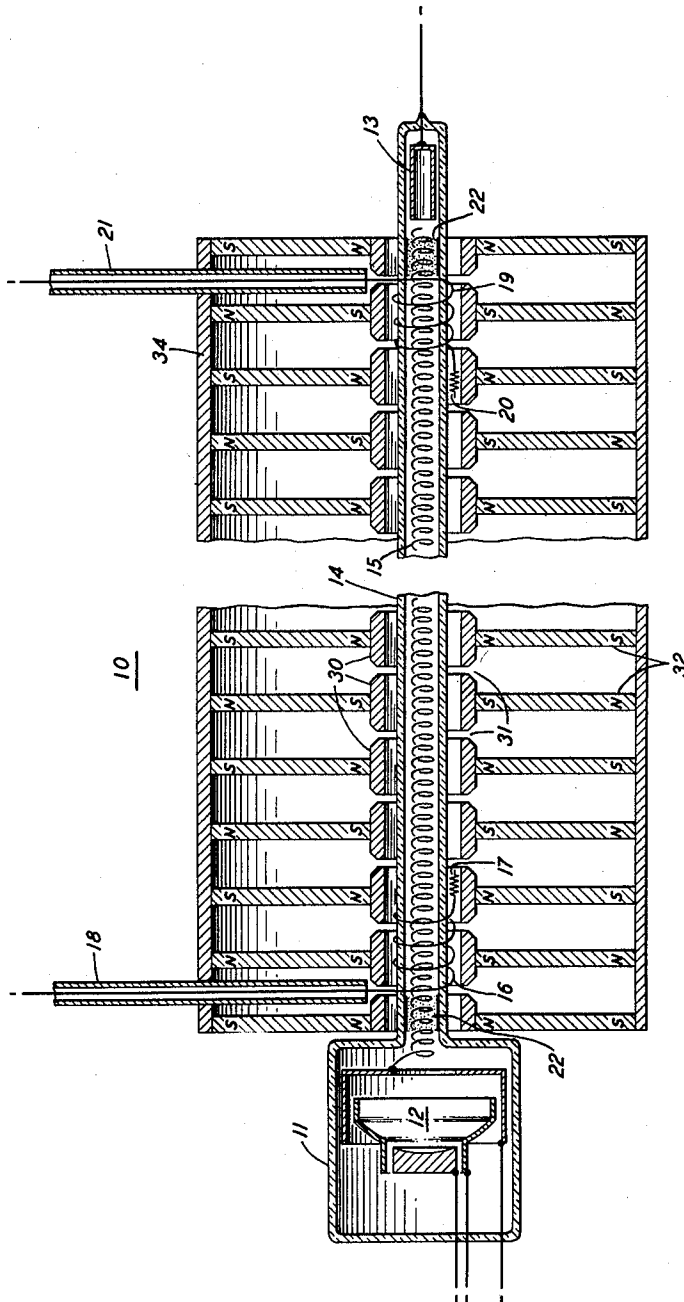


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R. KOMPFFNER
TRAVELING WAVE TUBE
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INVENTOR
R. KOMPFFNER
BY *Hugh S. Wertz*
ATTORNEY

1

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TRAVELING WAVE TUBE

Rudolf Kompfner, Far Hills, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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This invention relates to improvements in radio frequency devices which utilize the interaction between a traveling electromagnetic wave and an electron beam to amplify the electromagnetic wave, now generally designated as traveling wave tubes, and more particularly to improvements in the focusing of electron beams in such devices.

Among the various problems associated with the operation of such tubes is that of keeping the electron beam in alignment with the wave guiding structure used for propagating the traveling electromagnetic wave whereby a minimum number of electrons will be lost in striking the structure while yet the electron flow can be kept close enough to the structure for good interaction with the radio frequency electric fields associated therewith. To this end, it has been found advantageous to employ magnetic focusing to confine the electron beam. In United States Patent 2,847,607, issued August 12, 1958, of J. R. Pierce it is shown that good magnetic focusing can be achieved by a periodic succession of magnetic regions of a spatially alternating axially symmetric longitudinal magnetic field along the path of flow. Such periodic focusing is found to result in considerable economies in the size and weight of the auxiliary equipment necessary for magnetic focusing. In particular, in the arrangements described in the above-identified patent, the periodic spatially alternating magnetic field regions are achieved by spacing along the path of flow a succession of annular members which serve as pole pieces and poling successive pole pieces oppositely by bridging between each pair of adjacent annular members one of a succession of permanent magnets which are magnetized in a direction parallel to that of the electron flow.

With arrangements of this kind, it is found that with changes in the magnetic period and the magnetic field strength along the path of flow, the focusing exhibits "pass" and "stop" bands, i. e., regions of good and poor focusing. The highest beam transmission efficiency usually can be had by operation in the pass band corresponding to the shortest magnetic period. Moreover, it is found that the magnetic period and magnetic field strength necessary for optimum focusing in this pass band is related to the beam current and beam perveance. Accordingly, in traveling wave tubes which use a large beam current and high beam perveance, short magnetic periods and high magnetic field strengths are important for high beam transmission efficiencies. However, in the various focusing arrangements described in the aforementioned patent, a short magnetic period requires a short pole-piece to pole-piece spacing and hence a short permanent magnet for bridging adjacent pairs of pole pieces. Short permanent magnets generally have low efficiencies, and, accordingly, it becomes difficult to achieve high magnetic field strengths along the path of flow conveniently. Accordingly, it has been difficult hitherto to utilize periodic focusing principles efficiently for focusing electron beams of high density and high perveances. One object of the present invention is to better to adapt the principles of

2

periodic focusing to beams of high density and perveances where short magnetic periods are desirable.

