Dec. 27, 1966 K. D. FROOME 3,295,062

HIGH FREQUENCY ELECTRICAL OSCILLATION GENERATORS

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Fig. 1.

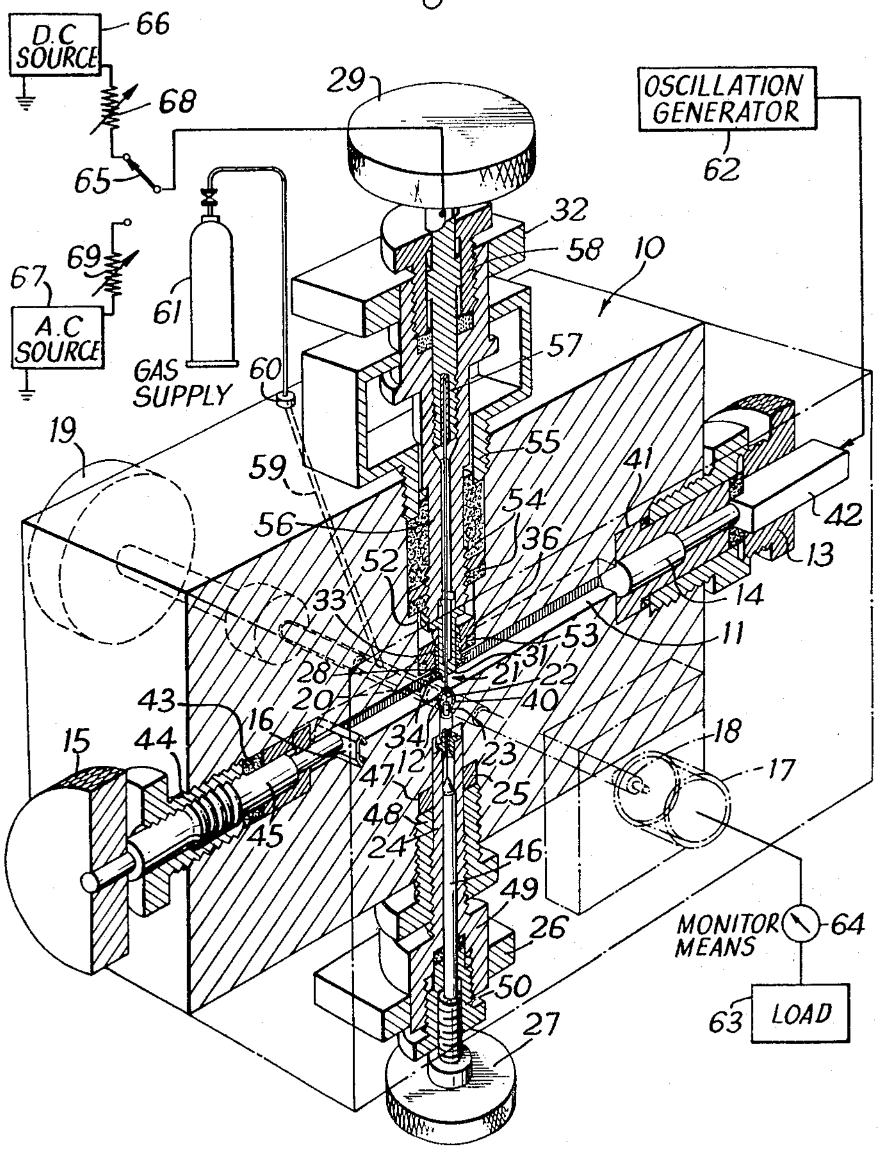

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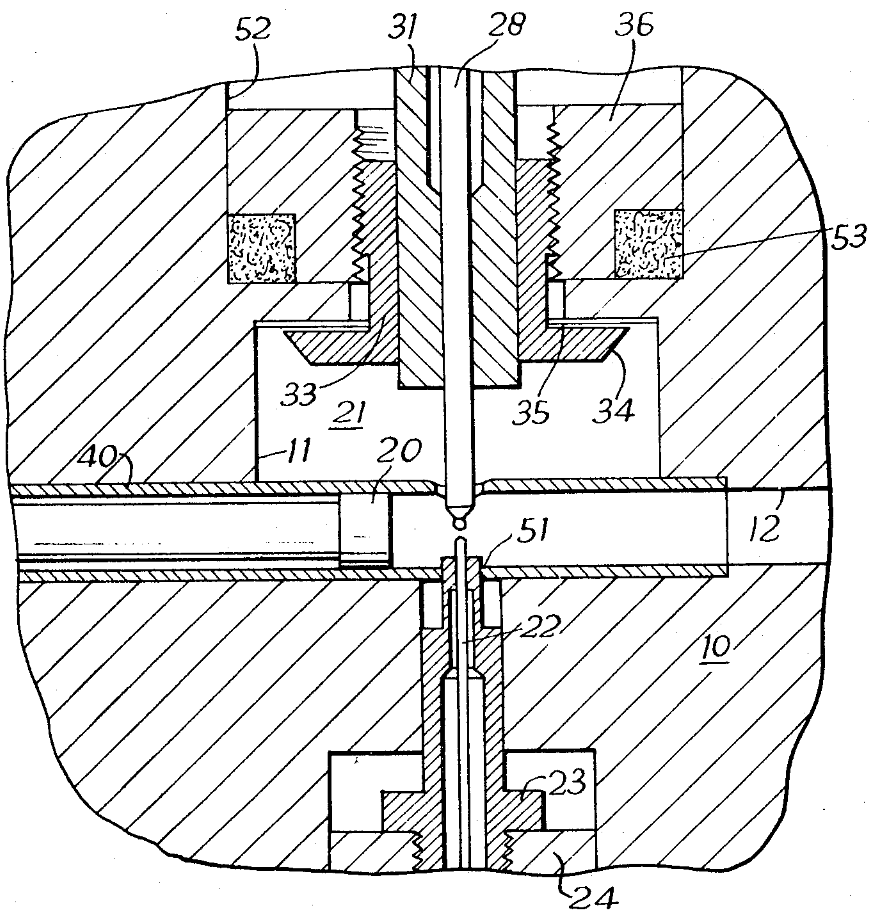
Fig. 2.



United States Patent Office 3,295,062 Patented Dec. 27, 1966

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3,295,062
HIGH FREQUENCY ELECTRICAL OSCILLATION GENERATORS

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Filed Feb. 3, 1964, Ser. No. 342,002
Claims priority, application Great Britain, Feb. 8, 1963, 5,279/63
15 Claims. (Cl. 328—19)

This invention relates to high frequency electrical oscillation generators and is more particularly concerned with the generation of energy at microwave frequencies by arrangements resembling those already described in prior U.K. patent specification No. 944,983 and in which a very short high intensity cold cathode arc discharge is coupled to and maintained by energy from a microwave power source and which includes an output circuit, e.g., a suitable waveguide, designed to extract and transmit output power at harmonic frequencies of the input microwave energy.

Objects of the invention include the improvement of the operating efficiency of such generators and the reduction or elimination of unwanted harmonic frequencies in the output energy.

According to the present invention, in a high frequency electrical oscillation generator of the kind comprising means for establishing a high current density arc discharge between first and second arc electrodes, means for coupling input energy from a microwave power source to said arc discharge and means for extracting from said arc discharge output energy at a harmonic frequency of said input energy, each of the said first and second arc electrodes is of metal rod or wire form and means are provided for operating said arc discharge in an inert gas at a high pressure of between 1,000 and 4,000 lbs./sq. inch in order to provide a dense plasma region between and joining said arc electrodes. Preferably the gas filling is mainly of argon with a small percentage, say, 4% to 15% of hydrogen to inhibit plasma diffusion.

In one embodiment of the invention the arc discharge is located within a cavity or waveguide forming part of the power output circuit and the coupling of the input microwave power to the arc is effected by the disposition of one arc electrode across a rectangular section waveguide carrying the input microwave energy.

