Feb. 8, 1966 R. K. ORTHUBER 3,234,427

ELECTRON PULSING DEVICE

Filed May 13, 1960 2 Sheets-Sheet 1

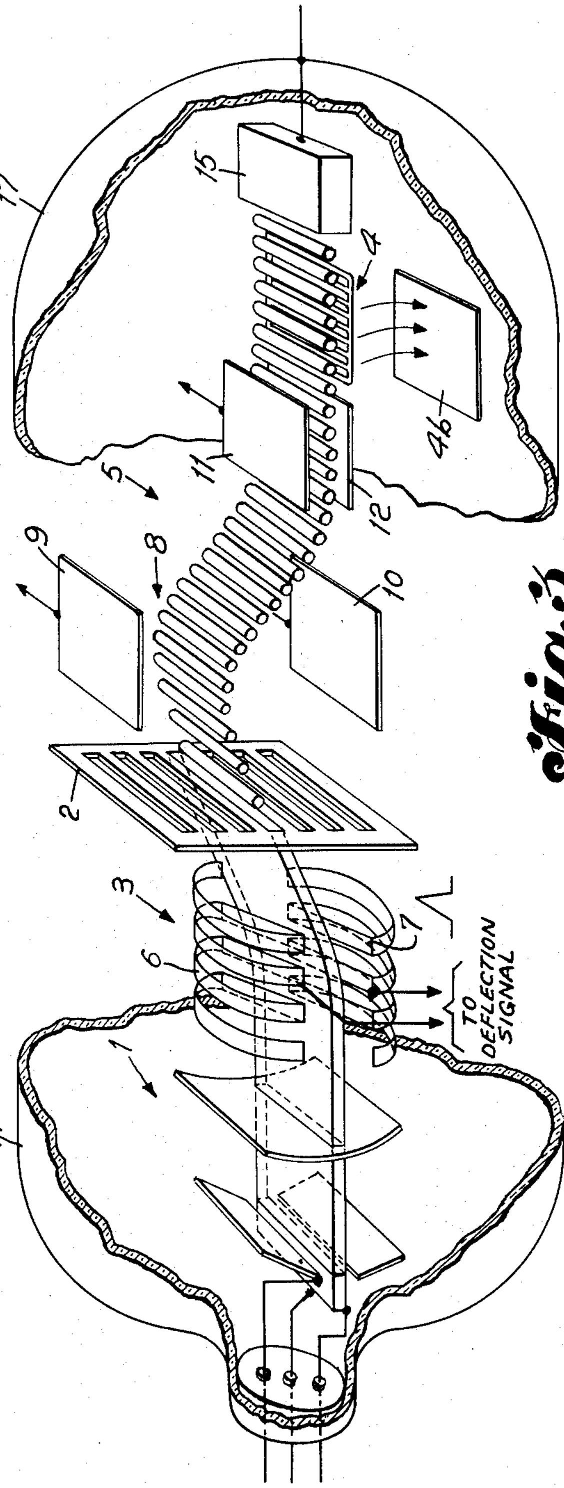


Fig. 1

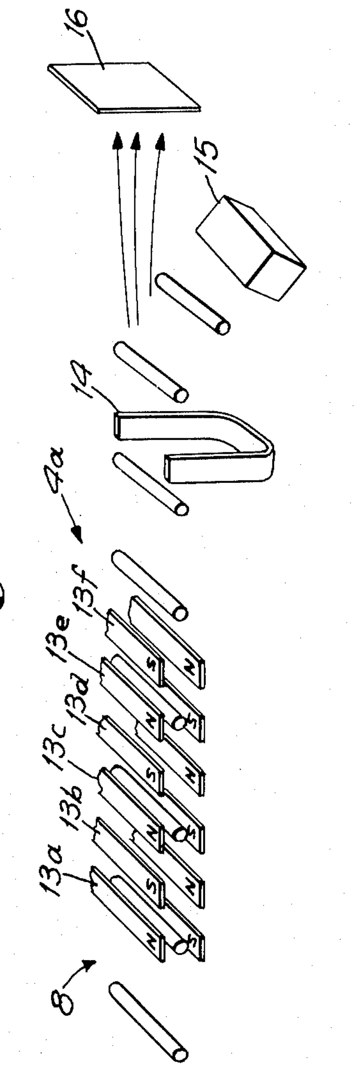
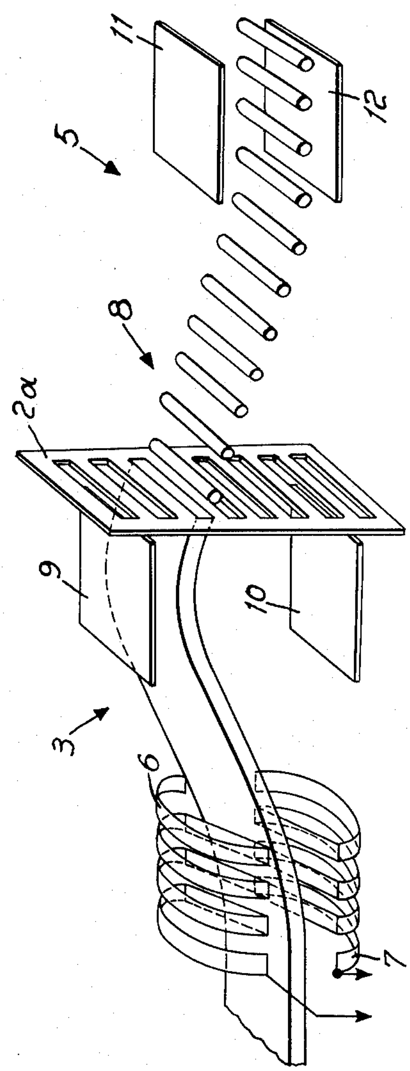


Fig. 3

INVENTOR.
RICHARD K. ORTHUBER

BY Philip M. Bolton
ATTORNEY

Fig. 2



INVENTOR.
RICHARD K. ORTHUBER
BY Philip M. Bolton
ATTORNEY

United States Patent Office

3,234,427

Patented Feb. 8, 1966

3,234,427

ELECTRON PULSING DEVICE

Richard K. Orthuber, Sepulveda, Calif., assignor to International Telephone and Telegraph Corporation, Nutley, N.J., a corporation of Maryland

Filed May 13, 1960, Ser. No. 28,941
18 Claims. (Cl. 315—4)

The present invention relates to electron pulsing devices and more particularly to electron beam devices which may be employed as microwave generators or frequency multipliers.

Heretofore, it has been known that it is useful in certain classes of art to employ a device to produce electron density modulation or "bunching". Bunching is the term used to describe the condition of an electron stream, wherein spaced groups of electrons are of substantially greater density than the spaces of the stream between such groups. Electron bunching devices can be employed in cooperation with a resonant structure to generate high frequency signals. They can also be employed to effect a frequency multiplication, or can be utilized as the input source to a magnetic undulator to generate millimeter waves.

Some existing devices which provide bunched electrons are of the type employing velocity modulation and include klystrons which are employed as microwave generators and as frequency multipliers. Other bunching devices are of the cathode ray tube which are utilized as frequency multipliers. In this type device a cathode ray beam is usually circularly rotated across the surface of a mask having apertures positioned in a circular path, which arrangement periodically interrupts the beam's impingment on a secondarily emissive target. These above mentioned electron bunching devices are necessarily of complex construction. Klystrons generally require a large input power and cathode ray tube frequency multipliers of the type described require complex deflection systems and collector arrangements.

An object of the present invention is to provide an improved device for producing bunched electrons having the advantage of simple construction.

Another object of the present invention is to provide a device for producing bunched electrons which may be employed with more than one type of utilization device.

Still another object of the present invention is an electron bunching device which provides frequency multiplication.

