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3,376,524

DOUBLE-MODE BROADBAND RESONANT CAVITY

Filed July 13, 1964

2 Sheets-Sheet 1

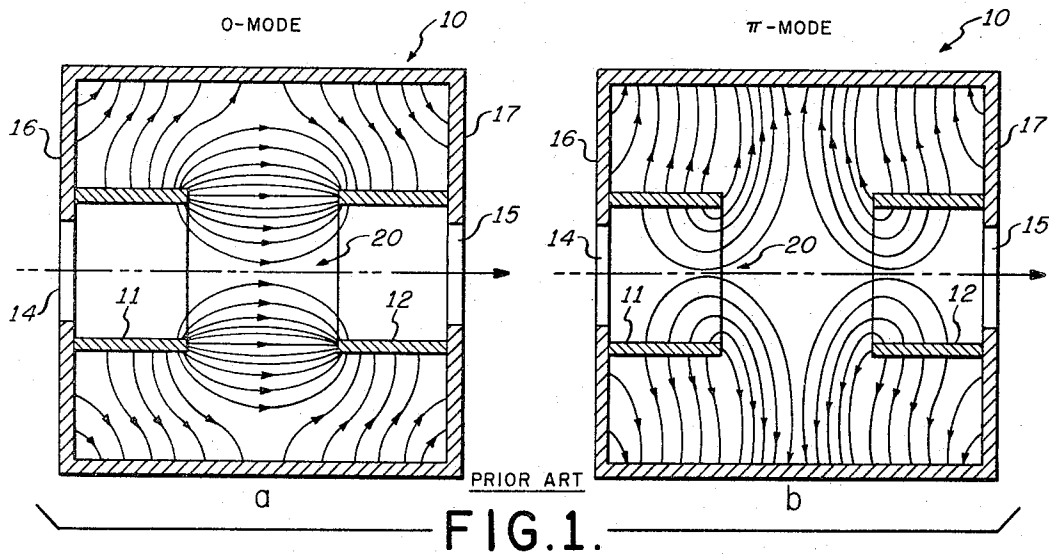
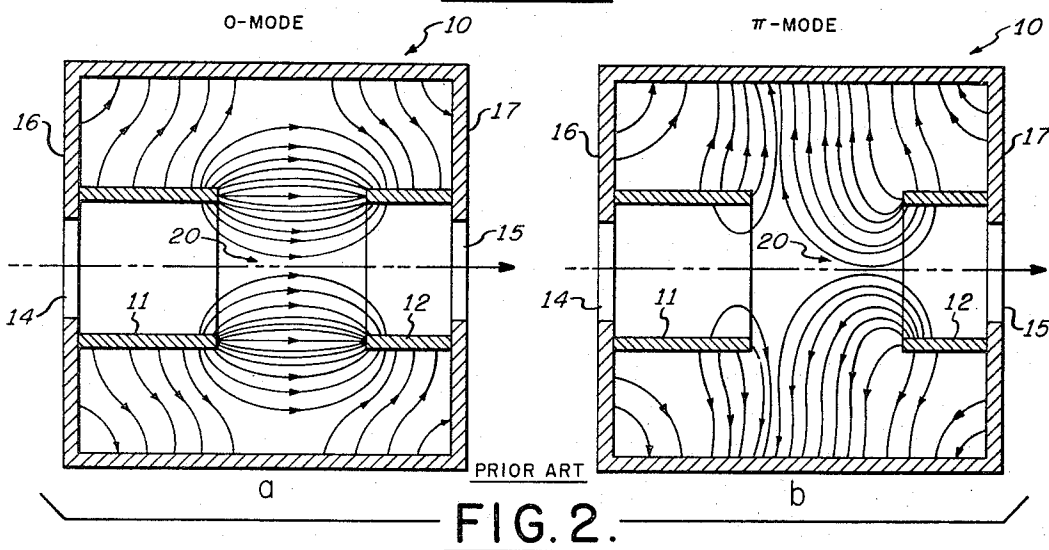
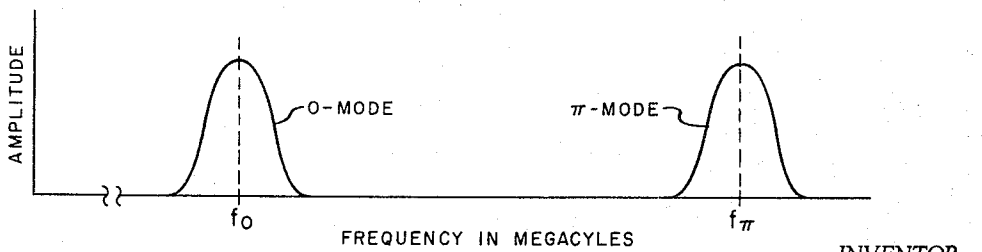


FIG. 3.