The invention also includes a method of operating a generator as referred to above and in which one arc electrode is of smaller cross section than the other in order to first obtain and thereafter maintain the optimum arc dimension for deriving a chosen harmonic output frequency. In such method of operation the arc is initially driven by the combined action of the input microwave energy and a D.C. voltage across the arc electrodes to cause transport of electrode metal from the smaller cross section electrode to the larger cross section electrode whereby the arc dimension is progressively changed towards a value at which it becomes resonant at the required harmonic frequency. Upon attainment of the desired resonant dimension of the arc, the initial D.C. energisation is replaced by an A.C. energisation, preferably of square waveform, at a suitable frequency, preferably but not essentially within the range of 200–5,000 c.p.s., whereby the optimum arc dimension is thereafter maintained by successive transfer of electrode material backwards and forwards from one electrode to the other.

The above and other features of the invention will be more readily understood from the following description of one practical embodiment given by way of example with reference to the accompanying drawing in which:

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FIGURE 1 is a perspective view, with parts broken away, of an ultra-high frequency electrical oscillation generator constructed in accordance with the invention, while

FIGURE 2 is a cross sectional view of the central arc discharge region of the device of FIG. 1 drawn to an enlarged scale.

The embodiment illustrated comprises a rectangular shaped base block 10 of metal, e.g., brass, having three borings therethrough extending respectively between the approximate centre points of its three pairs of opposite side walls. One of the horizontal bores is formed at its central region as a rectangular section input waveguide 11 while the other horizontal bore is provided at its central region with an inserted circular section metal tube 40, e.g. of phosphor bronze, to form a circular section output waveguide 12. The longitudinal axes of the two waveguides 11, 12 are disposed at right angles to one another and are so positioned that the outer surface of the tube 40 just breaks into the input waveguide 11 so that such tube surface is parallel and coincident with the lower wider surface of the input waveguide as may be seen more clearly in FIG. 2.

The bore defining the input waveguide 11 is formed at one end with a suitable screw threaded counterboring 41 to accommodate an input coupling connector 13 for the attachment of a further waveguide 42 by which input energy at a suitable Q-band frequency may be supplied to the input waveguide 11 through a cylindrical quartz window 14 which is secured by the coupling connector and serves hermetically to seal such input end of the guide. The opposite end of the same bore is also counterbored and screw threaded at 43 to receive a plug 44 forming part of input matching control means which includes a screw threaded spindle 45 terminating at its outer end in a matching control knob 15 and at its inner end in a rectangular tuning piston 16 which is slidable along the longitudinal axis of the rectangular waveguide 11. The plug 44 forms part of sealing means by which this end of the waveguide 11 is also hermetically sealed. The position of the piston 16 is adjustable along the guide by means of the knob 15.

The bore defining the output waveguide 12 is similarly counterbored and screw threaded at one end to accommodate a screwed plug containing a threaded spindle to the outer end of which is attached a matching control knob 19 and to the inner end of which is secured a circular tuning piston 20 which is slidable along the axis of the circular waveguide 12 to a position controlled by the knob 19. This piston is adjustable with an inner limit such that it can just touch a part of the "cathode" arc electrode as will be described later. The plug accommodating this matching control means likewise forms part of means for hermetically sealing the related end of the waveguide 12 while at the opposite end the same bore continues the waveguide surface defined by the inner surface of the tube 40 and terminates in an output coupling connector 17 which also includes a cylindrical quartz window 18 to effect hermetic sealing of this end of the waveguide 12.

The third bore in the block 10 is disposed so as to be perpendicular to each of the waveguides 11, 12 and is at a position where its axis intersects each of the longitudinal axes of such guides. Within this third bore is disposed the arc assembly indicated generally at 21 and comprising a lower "cathode" arc electrode 22 and an upper "anode" arc electrode 28 each disposed to lie coincident with the said third bore axis.

