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FREQUENCY STABLE CROSSED FIELD DEVICE HAVING THERMAL SENSITIVE MEANS CONNECTED BETWEEN THE SLOW WAVE STRUCTURE AND SOLE ELECTRODE

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Fig. 1

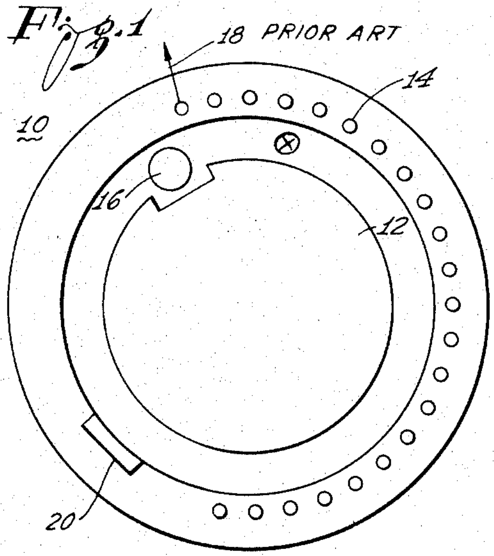


Fig. 2

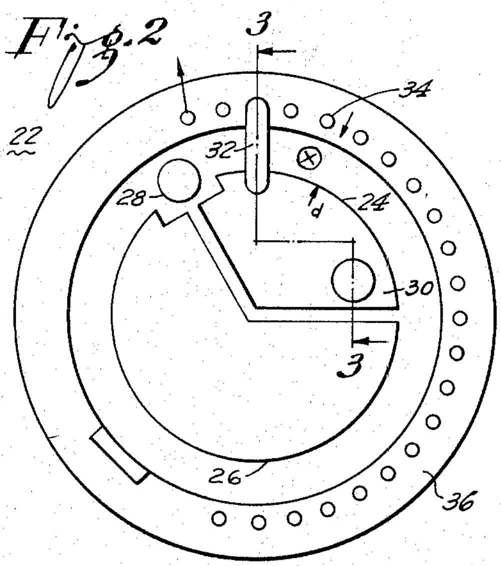


Fig. 4

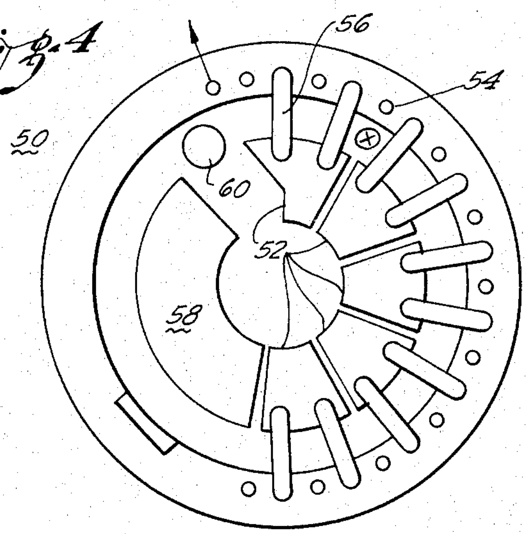
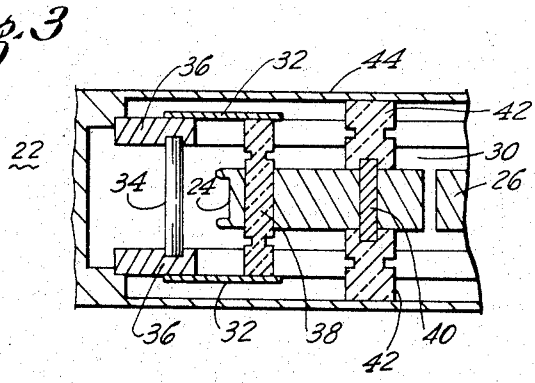


Fig. 3



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FREQUENCY STABLE CROSSED FIELD DEVICE HAVING THERMAL SENSITIVE MEANS CONNECTED BETWEEN THE SLOW WAVE STRUCTURE AND SOLE ELECTRODE

