequency near the frequency of said signal voltage; a second hollow cavity located around the second gap in said drift tube to form a re-entrant cavity resonant at a frequency higher than said signal voltage frequency; means for extracting wave energy at said higher frequency from said second cavity; and means for collecting said beam downstream of said second cavity.

The present invention is set out in Claim 1.

An example of the invention will now be described with reference to the accompanying drawings in which:

Figure 1 is a schematic axial section of an amplifier tube, and

Figure 2 is a graph of the harmonic content of the beam current.

Figure 1 illustrates a tube which has a thermionic cathode with preferably concave emitting surface 11, heated by a radiant wire coil 12. A convergent beam of electrons 14 is drawn from emitter 11 by a hollow anode 16. Directly in front of emitter 11 is an electron-permeable grid, preferably of pyrolytic graphite bars 18 bounding apertures 20.

Beam 14 is converged toward anode 16 by the convergent electrostatic field. It passes through anode 16 and an annular ferro-magnetic polepiece 22 which forms one terminus of a strong axial magnetic focusing field generated by a surrounding solenoid coil (not shown). Beam 14 then passes through a hollow metallic drift tube 24 and crosses an interaction gap 26 between input drift tube 24 and an exit drift tube 28. Drift tubes 24 and 28 form the center conductor of a coaxial cavity 30, resonant at preferably a frequency just above the frequency band of the

tube's input signal.

After passing through cavity 30, beam 14 traverses a second cavity 32 having an axial drift tube 34 divided by an interaction gap 36. Cavity 32 is resonant at a harmonic of the band-center input frequency and is excited by the harmonic component of the modulated beam current.

After leaving harmonic output cavity 32, beam 14 passes through a second annular polepiece 37 which terminates most of the axial field. Beam 14 then expands under its own space-charge repulsion and is collected on the hollow, inner surface of a beam collector 38. The heat energy dissipated is removed by a coolant 40 (such as water) circulating from a coolant pipe 42.

In operation an input signal to be amplified and frequency-multiplied is fed in from a coaxial transmission line 46 through a coaxial dielectric vacuum window 48 to the space between the grid support 50 (usually at rf ground) and cathode support 52. This space may be partially blocked from input line 46 to form a resonant cavity to properly match impedances.

Drift tube 34 of harmonic cavity 32 is smaller in diameter than drift tube 24 of fundamental cavity 30, to provide good interactive coupling between beam and cavity at the higher frequency. The beam size is tapered down by a gradual increase in strength of the focussing magnetic field by increasing the wire turns per unit length of the solenoid. Shaping of polepieces 22, 37 to concave-convex shapes may also be used to generate the tapered field. In the strong "confined flow" focussing, the electrons follow the magnetic flux lines.

Useful harmonic energy is extracted from output cavity 32 via a coupling orifice 54 into an output waveguide 56 which is sealed off by a dielectric vacuum window 57.

The distinct advantage of the "Klystrode" frequency multiplier arises from the surprisingly high harmonic content of the beam current which is obtainable. The harmonic current increases with the shortness of the electron bunches. In a klystron frequency multiplier, it is impossible to get all the electrons into a short bunch by simple velocity modulation. This is illustrated in U.S. Patent US-A-3,622,834 issued November 23, 1971 and U.S. Patent US-A-3,811,065 issued May 14, 1974, both to E.L. Lien. In both patents, FIG. 4 shows calculated trajectories (in rf phase) of sample electrons where harmonic content of beam current is enhanced by bunching at a harmonic frequency. On the other hand, in the present apparatus with class B or class C grid modulation, there is no current at all in the antibunch. The Lien patents show that getting current out of the antibunch regions is a distinct limitation to klystron bunching. When we start out with vacant antibunches followed by velocity modulation compression, the bunches can be made re-

markably tight, and thus the harmonic content is surprisingly high.

FIG. 2 is a graph of calculated harmonic components of beam current in the present frequency multiplier, plotted as functions of distance Z from the amplitude-modulating grid. Graph 60 is the fundamental component having a decreasing value 62 after leaving grid 18 due to space-charge debunching. In gap 26 of floating cavity 30 beam 14 receives velocity modulation which in following drift tube 28 increases the A.C. component 64. At the position of output gap 36, the A.C. component reaches a maximum value 66. In the calculated design an output circuit with a gap at the position of harmonic gap 36 but resonant at the fundamental frequency gives a conversion efficiency of 87%.