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2 Sheets-Sheet 2

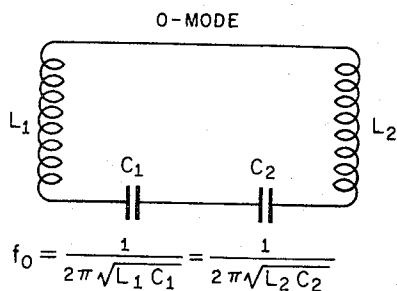


FIG. 4a.

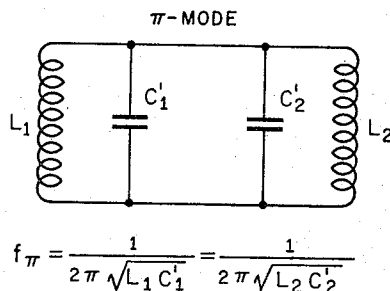


FIG. 4b.

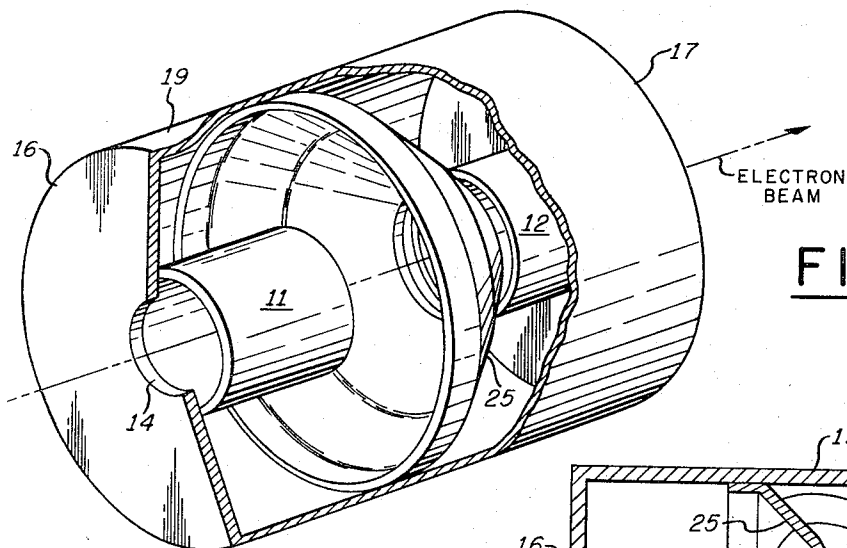


FIG. 5.

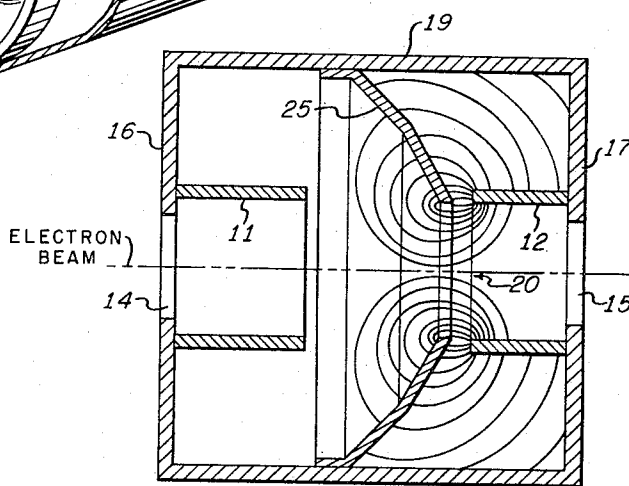


FIG. 6.

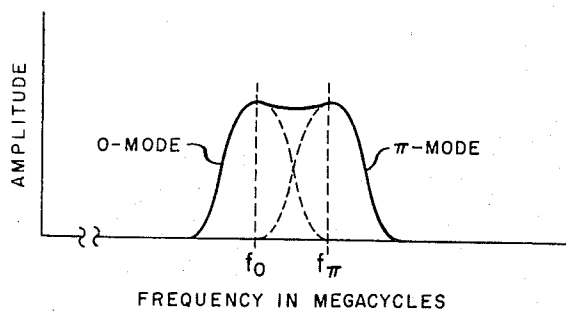


FIG. 7.