A feature of the present invention is the provision of a device for producing bunched electrons comprising means to produce an electron beam, electrode means positioned in the path of said electron beam, said electrode means having a plurality of openings therein through which said electron beam may pass, means to deflect said electron beam across the face of said electrode means to spatially separate said beam into a plurality of beam segments, means responsive to said beam segments to produce an output signal therefrom, and means intermediate said electrode and said output means to sequentially direct said beam segments past said output signal producing means. Another feature of the present invention is the provision of an electron bunching device of the type described wherein the responsive means is a multi-slot electrode.

A further feature of the present invention is the provision of an electron bunching device of the type described wherein the responsive means is a magnetic undulator.

The above-mentioned and other features and objects of this invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a representation of one embodiment of an electron bunching device following the principles of the present invention.

FIG. 2 is an alternative arrangement of the components of the electron bunching device represented in FIG. 1.

FIG. 3 is a representation of a magnetic undulator employed as a load device for the electron bunching device of FIG. 1 or FIG. 2.

Referring to FIG. 1, an electron bunching device is shown comprising means **1** to produce an electron beam, an electrode means **2** positioned in the path of the electron beam, means **3** to deflect said electron beam across the face of electrode means **2** to spatially separate the beam into a plurality of beam segments **8**, means **4** responsive to the beam segments to produce an output signal therefrom and means **5** intermediate electrode means **2** and responsive means **4** to direct the beam segments past responsive means **4**. The electron bunching device assembly is contained in a suitable evacuated tube, container, or shell **17** whose axis coincides with the direction of the electron beam.

More particularly, means **1** to produce an electron beam includes an electron gun to produce an electron beam of rectangular cross-section of the type known as a ribbon beam. Electron guns of this type are readily available in the prior art. The ribbon beam generated by means **1** is directed through deflection means **3** where the beam is periodically deflected in accordance with a signal applied to deflection plates **6** and **7**. In the preferred embodiment deflection plates **6** and **7** represent the well-known flattened helix type slow wave structures having coils wound in the form of a semicircular cross-section with flat facing portions as employed in traveling wave oscilloscopes, an example of which is described in the IRE Transactions on Electron Devices, Vol. Ed. 4, No. 2, page 157. Also, in the preferred embodiment the deflection signal applied to deflection means **3** is a triangular wave. With a triangular deflection signal applied to plates **6** and **7** of deflection means **3** the ribbon beam will be periodically deflected across the face of electrode **2** in a vertical direction. Electrode **2** is preferably constructed of a thin metallized plate having an arrangement of long narrow parallel slots therethrough. As the ribbon beam is deflected across the face of electrode **2** the beam will alternately be intercepted or pass sequentially through the narrow slots. Assuming that the total vertical deflection of the beam at electrode **2** is .4 inch and that the parallel slots of electrode **2** have a vertical dimension of 4 mils and are spaced from each other by 4 mils, and further assuming that the ribbon beam has a thickness of 4 mils, then the ribbon beam will be interrupted by electrode **2** one hundred times for each period of triangular deflection voltage since there are a total of 50 slots.

The ribbon beam will emerge from the other side of electrode plate **2** in the form of narrow bunches of electrons **8** in the approximate shape of closely spaced parallel cylinders traveling in a direction normal to their axes. With a beam velocity of 3×10^9 cm./sec. (approximately 2.6 kv. electron velocity) and a deflection signal rate of 1 kmc. the beam will be interrupted at the rate of 100 kmc. thereby producing bunches spaced mutually by an axis-to-axis distance of

$$\frac{3\times10^9}{10^{11}}\frac{\text{cm.}}{\text{sec.}}\Big/\frac{\text{cycles}}{\text{sec.}}=.3\text{ mm.}$$

with dimensions along the direction of flight of .15 mm. for a 50% chopping duty cycle.

After emerging from electrode **2**, the electron bunches may require additional acceleration, and this may be accomplished by any of the well-known acceleration schemes, an example being conventional acceleration rings. For the sake of clarity an acceleration system is not shown in FIG. 1.