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ABSTRACT OF THE DISCLOSURE

A crossed field electron discharge device having a slow wave structure and a sole electrode facing each other across and defining therebetween an interaction region is compensated for thermally induced differences in expansion between the slow wave structure and sole electrode during the warm up period. This is accomplished with a design in which the sole electrode is segmented so that one portion thereof can be moved independently of another portion. A strap or coupling means advantageously constructed of low thermal expansion material couples the slow wave structure to at least one point of a sole electrode segment. Any differences in temperature between the slow wave structure and the sole electrode, which causes the slow wave structure to expand to a greater degree than the sole electrode, during the warm up period of the electrode device and which would otherwise enlarge the interaction region is compensated for with the strap by moving at least one portion of the sole electrode segment along with the expansion of the slow wave structure. Accordingly, because the strap maintains the spacing between at least that point on the segment and the slow wave structure substantially constant independent of the aforesaid temperature differences, changes of frequency that would otherwise as a result of variation in the size of the interaction region are thus lessened.

This invention relates to electron discharge devices and more particularly to a frequency stable crossed field backward wave oscillator.

There is a class of electron discharge devices known as crossed field traveling wave tubes in which the electron beam is injected into an interaction region bounded by a slow wave structure and a sole electrode. An electric field is established in the interaction region by applying a suitable potential difference between the slow wave structure and sole electrode and a magnetic field is applied to the interaction region which is transverse to both the electric field and the direction of travel of the electron beam. The basic theory of the operation of such a device is well known to those skilled in the art. For example, in my earlier filed application Ser. No. 322,330, filed on Nov. 8, 1963, and entitled, "Depressed Collector for Crossed Field Travelling Wave Tubes," the theory of operation of such devices is described in greater detail. Accordingly, no detailed description of the theory of operation of such a device, except as it may relate to the particular improvements of the present invention, will be given in this specification.

There is a particular type of such crossed field travelling wave tubes known as M-type backward wave oscillators in which the electron beam induces an electromagnetic wave on the slow wave structure and interacts with a space harmonic of the wave travelling on the slow wave structure in the direction opposite that of the electron beam (a so-called backward wave), amplifying the wave and transferring power from the beam to the wave. The so-generated electromagnetic wave is removed from the

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slow wave structure by any suitable output means at the end of the slow wave structure adjacent the electron gun. As is well known to those skilled in the art, the electron beam interacts with the space harmonic having a phase velocity equal to the velocity of the electron beam and, in properly designed tubes, the frequency of this space harmonic is essentially a linear function of the velocity of the electron beam. Thus, changes in the electron beam velocity result in changes of the frequency of the output signal. As is further well known to those skilled in the art, the electron beam in a crossed field seeks to have a velocity of E/B, where E is the electric field intensity in the interaction region and B is the magnetic field intensity in the interaction region. Thus, it is obvious that change in the electric field intensity is directly reflected in changes in the frequency of the output signal and one of the useful properties of such devices is that they are easily voltage tunable.

Unfortunately, this voltage tunable property is also at times deterimental to the operation of such devices. The electric field intensity is, of course, the ratio of the potential difference applied to the slow wave structure and sole electrode and the spacing between the slow wave structure and sole electrode. When a constant potential difference is applied between these electrodes, any slight changes in interelectrode spacing for any reason whatsoever results in a different electric field intensity in the interaction region and a different frequency of the output signal.