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DOUBLE-MODE BROADBAND RESONANT CAVITY

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5 Claims. (Cl. 33—83)

This invention relates to a broadband resonant cavity for use in high power electron beam tubes such as klystron tubes, and more particularly the invention relates to a novel cavity construction that permits the cavity to be resonant for electromagnetic waves in two distinct cavity modes, wherein the waves in the respective modes fall within contiguous frequency ranges.

Broadband klystron amplifier tubes are comprised of an electron beam source and a number of electron beam permeable cavities successively disposed along the beam path for successively amplifying input electromagnetic waves. Because waveguide cavities inherently are rather narrow band devices, a considerable number of cascaded cavities, each resonate at a different center of frequency, are required in order to achieve amplification over an appreciable bandwidth. As the number of cavities is increased in order to achieve broader bandwidths of amplification, the complexity of construction, the size, weight, and the cost of the tube rise accordingly. It always is a matter of concern to provide resonant cavities that have bandwidths as wide as possible in order to reduce the number of cavities required and thus minimize the above-named considerations, and this is particularly true of high power tubes where all of the named considerations are of sizable proportions.

The present invention developed out of efforts to eliminate certain undesirable oscillations that are particularly prevalent in high power klystron amplifiers. I have found that not only can I eliminate the oscillations by altering the configuration of the electromagnetic wave field mode that gives rise to them, but further, by the addition of a simple structure to a cavity, the altered mode may be utilized to increase the bandwidth of amplification obtainable from the cavity.

It therefore is an object of this invention to provide a broadband resonant cavity suitable for use in a high power electron beam tube.

Another object of this invention is to provide a high power klystron cavity that is doubly resonant at closely adjacent frequencies to provide a continuous broad frequency band of amplification.

A further object of this invention is to provide means for bringing the resonant frequency of a second ordinarily deleterious mode of oscillation into a useful frequency range for enhancing the bandwidth of amplification of a klystron cavity.

The invention will be described and explained by referring to the accompanying drawings wherein:

FIGS. 1a and 1b are representations of the electric field lines of force of the two modes of oscillation commonly associated with a symmetrical doubly reentrant cylindrical cavity that is used in high power klystron tubes;

FIGS. 2a and 2b are representations of the electric field lines of force of the two modes of oscillation commonly associated with an asymmetrical doubly reentrant cylindrical cavity that is used in high power klystron tubes;

FIG. 3 is a sketch illustrating the resonant frequencies of the two cavity modes of FIG. 2;

FIG. 4 is a sketch that is used to explain the electrical reactance effects that are associated with the two cavity modes illustrated in FIG. 2;

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FIG. 5 is a perspective view, partially broken away, of a doubly resonant cavity constructed in accordance with the principles of this invention;

FIG. 6 is a sectional view of the cavity of FIG. 5, taken at section 6—6; and

FIG. 7 is a graph illustrating the frequency response of a cavity constructed in accordance with the teachings of this invention.

In accordance with the present invention a double reentrant cavity for use in a high power klystron tube is made to support oscillations over a relatively broad frequency range by first providing reentrant nibs of unequal lengths so that the electron beam-electromagnet wave interaction gap between the nibs is positioned asymmetrical-ly between the end walls of the cavity. This has the effect of altering the normal field pattern of the first higher order mode (π -mode) that ordinarily exists in a symmetrical cavity, and eliminates deleterious monotron oscillations that result from negative beam loading by the higher order mode. The natural resonant frequency of the waves in this altered higher order mode are outside of the desired bandwidth of amplification for the tube. This resonant frequency is brought within the desired bandwidth for amplification by introducing within the gap region of the tube an apertured cup-shaped member whose surface in the region of said gap is substantially normal to the electric field lines of the fundamental O-mode, but has at least a component of its direction substantially parallel to the altered π -mode field lines, thereby shortening the π -mode field lines. This has the effect of adding capacitive reactances for the π -mode, thereby lowering its resonant frequency and bringing it closely adjacent the resonant frequency of the fundamental O-mode. The combined resonances of the two modes now overlap to constitute a continuous broad resonant frequency response for the single cavity.

Before going into a detailed description of the broadband cavities of this invention, it is believed that it will be helpful first to consider the nature of the monotron oscillations that frequently are encountered in high power klystron tubes so that it may be understood more clearly how the formerly deleterious conditions may be altered so as to be useful in achieving the objectives of this invention.