The narrow parallel cylinders of bunched electrons **8** emerge from each of the narrow slits of electrode plate **2** in accordance with the position of the deflected ribbon beam. A deflection system **5** is provided to direct the electron bunches **8** into a position wherein they can be usefully received by a load device. System **5** includes second set of deflection plates **9** and **10** representing the same flattened helical form as previously described, to cancel the original deflection angle imparted to the beam by deflection plates **6** and **7**. Cancellation deflection plates **9** and **10**, with the proper phasing, cause the electron bunches **8** to leave electrode **2** with a convergence angle toward the tube axis equal to the divergence angle imparted by deflection plates **6** and **7**.

Another set of deflection plates **11** and **12**, representing flattened helices, are included in means **5** for the purpose of alignment deflection. That is, to arrange the electron bunches in a suitable manner to interact with a utilization device. In the embodiment of FIG. 1 plates **11** and **12** align the electron bunches **8** in the plane of the tube axis since the bunches will ultimately be directed past a radiating structure **4** such as an array of parallel wires, or multislot electrode such that the electron bunches are oriented parallel to the slots or wires of radiating structure **4**. The dimensional periodicity of the radiating structure **4** should be equal to the spacing between the individual electron bunches. With the correct dimensional periodicity and a bunching rate of 100 kmc. as stated the radiating structure or electrode will emit a plane wave of 100 kmc. frequency. The useful results obtained with the embodiment of FIG. 1 is that a microwave signal has been generated and a 100:1 frequency multiplication has been effected. The output signal from radiating structure **4** then passes through radiation window **4*b***. After passing the radiating structure **4**, the electron bunches are received by a suitable collector **15**.

Referring to FIG. 2, an alternative physical arrangement of the components of the electron bunching device of FIG. 1 is shown. FIG. 2 only shows the modified portion of the electron bunching device, and it is to be understood that the remaining components of FIG. 1 are to be likewise included in the arrangement of FIG. 2.

More particularly FIG. 2 shows a ribbon electron beam identical to that shown in FIG. 1. Electrode means **2*a*** is positioned in the path of said electron beam, means **3** in this embodiment includes deflection plates **6, 7** and cancellation deflection plates **9, 10** which deflect the electron beam across the face of electrode means **2*a*** to spatially separate the beam into a plurality of beam segments. Means **5**, including deflection plates **11, 12** is provided to align electron bunches **8** in a suitable manner to interact with a utilization device, which may be a radiating structure **4** as shown in FIG. 1, or a magnetic undulator as to be later described in conjunction with FIG. 3.

The advantage of arranging electrode **2*a*** as shown in FIG. 2 is that after the electron bunches **8** emerge from electrode **2*a*** they have a shorter overall distance to travel before reaching the utilization device, thereby reducing the amount of undesired debunching which may occur.

Another useful embodiment of the present invention is illustrated in FIG. 3, wherein the radiating structure **4** of FIG. 1 is replaced with a magnetic undulator **4*a***, all other components of FIG. 1 remaining unchanged with the exception of collector **15** being displaced as later described. A magnetic undulator is a millimeter wave generator and is described in detail beginning on page 826, Journal of Applied Physics, vol. 24, No. 7. The magnetic undulator is based on the fact that electrons passing through a magnetic field, the direction of which alternates in space along the electron path, describe a periodic orbit in a plane perpendicular to that of the field and thereby radiate electromagnetic waves in the millimeter region. The design of magnetic undulator **4*a***, includes a plurality of pairs of permanent magnets, numbering six for purposes of explanation and designated **13*a*** to **13*f***, arranged to produce a magnetic field which alternates in polarity in a longitudinal direction. It has been shown in the aforesaid Journal of Applied Physics that the maximum possible magnetic undulator power output in the millimeter region results when the input electrons are in bunched form. The present invention may usefully be combined with a magnetic undulator load device to produce millimeter wave output signals. Referring to FIG. 3, the bunched electrons **8** of FIG. 2 are shown at the point subsequent to deflection plates **11** and **12** of FIG. 1. The electron bunches **8** travel in a direction transverse to the magnetic field of magnetic undulator **4*a*** and are caused to describe periodic oscillations as they proceed in the transverse direction in accordance with the theory of magnetic undulators. The periodic oscillations thereby produce radiation in the millimeter range. After the electron bunches travel past the permanent pairs **13*a*** to **13*f*** they are deflected by magnetic deflector **14** down into collector **15** permitting the millimeter wave radiation to emerge through window **16** without any obstruction by collector **15**.