The second graph shows the second harmonic component 70 of beam current. The space-charge debunching 72 is more severe than for the fundamental current 60 due to the shorter wavelength. After velocity modulation in gap 26, the second harmonic current also increases faster due to the increased number of wavelengths traversed. The peak value 76 is reached at about the same distance as that of fundamental 60. At this point output gap 36 is located. The conversion efficiency for second harmonic power was calculated as 75%, a value completely out of reach in klystrons or simple grid-controlled tubes.

In a practical case, the second or third harmonic would be used. With the high fundamental current available at the lower driving frequency, the limits of power and frequency available from the multiplier are greatly extended.

The above-described tube is a single preferred embodiment of the invention. Other embodiments will occur to those skilled in the art. Additional cavities could be added for still higher efficiency.

Claims

1. A linear-beam frequency-multiplier electron vacuum tube comprising:
 - an electron emissive cathode (10) for emitting an electron beam ;
 - an electron-permeable control grid (11) for controlling said beam, said grid being closely spaced from the emissive surface of said cathode;
 - means (46-52) for supplying a high-frequency signal voltage between said cathode and said grid;
 - an anode (16) spaced from said grid and facing said emissive surface, apertured for passage of said electron beam ;
 - a hollow conductive drift tube (24, 28) for transmitting said beam beyond said anode, the drift tube being formed with a first and a second

gap, the second gap being on the side of the first gap remote from the anode;

a first hollow cavity (30) for velocity modulation of said beam, said first hollow cavity being located around the first gap in said drift tube to form a re-entrant cavity resonant at a frequency near the frequency of said signal voltage;

a second hollow cavity (32) located around the second gap in said drift tube to form a re-entrant cavity resonant at a frequency near a harmonic of said signal voltage frequency;

means (54-57) for extracting wave energy at said harmonic frequency from said second cavity; and

means (38) for collecting said beam downstream of said second cavity.

2. A tube as claimed in claim 1 wherein said first cavity (30) is resonant at a frequency higher than the frequency band of said signal and lower than the frequency band of said harmonic.
3. A tube as claimed in claim 1 or claim 2 wherein said second cavity (32) is resonant at a frequency approximating the centre of the frequency band of said harmonic.
4. A tube as claimed in any one of claims 1 to 3 wherein said grid (11) is of pyrolytic graphite.
5. A tube as claimed in any one of claims 1 to 4 wherein said means for supplying signal voltage comprises a resonant circuit connecting said cathode and said grid.
6. A tube as claimed in any one of claims 1 to 5 wherein said drift tube (24, 28) is smaller at said second gap (36) than at said first gap (26).
7. A tube as claimed in any one of claims 1 to 6 wherein said second gap (36) is shorter than said first gap (26).
8. A tube as claimed in any one of claims 1 to 7 comprising means (22, 37) for generating a steady magnetic field in the direction of said beam between said anode and said second gap.
9. A tube as claimed in claim 8 wherein said magnetic field means comprises ferromagnetic polepieces (22, 37) surrounding said drift tube.
10. The tube of claim 8 wherein said magnetic field means is arranged to generate a magnetic field stronger at said second gap than at said first gap whereby said beam is compressed between said gaps.

Patentansprüche

1. Linearstrahlelektronenröhre für einen Frequenzvervielfacher mit:
einer Elektronenemissionskathode (10) zum Emittieren eines Elektronenstrahls;
einem elektronendurchlässigen Steuergitter (11) zum Steuern des Strahls, das in engem Abstand von der emittierenden Oberfläche der Kathode angeordnet ist;
Mitteln (46 bis 52) zum Anlegen einer hochfrequenten Signalspannung zwischen Kathode und Gitter;
einer Anode (16), die vom Gitter beabstandet und der emittierenden Oberfläche gegenüberliegend angeordnet ist, mit einer Öffnung zum Durchgang des Elektronenstrahls;
einer hohlen leitfähigen Driftröhre (24, 28) zum Transmittieren des Strahls über die Anode hinaus, mit einem ersten und einem zweiten Spalt, wobei der zweite Spalt auf der Seite des ersten Spalts entfernt von der Anode angeordnet ist;
einem ersten Hohlraum (30) zur Geschwindigkeitsmodulation des Strahls, wobei der erste Hohlraum um den ersten Spalt herum in der Driftröhre angeordnet ist, um einen Reentrant-Resonator zu bilden, der in der Nähe der Frequenz der Signalspannung resoniert;
einem zweiten Hohlraum (32), der um den zweiten Spalt der Driftröhre angeordnet ist, um einen Reentrant-Resonator zu bilden, der in der Nähe einer Harmonischen der Frequenz der Signalspannung resoniert;
Mitteln (54 bis 57) zur Entnahme von Wellenenergie mit der Frequenz der Harmonischen am zweiten Hohlraum; und
Mitteln (38) zum Aufnehmen des Strahls in Strahlrichtung hinter dem zweiten Hohlraum.
2. Röhre nach Anspruch 1, bei der der erste Hohlraum (30) eine Resonanzfrequenz aufweist, die höher ist als das Frequenzband des Signals und die niedriger ist als das Frequenzband der Harmonischen.
3. Röhre nach Anspruch 1 oder 2, bei der der zweite Hohlraum (32) eine Resonanzfrequenz aufweist, die sich der Mitte des Frequenzbandes der Harmonischen annähert.
4. Röhre nach einem der Ansprüche 1 bis 3, bei der das Gitter (11) aus pyrolytischem Graphit besteht.
5. Röhre nach einem der Ansprüche 1 bis 4, bei der die Mittel zum Zuführen der Signalspannung einen die Kathode und das Gitter verbindenden Resonanzkreis enthalten.