A serious problem in maintaining a constant interelectrode spacing is encountered during the time period immediately after such a device is turned on. Such devices are usually designed so that about one half of the electrons are collected on slow wave structure and the kinetic energy of these electrons must be dissipated as heat in the slow wave structure. This, of course, increases the temperature of the slow wave structure and causes thermal expansion of the slow wave structure. After a suitable time period, the heat is dissipated throughout the device and thermal equilibrium is achieved, but for some period after turn on, due to the inherent thermal lag of the device, the slow wave structure will be considerably hotter than the sole electrode. Due to thermal expansion, the distance between the two electrodes will then be somewhat greater until the temperature of the sole electrode also rises to the new value at which time it also will expand and essentially the previous electrode spacing will again be achieved. During the time period before the same spacing is again achieved, the electric field intensity in the interaction region will be somewhat lower, due to the increased electrode spacing, and the output frequency of the device will also be somewhat lower due to the resultant decreased electron beam velocity. In a typical operative X-band (about 10,000 megacycles) tube the diameter of the slow wave structure may be 2" and the spacing between the concentric sole electrode and slow wave structure may be 0.044". When the electron beam is first turned on and begins impinging on the slow wave structure, the temperature of the slow wave structure may rise to a level about 130° C. greater than that of the sole electrode and the resultant thermal expansion of the slow wave structure will cause the interelectrode spacing to increase about 0.001", with a resultant drop in the output frequency about 2.5%. It may take about two minutes before the sole electrode has become sufficiently heated to bring the output frequency back to the desired level.

There are many applications, such as airborne radar and countermeasure applications, in which it is essential that output power be available on much shorter notice. For example, the designers of such equipment desire that the output frequencies be stabilized to less than 0.1% in 15 seconds or less. The only way in which this could be achieved in the prior art was either to continue to maintain the device operative, thus resulting in a much shorter useful life of the device and considerably power wastage; or to provide some heating or cooling means to continuously maintain the entire body of the tube at a constant temperature, regardless whether it was operative or not. Obviously this later method is also quite expensive and would require relatively heavy controls and equipment which are not practical for use in airborne applications.

It is accordingly an object of the present method to provide an improved crossed field travelling wave electron discharge device which requires no lengthy warm-up period to become frequency stable.

It is another object of the present invention to provide an improved crossed field backward wave oscillator in which the interelectrode spacing remains relatively constant, despite any difference between the temperature of the electrodes.

Briefly stated, and in accordance with one embodiment of the present invention, a crossed field travelling wave electron discharge device is provided which includes a slow wave structure and a sole electrode, with these electrodes defining therebetween an interaction region. An electron gun is provided at one end of the interaction region for injecting an electron beam into the interaction region and a collector electrode is provided at the other end of the interaction region for collecting all electrons which have not impinged either on the slow wave structure or the sole electrode. The sole electrode is divided into segments and those segments nearest the electron gun end of the interaction region are supported directly from the slow wave structure so that the spacing between these segments of the slow wave structure and the sole electrode remains constant even though the electron beam impinges upon the slow wave structure and causes thermal expansion of the slow wave structure.

For a complete understanding of the invention, together with other objects and advantages thereof, reference may be had to the accompanying drawings, in which:

FIGURE 1 is a schematic view of a circular crossed field backward wave oscillator in accordance with the prior art;

FIGURE 2 is a schematic representation of a similar crossed field backward wave oscillator in which one embodiment of the present invention is employed;

FIGURE 3 is a section view taken along the lines III—III in FIGURE 2; and

FIGURE 4 is a schematic representation of a crossed field backward wave oscillator utilizing a second embodiment of the present invention.

In the following description, like reference numerals are used to designate like parts whenever practical.

Referring now to FIGURE 1, therein is shown a schematic representation of a crossed field backward wave oscillator in accordance with the prior art. For purposes of clarity in this figure and in FIGURES 2 and 4 also, the housing of the device is not shown and only the electrode structure is shown. The device **10** includes a sole electrode **12** and a slow wave structure **14**, which in the shown device **10** may conveniently take the form of the conventional interdigital delay line, although any of the known slow wave structure may be used instead. An interaction region is defined by the sole electrode **12** and the slow wave structure **14** into which an electron gun **16** injects a beam of electrons. The electron gun **16** is shown schematically since the details of the gun **16** form no part of the present invention and any of the electron guns known to those skilled in the art may be utilized in a device employing the present invention. Both sole electrode **12** and the slow wave structure **14** are directly supported from the body of device **10**, with sole electrode **12** being electrically insulated from the body.