It is preferable that the electron bunches travel past magnet pairs **13*a*** to **13*f*** with constant velocity. In order to effect such constant velocity, it is possible to provide successive acceleration steps within the undulator structure by employing accelerator rings (not shown) between the gaps of magnet pairs **13*a*** to **13*f***. By maintaining the potentials on the accelerator rings located in the gaps between magnet pairs **13*a*** to **13*f*** at increasingly higher levels, the energy loss of the electron bunches can be compensated by the acceleration rings as the electron bunches are directed through magnetic undulator **4*a***.

It is seen, from the discussion, hereinabove, that a new and useful electron bunching device has been conceived which may be employed as a microwave generator, a frequency multiplier, or with a magnetic undulator as a millimeter wave generator, and exhibits simplicity of structure and operation.

I claim:

1. A device for producing energy pulses comprising means to produce an electron beam, electrode means positioned transversely in the path of said electron beam, said electrode means having a plurality of aligned openings therein through which said electron beam may pass, means to deflect said electron beam periodically across the face of said openings to spatially separate said beam into a plurality of equal beam segments, second deflection means to align said beam segments in a given axial plane and means responsive to said aligned axial beam segments to produce an output signal therefrom, said responsive means including a plurality of transverse members equally spaced along said axial plane.

2. A device for producing energy pulses comprising means to produce an electron beam, electrode means popositioned transversely in the path of said electron beam, said electrode means having a plurailty of equal aligned openings therein through which said electron beam may pass, means to linearly deflect said electron beam across the face of said electrode means to spatially separate said beam into a plurality of equal beam segments composed of bunched electrons, means responsive to said equal beam segments to produce an output signal therefrom, and means intermediate said electrode and said output signal producing means to align said beam segments into a given axial plane for interaction with said output signal producing means, said responsive means include a plurality of transverse members equally spaced along said axial plane.

3. The device of claim 2 wherein said deflection means comprise helices having flattened facing portions.

4. A device for producing energy pulses comprising means to establish a linearly varying field, means to direct an electron beam through said field whereby said electron beam is linearly deflected, an electrode transversely positioned in the path of said deflected beam, said electrode having equally aligned openings between the ends thereof so that said deflected beam is spatially separated into a plurality of discrete equal beam segments, means to substantially align said segments in a given longitudinal plane, and means responsive to said aligned beam segments to produce an output signal therefrom, said responsive means including a plurality of transverse members equally spaced along said longitudinal plane.

5. A device for producing energy pulses comprising means to produce an electron beam having a given cross-section, electrode means positioned transversely in the path of said electron beam, said electrode means having a plurality of aligned openings between the ends thereof, each opening having dimensions equal to said given cross-section through which said electron beam may pass, means to linearly deflect said electron beam across said plurality of openings to spatially separate said beam into a plurality of equal beam segments composed of bunched electrons, means to substantially align said beam segments in a given longitudinal plane, and means responsive to said aligned beam segments to produce an output signal therefrom, said responsive means including a plurality of transverse members equally spaced along said longitudinal plane.