6. Röhre nach einem der Ansprüche 1 bis 5, bei der die Driftröhre (24, 28) an dem zweiten Spalt (36) schmaler ist, als an dem ersten Spalt (26).
7. Röhre nach einem der Ansprüche 1 bis 6, bei der der zweite Spalt (36) kürzer ist als der erste Spalt (26). 5
8. Röhre nach einem der Ansprüche 1 bis 7, mit Mitteln (22, 37) zum Erzeugen eines dauerhaften Magnetfeldes in Strahlrichtung zwischen der Anode und dem zweiten Spalt. 10
9. Röhre nach Anspruch 8, bei der die Magnetfeldmittel ferromagnetische Polelemente (22, 37) enthalten, welche die Driftröhre umgeben. 15
10. Röhre nach Anspruch 8, bei der die Magnetfeldmittel ein Magnetfeld erzeugen, das an dem zweiten Spalt stärker ist als an dem ersten Spalt, wobei der Strahl zwischen den Spalten zusammengedrückt wird. 20

Revendications

1. Tube électronique à vide multiplicateur de fréquence à faisceau linéaire comportant :
 une cathode émissive d'électrons (10) pour l'émission d'un faisceau d'électrons ;
 une grille de commande (11) perméable aux électrons pour commander ledit faisceau, ladite grille étant très voisine de la surface émissive de ladite cathode ;
 un moyen (46-52) pour fournir une tension de signal à haute fréquence entre ladite cathode et ladite grille ;
 une anode (16) espacée de ladite grille et faisant face à ladite surface émissive, comportant des ouvertures pour le passage dudit faisceau d'électrons ;
 un tube de transit conducteur creux (24, 28) pour transmettre ledit faisceau au-delà de ladite anode, le tube de transit comportant un premier et un deuxième espaces, le deuxième espace étant situé du côté du premier espace éloigné de l'anode ;
 une première cavité creuse (30) destinée à la modulation en vitesse dudit faisceau, ladite première cavité creuse étant située autour du premier espace dans ledit tube de transit pour constituer une cavité de ré-entrée résonant à une fréquence voisine de la fréquence de ladite tension de signal ;
 une deuxième cavité creuse (32) située autour du deuxième espace dans ledit tube de transit pour constituer une cavité de ré-entrée résonant à une fréquence voisine d'un harmonique

de ladite fréquence de tension du signal ;
 un moyen (54-57) pour extraire l'énergie de l'onde à ladite fréquence d'harmonique depuis ladite deuxième cavité ; et
 un moyen (38) pour recueillir ledit faisceau en aval de ladite deuxième cavité.

2. Tube selon la revendication 1, dans lequel ladite première cavité (30) est résonante à une fréquence supérieure à la bande de fréquence dudit signal et inférieure à la bande de fréquence dudit harmonique.
3. Tube selon la revendication 1 ou la revendication 2, dans lequel ladite deuxième cavité (32) est résonante à une fréquence située approximativement au centre de la bande de fréquence dudit harmonique.
4. Tube selon l'une quelconque des revendications 1 à 3, dans lequel ladite grille (11) est en graphite pyrolytique.
5. Tube selon l'une quelconque des revendications 1 à 4, dans lequel ledit moyen d'alimentation en une tension de signal comporte un circuit résonant connecté à ladite cathode et à ladite grille.
6. Tube selon l'une quelconque des revendications 1 à 5, dans lequel ledit tube de transit (24, 28) est plus petit au niveau dudit deuxième espace (36) qu'au niveau dudit premier espace (26).
7. Tube selon l'une quelconque des revendications 1 à 6, dans lequel ledit deuxième espace (36) est plus court que ledit premier espace (26).
8. Tube selon l'une quelconque des revendications 1 à 7, comportant un moyen (22, 37) pour produire un champ magnétique stable dans la direction dudit faisceau entre ladite anode et ledit deuxième espace.
9. Tube selon la revendication 8, dans lequel ledit moyen de champ magnétique comporte des pièces polaires ferromagnétiques (22, 37) entourant ledit tube de transit.
10. Tube selon la revendication 8, dans lequel ledit moyen de champ magnétique est agencé pour produire un champ magnétique plus puissant au niveau dudit deuxième espace qu'au niveau dudit premier espace, grâce à quoi ledit faisceau est comprimé entre lesdits espaces.