In operation, an electric field is established between the slow wave structure **14** and the sole electrode **12**, usually by applying a relatively high negative voltage to the insulated sole electrode **12** and by maintaining the body of device **10**, and thus the slow wave structure **14**, at ground potential. A magnetic field B having its direction into the plane of FIGURE 1, as indicated by the encircled X, is established by any suitable source, such as permanent magnets or an electromagnet. The electron beam from electron gun **16** travels through the interaction region, induces an electromagnetic wave on slow wave structure **14** and interacts with a backward wave space harmonic of the wave which has a phase velocity equal to the velocity of the electron beam. Output power from the device **10** is removed through any suitable output means **18** from the end of the slow wave structure **14** adjacent the electron gun **16**. Any electrons from the beam which are not collected on either sole electrode **12** or slow wave structure **14** are collected on a collector electrode **20**.

As was previously discussed, the frequency of the output signal of the device **10** is a function of the velocity of the electron beam, which is in turn a function of the electric field intensity in the interaction region between the sole electrode **12** and slow wave structure **14**. This electric field intensity is, of course, the ratio of the potential difference applied between these electrodes and the distance d between the electrodes and thus any changes in d are directly reflected as changes in the frequency of the output signal of device **10**. Again, as was previously discussed, there is a time period immediately after the device **10** is turned on in which the dimension d is relatively unstable due to unequal thermal expansion of the electrodes. This unequal thermal expansion is caused by electrons from the beam impinging upon slow wave structure **14**, thereby heating slow wave structure **14**. Since sole electrode **12** is insulated from slow wave structure **14**, there is some time delay before heat is conducted from slow wave structure **14** through the body of the tube to sole electrode **12** and thermal equilibrium is reached. During this time delay period, the diameter of slow wave structure **14** increases due to thermal expansion, while the diameter of the sole electrode **12** remains relatively constant before it, too, expands, thereby increasing its diameter. During this time, the dimension d is somewhat increased, thereby causing a decrease in the electric field intensity in the interaction region, a lower velocity of the electron beam and a lower frequency of the output signal of device **10**.

In a typical X-band device, the diameter of slow wave structure **13** may be 2.000″ while the distance d may be 0.044″. During the previously mentioned time period, the temperature of the slow wave structure **14** may increase by about 130° C. over that of the sole electrode **12** and the resultant thermal expansion, assuming the electrodes are to be made of copper, as is usually the case, causes the distance d to increase by about 0.001″, causing a decrease of about 2.5% in the electric field intensity and a resultant decrease of about 2.5% in the frequency of the output signal. The device requires about two minutes of warm-up period after turn-on for the sole electrode **12** to also expand and for frequency stable operation to occur.

FIGURE 2 shows a schematic view of a crossed field backward wave oscillator **22** similar to that shown in FIGURE 1 which employs one embodiment of the present invention to eliminate the previously described frequency instability which is exhibited by device **10**. The sole electrode of device **22** is divided into two segments, **24** and **26**. The segment **24** which defines one boundary of the interaction region nearest the electron gun **28** is supported and pivoted at point **30** remote from the electron gun **28** and is coupled and supported by a strap **32** directly from the slow wave structure **34** at a point adjacent electron gun **28**. Strap **32** may be made from a low thermal expansion material such as alumina or tungsten. If a conductive material such as tungsten is employed, some means must be utilized to electrically insulate sole electrode **24** from slow wave structure **34**.

The previously discussed frequency instability of the prior art device is eliminated by the employment of the present invention in the following manner: When electrons impinge upon slow wave structure **34** thereby heating it and causing thermal expansion, strap **32** continues to maintain a relatively constant spacing between slow wave structure **34** and the sole electrode, with segment **24** of the sole electrode pivoting slightly at point **30** to allow the spacing between the electrodes to remain constant. Since the length of strap **32** is considerably less than the diameter of the slow wave structure **34**, and since the strap **32** may be constructed from a material having a much lower thermal expansion constant than the copper used in slow wave structure **34**, the thermal expansion of strap **32** is considerably less than the change in the diameter of slow wave structure **34** and the spacing between slow wave structure **34** and that portion of sole electrode **24** near strap **32** is maintained quite constant. In this shown embodiment, as the segment **24** of the sole electrode pivots on point **30**, the distance d increases in the interaction region in the direction away from the electron gun **28**, but the spacing in the most important region, that portion of the interaction region nearer the electron gun **28** in which the greatest power transfer from the beam to the electromagnetic wave occurs, remains relatively constant.