6. A device for producing energy pulses comprising means to produce an electron beam having a given cross-section, electrode means positioned transversely in the path of said electron beam, said electrode means having a plurality of aligned openings therein, each opening having dimensions equal to said given cross-section through which said electron beam may pass, first linear deflection means to deflect said electron beam in a divergent manner, second deflection means to deflect said diverging electron beam in a converging manner across said plurality of openings of said electrode means to spatially separate said beam into a plurailty of equal beam segments composed of bunched electrons, third deflection means to substantially align said beam segments in a given axial plane, and means responsive to said aligned beam segments to produce an output signal therefrom, said responsive means including a plurality of transverse members equally spaced along said axial plane.

7. A high frequency generator comprising means to produce an electron beam, electrode means positioned transversely in the path of said electron beam, said electrode having a plurality of equal aligned openings between the ends thereof through which said electron beam may pass, first linear deflection means to deflect said electron beam periodically across the face of said electrode to spatially seperate said beam into a plurailty of equal beam segments substantially arranged in a single plane, second deflection means to align said beam segments in a second axial plane at an angle to said first plane, and electrode means responsive to said beam segments arranged in said second plane to produce an output signal therefrom, said electrode means including a plurality of transverse members equally spaced along said axial plane.

8. A high frequency generator comprising cathode means to produce a continuous electron beam having a rectangular cross-section, anode means positioned in the path of said electron beam, said anode having a plurality of longitudinal openings therein through which said electron beam may pass, first deflection means to deflect said electron beam periodically across the face of said plurality of longitudinal openings to spatially separate said beam into a plurality of beam segments composed of bunched electrons, second deflection means to align said beam segments in a given plane, and electrode means responsive to said aligned beam segments to produce an output signal therefrom.

9. A high frequency generator comprising cathode means to produce a continuous electron beam having a rectangular cross-section, anode means positioned in the path of said electron beam, said anode having a plurality of longitudinal openings therein through which said electron beam may pass, first deflection means to deflect said electron beam periodically across said plurality of longitudinal openings of said anode to spatially separate said beam into a plurality of beam segments composed of bunched electrons, second deflection means to align said beam segments in a given plane, and an array of parallel electrode wires arranged parallel to said given plane and responsive to said aligned beam segments to produce an output signal therefrom.

10. A high frequency generator comprising means to produce a continuous electron beam having a rectangular cross-section, anode means positioned in the path of said electron beam, said anode having a plurality of rectangular openings therein having dimensions equal to said rectangular cross-section of said electron beam enabling said electron beam to pass through, a flattened helix type deflection means to deflect said electron beam across said plurality of rectangular openings to spatially separate said beam into a plurality of beam segments, means to deflect said beam segments to substantially align said beam segments in a given plane, and a multislot electrode positioned parallel to said given plane and responsive to said aligned beam segments to produce an output signal therefrom.

11. A high frequency generator comprising cathode means to produce a continuous electron beam having a rectangular cross-section, anode means positioned in the path of said electron beam, said anode having a plurality of longitudinal openings therein through which said electron beam may pass, first deflection means to deflect said electron beam periodically in a divergent manner, second deflection means to deflect said diverging electron beam periodically in a converging manner across said plurality of longitudinal openings of said anode to spatially separate said beam into a plurality of beam segments composed of bunched electrons, third deflection means to align said beam segments in a given plane, and an electrode means arranged parallel to said given plane and responsive to said aligned beam segments to produce an output signal therefrom.

12. A frequency multiplier comprising means to produce an electron beam, means to linearly deflect said electron beam at a given frequency, electrode means positioned transversely in the path of said electron beam, said electrode means having a plurality of aligned openings therein through which said electron beam may pass so that the deflection of said electron beam across said electrode causes said electron beam to spatially separate into a plurality of beam segments occurring at a frequency greater than said given frequency, means to align said beam segments in a given axial plane, and means responsive to said aligned beam segments to produce an output signal therefrom having said greater frequency.