The lower "cathode" electrode 22 is constituted by a very thin platinum wire, e.g. of 0.008 inch diameter. This wire is secured to the upper end of a rod 46 which can be adjusted axially as described later. As seen more clearly in FIG. 2 the upper end of the "cathode" wire **22** is embraced by and is slidable within the bore of a cylindrical "cathode" sheath **23**, conveniently formed of annealed molybdenum. This sheath is itself secured in the upper end of a sleeve **24** which is also adjustable axially as described later. The lower end of the said third bore is counterbored and screw threaded at **47** to receive a sealing plug **48** forming part of a sealing gland which includes the sealing elements **25** (FIG. 1) conveniently made of P.T.F.E. (polytetrafluoroethylene). The sealing plug just referred to is itself bored internally and screw threaded to receive a threaded external region of the sleeve **24**, the latter terminating outwardly in an enlarged head **49** to which is attached a "cathode" plunger adjustment control member **26**. Such enlarged head **49** of the sleeve **24** is itself counterbored and screw threaded to receive the plug **50** of a further sealing gland surrounding the rod **46** carrying the "cathode" wire **22**. Such rod **46** is screw threaded at its outer end and this region is received within a threaded bore of the plug **50** and terminates at its outward end in a "cathode" arc adjusting knob **27**.

The inner, reduced diameter, end of the sheath **23** extends through a snug fitting aperture **51** in the output guide tube **40** to a chosen position just inside the inner guide surface, such choice of position being under the control of the "cathode" plunger adjusting member **26**. The "cathode" wire **22** itself extends still further inwards beyond the inner end of the sheath **23** towards the centre of the output waveguide to a position which is accurately controllable by the arc adjusting knob **27**. The various sealing glands provide for hermetic sealing of this end of the third bore.

The opposing upper or "anode" electrode of the arc assembly **21** comprises a platinum wire **28** of substantially greater diameter and therefore cross sectional area than the "cathode" wire **22**, e.g. of 0.020 inch diameter. This "anode" wire projects through a clearance aperture **30** in the tube **40** of the output waveguide, the clearance between the "anode" wire and the edge of the aperture being not more than 0.004 inch. The lowermost end of the "anode" wire **28** which immediately faces the upper end of the "cathode" wire **22** is of pointed or conical shape. The "anode" wire is adjustable axially by means described later and is slidable within a cylindrical tuning plunger **31** made of copper or other similar metal and itself adjustable in the same axial direction by control means to be described later. Such tuning plunger **31** is slidable within the bore of a surrounding metal sleeve **33** made of copper or similar metal. This sleeve is provided at its lower end with an enlarged diameter flange **34** the upper surface of which opposes the upper surface of the adjoining region of the input waveguide **12** formed in the block **10** but is separated and insulated therefrom by an interposed mica sheet **35** so as to provide a capacitive coupling between the "anode" electrode **28** and the metal base block **10**. The sleeve **33** is secured in position within an accommodating counterbore **52** of the said third bore by means of a screwed collar **36** made of insulating material and having an annular recess for accommodating a resilient sealing washer **53**. Such counterbore **52** is itself sealed through the intermediary of packing elements **54** by a sealing plug **55** inserted in an internally threaded counterbore at the upper end of the said third bore. The said plug **55** is bored axially to accommodate a tubular member **56** the lower end of this is screw threaded for engagement with a threaded element of the packing elements **54** and carries the tuning plunger **31**. The upper end of such tubular member has an enlarged head to which is secured an anode plunger control member **32** whereby the axial position of the aforesaid tuning plunger **31** may be controlled from outside of the block **10**. The said tubular member **56** is itself bored axially to accommodate a screw threaded member **57** whose lower end is connected to the "anode" wire **28** and whose upper end, after emerging through a packing gland **58**, has secured thereon the "anode" arc control knob **29** whereby the precise position of the lower end of the "anode" wire can be controlled from the exterior of the block **10**. The sealing glands provided ensure the hermetic sealing of the upper end of the third bore whereby the arc chamber and the intercommunicating regions of the waveguides **11**, **12** are hermetically sealed and can be filled with a suitable inert gas under high pressure provided by way of communicating conduit **59** and external connector **60** to a gas supply source shown schematically at **61**. The gas supply preferably is of argon with the addition of a small amount of between 4% and 15% of hydrogen and the operating pressures, preferably controllable, lie between 1,000 and 4,000 pounds per square inch.