To this end, the principal feature of the present invention is a periodic focusing arrangement which comprises a succession of annular members which serve as pole pieces along the path of flow and associated therewith a like succession of annular permanent magnets which are magnetized in a radial direction, successive magnets being magnetized in a reverse sense. These are enclosed by a magnetically soft cylindrical shield which simultaneously serves as the return path of the magnetic flux between adjacent permanent magnets.

One advantage of this arrangement is that the combination of the cylindrical shield and the pole pieces serves to concentrate the flux from the permanent magnets along the path of flow causing few stray fields and increasing the efficiency of the permanent magnets.

Moreover, since the magnetomotive force developed across the gaps between adjacent pole pieces is related to the length along the magnetic axis of the permanent magnets, higher magnetomotive forces and higher magnetic field intensities can be achieved efficiently by extending the dimension of the magnets in the radial direction with no change in the periodicity of the pole pieces along the path of flow.

The invention will be better understood from the following more detailed description taken in conjunction with the accompanying drawing which illustrates the embodiment of the principles of the invention in a helix-type traveling wave tube.

Referring more particularly to the drawing, in the illustrative traveling wave tube 10 shown in longitudinal cross section, an evacuated glass envelope 11 houses the various tube elements. At opposite ends of the envelope an electron source 12 and a target electrode 13 define a longitudinal path of flow for the electron beam along the axis of the elongated portion 14 of the tube envelope. The electron source 12 is a conventional-type electron gun for providing a concentrated electron beam. Disposed along the path of flow coaxial with the longitudinal axis of the tube is the wave interaction circuit comprising the helically wound conductor 15. The helix is adapted to propagate a traveling wave with an axial phase velocity sufficiently approximating the velocity of the electron beam that substantial interaction results whereby the wave is amplified. The electron velocity is adjusted by the beam accelerating voltage on the helix 15. The various lead-in connections for applying the necessary D.-C. voltages to the various tube elements have been omitted for the sake of simplicity.

An input wave to be amplified is applied to the wave interaction circuit by the external helix 16 which is coupled electromagnetically to the circuit helix 15. The principles of coupled helices are set forth in my United States Patent 2,811,673, issued October 29, 1957. For good coupling in this way, the winding of the outer helix 16 should be in a sense opposite to that of the inner helix 15 but the pitch of the outer helix should be approximately the same as that of the inner helix 15 whereby the axial phase velocities of waves propagating therealong will be substantially similar for the two helices. Additionally, the outer helix should overlap the inner helix for a distance which is a quarter of the "beat" wavelength. This "beat" wavelength may be defined as follows: The wave propagating along one of the two coupled helices has a phase velocity only slightly different from that of a wave propagating on one of the helices when uncoupled, but the amplitude of the wave propagating along one of two coupled helices varies sinusoidally with distance, exhibiting a phenomenon which may be called "spatial beating." The length of one cycle of this phenomenon for convenience is called the "beat" wave-

length. The end of the outer helix downstream along the path of flow (it is to be noted that the terms "upstream" and "downstream" are used with reference to relative distances from the source rather than the inclination of the tube) is terminated to be substantially reflectionless by a resistive termination 17, and the other end is connected to the inner conductor of a coaxial line 18 by means of which energy is guided from a suitable signal source to the input connection of the traveling wave tube.

The output wave is abstracted downstream from the interaction circuit for use by utilization apparatus by a similar coupled helix arrangement comprising the outer helix 19, its resistive termination 20, and the output coaxial line 21, corresponding, respectively, to the outer helix 16, its resistive termination 17, and the input coaxial line 18.

To minimize various undesirable effects resulting from mismatches at the coupling connections, it is advantageous to deposit on the inner surface of the elongated portion of the tube envelope 14 along regions adjacent the uncoupled upstream and downstream end turns of the inner helix 16 coatings 22 of a dissipative material such as aquadag.