13. A frequency multiplier comprising means to produce an electron beam, means to linearly deflect said electron beam at a frequency f, an electrode means positioned transversely in the path of said electrode means having n openings between the ends thereof through which said electron beam may pass so that the deflection cycle of said electron beam across said electrode causes said electron beam to spatially separate into a plurailty of beam segments occurring at a frequency $2nf$, means to align said beam segments in a given longitudinal plane, and means responsive to said beam segments to produce an output signal therefrom at a frequency $2nf$.

14. A frequency multiplier comprising means to produce an electron beam having a given cross-section, means

to linearly deflect said electron beam at a frequency f, an electrode means positioned transversely in the path of said electrode beam having n openings aligned between the ends thereof, each opening having dimensions equal to said given cross-section through which said electron beam may pass so that the deflection cycle of said electron beam across said electrode causes said electron beam to spatially separate into a plurality of beam segments occurring at a frequency $2nf$, means to align said beam segments in a given longitudinal plane, and electrode means responsive to said aligned beam segments to produce an output signal therefrom at a frequency $2nf$.

15. A frequency multiplier comprising means to produce an electron beam having a given cross-section, first deflection means to periodically deflect said electron beam in a divergent manner at a frequency f, second deflection means to periodically deflect said electron beam in a convergent manner, an electrode means positioned in the path of said convergently deflected electron beam, said electrode having n openings therein, each opening having dimension equal to said given cross-section through which said electron beam may pass so that the deflection cycle of said electron beam across said electrode causes said electron beam to spatially separate into a plurality of beam segments occurring at a frequency $2nf$, third deflection means to align said beam segments in a given plane, and electrode means responsive to said aligned beam segments to produce an output therefrom at a frequency $2nf$.

16. A millimeter wave signal generator comprising means to produce an electron beam, electrode means positioned transversely in the path of said electron beam, said electrode having a plurality of aligned openings therein through which said electron beam may pass, first deflection means to linearly deflect said electron beam periodically across the face of said electrode to spatially separate said beam into a plurality of equal beam segments substantially arranged in a transverse plane, second deflection means to align said beam segments in a longitudinal plane, and a magnetic undulator responsive to said beam segments arranged in said longitudinal plane to produce a millimeter wave output signal therefrom, said undulator including a plurality of transverse members equally spaced along said longitudinal plane.

17. A millimeter wave signal generator comprising means to produce a continuous electron beam having a

rectangular cross-section, anode means positioned transversely in the path of said electron beam, said anode having a plurality of aligned rectangular openings therein each opening having dimensions equal to said rectangular cross-section whereby said electron beam may pass through, means to periodically deflect said electron beam linearly across said plurality of rectangular openings to spatially separate said beam into a plurailty of equal beam segments, means to deflect said beam segments to substantially align said beam segments in a given axial plane, and a magnetic undulator positioned in said given plane responsive to said beam segments to produce a millimeter wave output signal, said undulator including a plurality of transverse members equally spaced along said axial plane.

18. A millimeter wave signal generator comprising means to produce an electron beam having a given cross-section, electrode means positioned transversely in the path of said electron beam, said electrode means having a plurality of aligned openings between the ends thereof, each opening having dimensions equal to said given cross-section through which said electron beam may pass, first linear deflection means to deflect said electron beam in a divergent manner, second deflection means to deflect said diverging electron beam in a converging manner across said plurality of openings of said electrode means to spatially separate said beam into a plurality of equal beam segments composed of bunched electrons, third deflection means to substantially align said beam segments in a given axial plane, and a magnetic undulator positioned in said given plane responsive to said aligned beam segments to produce a millimeter wave output signal, said undulator including a plurality of transverse members equally spaced along said axial plane.

References Cited by the Examiner

UNITED STATES PATENTS

2,275,480	3/1942	Varian et al.	315—7 X
2,289,319	7/1942	Strobel	315—5.29 X
2,434,446	1/1948	Toulon	331—80
2,529,408	11/1950	Montani	328—64 X

GEORGE N. WESTBY, *Primary Examiner.*

RALPH G. NILSON, *Examiner.*