For purposes of illustration the input waveguide **11** is shown symbolically connected to an input oscillation generator **62** such as a C.W. klystron type generator operating at a frequency in the Q-band, e.g. 35 gc./s. Similarly the output connector **17** is shown as supplying output energy to any desired load **63** by way of power monitoring means **64**. The upper or "anode" arc electrode **28**, which is insulated from the metal block **10**, is shown connected by way of a change-over switch **65** either to one terminal of a direct current supply source **66** or to one terminal of an alternating current supply source **67**. The opposite terminals of the two supply sources are connected to earth as is also the metal block **10** and the lower "cathode" arc electrode **22**. Variable resistances **68** and **69** are included in the respective D.C. and A.C. supply leads to control the amplitude of the currents supplied to the arc electrodes.

The D.C. source **66** is one capable of providing a current of the order of 1 ampere at 200 volts while the A.C. source **67** is one capable of providing a square wave output of 200 volts peak-to-peak and a current amplitude of up to 1 ampere. The frequency of this source is conveniently within the range 200–5,000 cycles per second.

In the operation of this embodiment, the input microwave power source **62** is arranged to supply input energy to the waveguide **11** and appropriate matching adjustments are made by the knob **15** serving to control the position of the tuning piston **16** in the input waveguide **11**. The switch means **65** is positioned to supply direct current to the arc electrodes **22**, **28** from the direct current source **66** and this is adjusted to a value of between 300 and 600 ma. by adjustment of the series resistance **68**. The input power from the oscillation generator **62** may be about 10 watts of microwave energy at the commencement of operation of the device. The applied gas pressure from the source **61** is conveniently adjusted to be of the order of 2,400 lb./sq. inch.

If the microwave input tuning is not approximately correct difficulty may be experienced in starting with the described direct current supply to the arc electrodes if the gas pressure is at the above quoted normal operating value of 2,400 p.s.i. In this case the gas pressure may be raised temporarily to 4,000 p.s.i. while adjustments are made and then lowered again.

The polarity of the applied direct current from the source **66** is such as to cause operation with the upper arc electrode **28** as an "anode" and as a result of this there is a transport of platinum from the lower and thinner "cathode" wire **22** to the lower tip of the upper "anode" wire **28** and this transport of metal may be used to form a small ball of molten platinum on the "anode" which is allowed to grow in size until it is of such dimension that it becomes resonant at a desired one of the harmonic frequencies of the input Q-band energy supplied by the source **62**. Such resonance point may be observed by the monitoring means **64** and when it is reached, the initial D.C. energisation of the arc electrodes is rapidly changed to A.C. operation from the source **67** by operation of the switch means **65**.

The arc current from the A.C. supply is preferably limited to a value comparable with that obtained under the initial D.C. operation by adjustment of the second, noninductive, resistance **69** in series with the A.C. supply. The change from D.C. to A.C. energisation of the arc inhibits further change in the mean size of the now-resonant arc and the molten ball end of the upper electrode **28** by reason of the alternate transport of electrode material from one arc electrode to the other.

Initial setting of the arc electrodes relative to one another is effected by means of the control knobs **27** and **29**. Efficient energisation of the arc by the input microwave source **62** arising from the pick-up constituted by the lower end of the anode rod **28** traversing the centre of the rectangular input guide **11** is facilitated by the provision of the matching control knob **15** and its attached tuning piston **16** and by positioning of the "anode" tuning plunger **31** through the intermediary of its control member **32**. Selection of the required harmonic output frequency and the attainment of maximum output at such frequency is effected by adjustment of the tuning piston **20** through the intermediary of the matching control knob **19** and by adjustment of position of the cathode sheath **23** relative to the arc electrode wire **22** through the intermediary of the adjusting member **26**.