FIGURE 3 is a cross-sectional view taken along the lines III—III of FIGURE 2 and shows details of the pivot arrangement **30** and the straps **32**. As shown in FIGURE 3, the slow wave structure includes the crown elements **36** from which are supported the fingers **34** which form the interdigital slow wave structure. The straps **32**, which in this shown embodiment may be tungsten, are connected directly to the crown elements **36**. The segment **24** of the sole electrode is supported from strap **32** by an insulative cylinder **38** which may be constructed, for example, from a ceramic material such as alumina or the like. The pivot arrangement **30** may include a pin **40** which is attached to segment **24** of the sole electrode and it has ends pivotly mounted in electrically insulative bearings such as ceramic cylinders **42** which are supported from the housing **44** of device **22**.

In the illustrated embodiments of FIGURES 2 and 3, the segments **24** and **26** of the sole electrode may be maintained at the same electrical potential. It is apparent that the spacing between these segments is exaggerated in the drawings to illustrate the present invention more clearly. In a typical operative device, the spacing between segments **24** and **26** may be about 0.020".

FIGURE 4 shows a schematic view of another crossed field backward wave oscillator **50** employing another embodiment of the present invention. As shown therein, the sole electrode induces a plurality of segment **52** each of which is supported directly from the slow wave structure **54** by suitable straps **56**, which may be similar to the straps **32** of FIGURE 2. The remaining portion **58** of the sole electrode may be supported from the body of devices **50** in any conventional manner. Again, in this embodiment, the portions of the sole electrode nearest the electron gun **60** are supported directly from the slow wave structure **54** so that during the initial period after turning the device **50** on, any expansion in the diameter of slow wave structure **54** causes no changes in the spacing between slow wave structure **54** and the segments **52** of the sole electrode, since straps **56** maintain a relatively constant spacing between these electrodes regardless of any temperature differential which may exist between the electrodes.

As was previously stated, in the preferred embodiment of the invention the straps **32** and **56** are made of a material having a low thermal expansion constant.

However, it will be observed that considerable improvement over the prior art can be obtained even if a material such as copper is used for the straps since the absolute expansion, which is the important figure concerned here, is proportional to the particular dimension in question, and the length of the straps is considerably less than the diameter of the slow wave structure.

While the invention is thus disclosed and several embodiments described, the invention is not limited to these shown embodiments, instead any modification will occur to those skilled in the art which lie within the spirit and scope of the invention. For example, the invention is illustrated in conection with a backward wave oscillator, but is equally applicable to any crossed field travelling wave device in which it is desired to maintain a constant interelectrode spacing, regardless of the temperature differential between the slow wave structure and sole electrode. Accordingly, it is intended that the invention be limited in scope by the appended scope.

What is claimed as new and desired to secure by Letters Patent of the United States is:

What is claimed is:

1. An electron discharge device comprising; a slow wave structure, a sole electrode, said slow wave structure and said sole electrode being spaced apart and defining an interaction region therebetween, means for providing an electron beam within said interaction region, and wherein said slow wave structure is initially heated at a greater rate then said sole electrode, said sole electrode including at least one movable portion, movable independently of other portions thereof, and means connected to a movable portion of said sole electrode responsive to thermally induced expansion of said slow wave structure for maintaining the spacing between said slow wave structure and at least a portion of said movable portion substantially constant independent of temperature differences therebetween.

2. An electron discharge device comprising; a slow wave structure, a sole electrode, said slow wave structure and said sole electrode defining therebetween an interaction region, means for providing an electron beam within said interaction region, said sole electrode having at least one segment movable independently of at least one other portion thereof, and low thermal expansion coupling means for supporting a movable segment of said sole electrode from said slow wave structure independently of said other portions of said sole electrode, whereby the distance between said slow wave structure and at least one portion of said sole electrode is independent of the relative temperatures of said slow wave structure and sole electrode.