FIG. 1

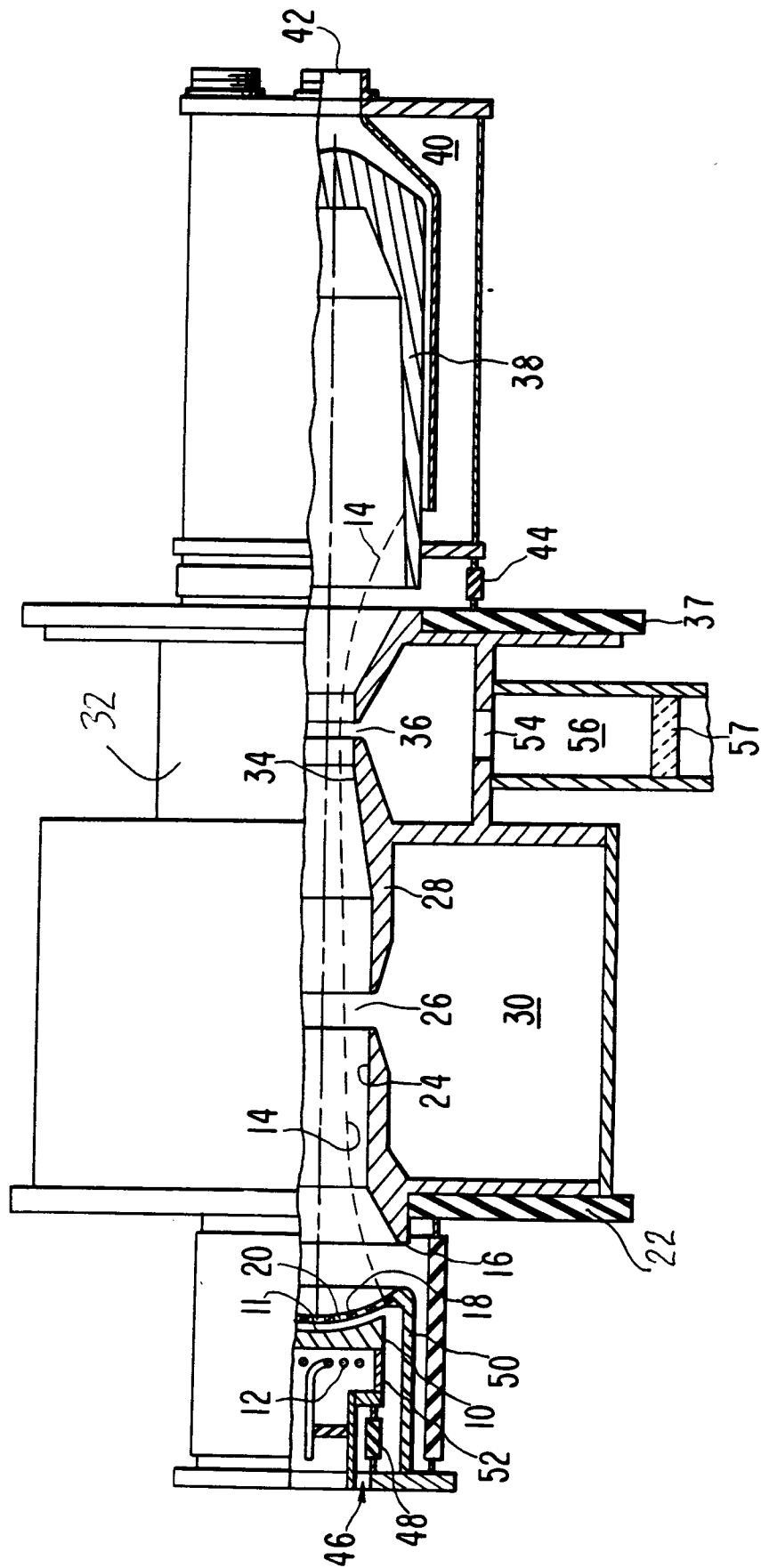


FIG. 2