Although the platinum arc electrodes should be adjusted as described above to operate in a molten state under the action of the heat of the arc, such arc is still believed to be of the "cold cathode" type in that the electron emission is throught not to be predominantly of thermionic origin but most probably to be thermionically enhanced "field emission" caused by a region of the positive ion space-charge at the boundary between the plasma and the negative electrode. The very dense plasma joining the "anode" electrode to the "cathode" electrode behaves like a wire and conducts the microwave drive into the space-charge regions. Thus this positive electric field is partly neutralised or partly enchanced depending upon whether the microwave drive is swinging negative or positive relative to the "cathode."

Operation of the arc with the resonant ball on the end of the "anode" electrode is not thought to be essential as operation with a pointed upper electrode is quite satisfactory although is rather less sharply tunable to one specific harmonic frequency. In this case, however, the tips of the platinum electrodes should be adjusted to run molten and it is preferable to employ alternating current, preferably square wave alternating current, at all times.

An arrangement as described above has been found capable of producing useful amounts of energy at frequencies in excess of 1,000 gc./s. (i.e. the 29th harmonic of a 35 gc./s. input drive).

I claim:

1. A high frequency oscillation generator comprising a body having a sealed chamber therein, a first arc electrode of rod form projecting into said chamber, a second arc electrode of thin wire form also projecting into said chamber opposite said first electrode to define an arc gap between the ends of said arc electrodes, electric power supply means connected to said electrodes for establishing an arc discharge between said first and second are electrodes, microwave power input means for coupling input energy from a microwave power source to one of said arc electrodes, microwave power output means for extracting from said arc discharge output energy at a harmonic frequency of said input energy, and a gaseous filling of inert gas at a pressure of at least 1000 pounds per square inch in said chamber to provide a dense plasma region between and joining the opposing ends of said first and second arc electrodes.

2. A generator according to claim **1** in which said microwave power input means comprise a first waveguide in said body, in which said microwave power output means comprise a second waveguide in said body, said first arc electrode extending across said first waveguide into said second waveguide and the arc gap between said arc electrodes being in said second waveguide.

3. A generator according to claim **2** in which said first and second arc electrodes lie in a common axial line which is normal to each of two spaced planes which respectively contain the longitudinal axes of said first and second waveguides.

4. A generator according to claim **3** in which the longitudinal axes of said first and second waveguides are at right angles.

5. A generator according to claim **2** in which said first waveguide is a rectangular section waveguide, said first arc electrode extending thereacross in a median plane parallel to the lesser side walls of said first waveguide and in which said second waveguide is a circular section waveguide, said arc gap being substantially coincident with the axis of said second waveguide.

6. A generator according to claim **1** in which said first arc electrode is of much greater cross section than said second arc electrode and is of pointed shape at its arc discharge end.

7. A generator according to claim **6** in which said second arc electrode is a platinum wire of the order of 0.008 inch diameter.

8. A generator according to claim **7** in which said first arc electrode is a platinum wire of the order of 0.020 inch diameter.

9. A generator according to claim **1** in which said inert gas comprises a major part of argon.

10. A generator according to claim **9** in which said inert gas comprises also between 4%–15% of hydrogen.

11. A generator according to claim **1** in which at least one of said arc electrodes is embraced adjacent the arc discharge end thereof by a surrounding conductive sheath of substantially greater cross section, said sheath being adjustable in the axial direction of the arc electrode to form a tuning plunger.

12. A generator according to claim **1** which includes means for supplying alternating current to said arc electrodes during operation of the generator.

13. A generator according to claim **12** in which said alternating current supply means are arranged to provide current having a square waveform.

14. A generator according to claim **13** in which said alternating current supply means are arranged to provide current having an alternation frequency in the range 200–5,000 cycles per second.

15. A generator according to claim **14** which also includes means for supplying direct current and switching means for connecting either said direct current supply or said alternating current supply to said arc electrodes.

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