For focusing the electron beam along its path of flow between the electron source 12 and the target 13 in accordance with the principles of the invention, a succession of annular members 30 of a magnetically soft material, such as permalloy, ferrite, or soft iron, is disposed along the path of flow. Successive members are spaced apart by a short gap 31. These members 30 are adapted to serve as pole pieces for establishing a spatially alternating time-constant longitudinal magnetic field along the path of flow. For polarizing successive members oppositely, there is associated with each successive annular member 30 a different one of a like succession of annular disk-shaped permanent magnets 32, each of which is magnetized in a radial direction, the polarities of successive permanent magnets being reversed in sense in the manner illustrated whereby adjacent members 30 of the succession are in contact with oppositely poled faces of the permanent magnets 32. A magnetically soft cylindrical shield 34 surrounds the succession of permanent magnets. Besides serving to confine the magnetic flux, the shield serves as the return path for the flux between adjacent permanent magnets. The shield 34 should have a wall thickness sufficient to keep it from becoming magnetically saturated. As a consequence, there are formed along the path of flow a succession of magnetic loops in each of which the only air (or unity permeability) gap is that corresponding to the gap 31 between successive annular members 30. As a consequence, there will be developed in these gaps magnetic fields of high intensities, and the magnetic flux thereacross will permeate the path of electron flow. Because of the reversal in the polarities of successive pole pieces 30, the direction of the magnetic flux between successive gaps 32 reverses, and, accordingly, the magnetic field along the path of flow will be spatially alternating having a magnetic period which corresponds to twice the mean separation of successive pole pieces.

The available magnetomotive force for developing flux across each air gap is now proportional to approximately twice the radial dimension of the permanent magnets 32 whereas in the previously known arrangements where permanent magnets are used to bridge successive pairs of pole pieces, the magnetomotive force useful is proportional approximately to only one half the permanent magnet length.

Additionally, where high magnetic field intensities along the path of flow are desired, high magnetomotive forces may be achieved by increasing the radial extension of the permanent magnets to dimensions long compared with the mean separation of successive pole pieces. However, in previously known arrangements of the kind described, the length of the magnet path in each magnetic path

is limited to the mean separation of successive pole pieces, making difficult the realization of high magnetomotive forces desired for creating high flux densities in the gaps between successive pole pieces and along the path of flow.

Various other advantages stemming from this improved form of focusing structure will be evident to workers skilled in the art.

It is to be understood that the specific embodiment which has been described is merely illustrative of the principles of the invention, various arrangements may be devised by one skilled in the art without departing from the spirit and scope of the invention. In particular, in arrangements of this kind it is generally advantageous to have the pole pieces as close to the path of electron flow as possible. To this end, the pole pieces themselves may be used to load a wave guide to form therefrom a wave interaction circuit. Alternatively, the permanent magnets may be used directly without the use of separate pole pieces.

What is claimed is:

1. In combination, means including an evacuated envelope and two electrodes spaced apart therein for defining a path of electron flow, a succession of annular permeable members spaced apart along the path of flow for serving as a succession of pole pieces, a succession of annular disk permanent magnets positioned transverse to the path of flow and magnetized in the radial direction, each of the successive magnets associated with one of the successive permeable members and adjacent magnets magnetized in an opposite direction whereby successive permeable members are oppositely poled, and a permeable shielding member surrounding the succession of permanent magnets for serving as the return path for the flux between adjacent magnets.

2. In combination, an evacuated envelope, an electron gun and target spaced apart in said envelope for defining therebetween a path of electron flow, a succession of annular permeable members spaced apart along the path of flow for serving as a succession of pole pieces, a succession of annular disk magnets positioned transverse to the path of flow and magnetized in the radial direction, each magnet of the succession being positioned to have one pole face in contact with one of the successive permeable members, the polarities of the pole faces in contact with adjacent members being opposite whereby successive members are oppositely poled, and permeable shielding means enclosing the magnets for serving as the return path for the flux between adjacent magnets whereby there results a succession of magnetic loops disposed along the path of flow each having a gap corresponding to the space between successive members adjacent the path of flow.

3. In a device which utilizes the interaction between an electromagnetic wave and an electron beam, an envelope, an electron gun and target spaced apart in said envelope for defining therebetween a path of electron flow, a slow wave transmission circuit positioned along the path of flow for propagating an electromagnetic wave in coupling relation with said electron flow, and means for maintaining a high intensity magnetic field which is spatially alternating with a short magnetic period along the path of electron flow for focusing said electron flow, said means including a succession of pole pieces spaced apart along the path of flow, a succession of annular permanent magnets positioned transverse of the path of flow and magnetized in the radial direction, each permanent magnet of the succession positioned to surround and have one pole face in close contact with a separate one of said pole pieces, the polarity of adjacent magnets being poled in opposite directions whereby the pole faces in contact with adjacent permeable members of the succession are oppositely poled, and permeable shielding means enclosing the magnets for serving as the return path for the flux between adjacent magnets.

4. In a traveling wave tube, an envelope, an electron gun and target spaced apart in said envelope for defining therebetween a path of electron flow, a slow wave transmission circuit positioned along the path of flow for propagating an electromagnetic wave in coupling proximity to said electron flow, and means for maintaining a large number of short high intensity magnetic field regions in succession along the path of electron flow, the polarity of adjacent field regions being reversed, said means including a succession of annular permeable members spaced apart along the path of flow for serving as a succession of pole pieces, a succession of annular disk magnets positioned transverse to the path of flow and magnetized in the radial direction, each magnet of the suc-

cession being positioned to have one pole face in contact with one of the successive permeable members, the polarities of the pole faces of adjacent magnets in contact with adjacent members being opposite whereby successive members are oppositely poled, and permeable shielding means enclosing the magnets for serving as the return path for the flux between adjacent magnets.

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