3. An electron discharge device comprising; a slow wave structure, a sole electrode, said slow wave structure and said sole electrode defining therebetween an interaction region, means for providing an electron beam within said interaction region, and wherein said slow wave structure is initially heated at a greater rate then said sole electrode, said sole electrode having at least one segment movable independently of at least one other segment thereof, coupling means connected between said slow wave structure and said one independently movable segment of said sole electrode responsive to thermal expansion of said slow wave structure for maintaining a substantially constant spacing between said slow wave structure and at least a portion of said movable segment substantially independent of the relative differences in temperature between the slow wave structure and sole electrode.

4. An electron discharge device comprising a slow wave structure, a sole electrode, said slow wave structure and sole electrode defining therebetween an interaction region, means for injecting an electron beam into one end of said interaction region, means for collecting electrons from said beam at the other end of said interaction region, and low thermal expansion means for supporting said sole electrode from said slow wave structure, whereby the distance between said slow wave structure and sole electrode is independent of the relative temperatures of said slow wave structure and sole electrode.

5. An electron discharge device comprising a slow wave structure, a sole electrode, said slow wave structure and sole electrode defining therebetween an interaction region, means for injecting an electron beam into one end of said interaction region, means for collecting electrons from said beam at the other end of said interaction region, said sole electrode being divided into a plurality of segments, and low thermal expansion means for supporting a predetermined number of said segments nearest said one end of said interaction region from said slow wave structure, whereby the distance between said slow wave structure and said sole electrode is independent of the relative temperatures of said slow wave structure and sole electrode.

6. An electron discharge device comprising a slow wave structure, a sole electrode, said slow wave structure and sole electrode defining therebetween an interaction region, means for injecting an electron beam into one end of said interaction region, means for collecting electrons from said beam at the other end of said interaction region, said sole electrode being divided into two segments, means for pivotally mounting the segment nearer said one end of said interaction region at a point remote from said one end, and means for coupling said nearer segment to said slow wave structure at a point adjacent said one end of said interaction region, whereby the distance between said slow wave structure and at least one portion of said sole electrode is independent of the relative temperatures of said slow wave structure and sole electrode.

7. An electron discharge device comprising, a slow wave structure, a sole electrode, said slow wave structure and said sole electrode defining therebetween an interaction region, means for injecting an electron beam into one end of said interaction region, means for collecting electrons from said beam at the other end of said interaction region, and a plurality of low thermal expansion straps for supporting said sole electrode from said slow wave structure, whereby the distance between said slow wave structure and sole electrode is independent of the relative temperatures of said slow wave structure and sole electrode.

8. An electron discharge device comprising, a slow wave structure, a sole electrode, said slow wave structure and said sole electrode defining therebetween an interaction region, means for injecting an electron beam into one

end of said interaction region, means for collecting electrons from said beam at the other end of said interaction region, said sole electrode being divided into a plurality of segments, and a plurality of low thermal expansion straps for supporting a predetermined number of said segments nearest said one end of said interaction region from said slow wave structure, whereby the distance between said slow wave structure and said sole electrode is independent of the relative temperatures of said slow wave structure and sole electrode.

9. The device as defined in claim 8 wherein said strap means includes a portion comprising tungsten material, and another portion of electrical insulating material for maintaining said sole electrode and slow wave structure in direct electrical isolation.

10. An electron discharge device comprising a slow wave structure, a sole electrode, said slow wave structure and said sole electrode defining therebetween an interaction region, means for injecting an electron beam into one end of said interaction region, means for collecting electrons from said beam at the other end of said interaction region, said sole electrode being divided into two segments, means for pivoting the segment nearer said one end of said interaction region at a point remote from said one end, and strap means for coupling said nearer segment to said slow wave structure at a point of said nearer segment adjacent said one end of said interaction region, whereby the distance between said slow wave structure and at least one portion of said sole electrode is independent of the relative temperatures of said slow wave structure and sole electrode.

11. The device as defined in claim 10 wherein said strap means include a portion comprising tungsten material, and another portion comprising electrical insulating material for maintaining direct electrical isolation between said sole electrode and said slow wave structure.

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