The types of resonant cavities commonly used in klystron tubes are double reentrant cylindrical cavities that have tubular nibs extending inwardly from the respective apertured end walls. Frequently, in low power tubes, the nibs are equal in length and provide a gap in the interior of the cavity that is positioned symmetrically between the end walls. These symmetrical double reentrant cavities support oscillations in two different modes, the fundamental TM_{010} cylindrical cavity mode, and the first higher order TM_{011} cylindrical cavity mode. In lower power tubes the resonant frequencies of these two modes are widely separated and the oscillations of the TM_{011} mode do not interfere with the oscillations of the TM_{010} mode, which ordinarily is the desired mode for beam-wave interactions in klystron tube operation. In terms of the resonant frequency of the TM_{010} mode, the transit angle of beam electrons through the cavity gap is of the order of one to two radians, and the beam loading for this mode is positive, as is required in the operation of the klystron tube. In low power tubes having symmetrically positioned gaps, the transit angle of electrons in terms of the TM_{011} mode resonant frequency is many times greater than for the TM_{010} mode, so that the beam loading due to the TM_{011} mode is of very small magnitude and creates no difficulties, even should it be negative. These conditions are represented by the graph of Fig. 3.4 on page 45 of the text Klystrons and Microwave Triodes, by Hamilton, Knipp and Kuper, Radiation Laboratory

Series, Volume 7, published in 1948 by McGraw-Hill Book Company, Inc., New York, N.Y.

In high power klystron tubes, however, where the gap spacing must be proportionately wider than in low power tubes, the resonant frequencies and the transit angles for the TM_{010} and the TM_{011} modes are relatively closer together, and because the transit angle for the TM_{011} mode now is a small value the negative beam loading for the TM_{011} mode may become quite significant and can lead to the generation of undesired self oscillations, known as monotron oscillations.

These conditions will be explained by referring to FIGS. 1a and 1b which represent a cross sectional view of a cylindrical cavity 10 having the tubular reentrant nibs 11 and 12 extending inwardly from the apertures 14 and 15 on the respective end walls 16 and 17. FIG. 1a represents the electric field configuration for the fundamental TM_{010} cylindrical cavity mode, referred to hereinafter as the O-mode, and FIG. 1b represents the electric field configuration for the first higher order TM_{011} cylindrical cavity mode, referred to hereafter as the π -mode. In FIG. 1a it may be seen that the electric field lines of the O-mode are unidirectional across the gap 20, and this gives rise to the positive beam loading condition upon which amplification of input electromagnetic waves is dependent. In FIG. 1b, however, it is seen that the π -mode has a reversal of direction of the electric field in the gap, and with the relatively low transit angles of the electrons through gap 20, appreciable negative beam loading effects occur, and this gives rise to the undesired oscillations that are known as monotron oscillations. In the high power cavities with relatively large gap dimensions the frequency of the undesired monotron oscillations may be within the desired band of frequencies for amplification.

To eliminate the undesired negative beam loading, cavities have been constructed as illustrated in FIGS. 2a and 2b wherein the nibs 11 and 12 are of unequal lengths so as to position the gap 20 asymmetrically between the two end walls 16 and 17. As seen in FIG. 2a, the electric field pattern of the O-mode retains its characteristic of being unidirectional in the gap region 20, and as seen in FIG. 2b, the reversal of the field of the π -mode in the gap region has been largely, although not completely, eliminated. With the condition illustrated in FIG. 2b, the positive beam loading of the π -mode will be enhanced and the negative beam loading will be greatly reduced to the point where the monotron oscillations will be eliminated.

This technique for suppressing monotron oscillations has been used with success and it has been found that the natural frequency of oscillations of input waves in the two modes of the asymmetrical reentrant cavity are sufficiently separated, as illustrated in FIG. 3, so that the π -mode oscillations fall without the desired frequency range for amplification.

With this background explanation, the details of my present invention now should be more readily understood. My invention resides in the addition of a structure to the interior of the cavity that will have the effect of lowering the resonant frequency of the π -mode, without reintroducing the field reversal that gives rise to negative beam loading, so that electromagnetic waves in the π -mode resonate at a frequency closely adjacent to the resonant frequency of the O-mode waves, whereby the combined resonances of the two modes now overlap to provide an overall broad frequency response for the cavity. The effect achieved in this one cavity then will be the same as was formerly achieved in two separate cavities cascaded along the beam path.

The concept underlying my invention may be explained by referring to FIGS. 4a and 4b which are simplified sketches illustrating the electrical reactances associated with the O-mode and π -mode in the asymmetrical double reentrant cavity illustrated in FIGS. 2a and 2b. The

capacitors C_1 and C_2 , FIG. 4a, represent the capacitance between the nibs 11 and 12 as "seen" by the O-mode, see FIG. 2a, and the inductances L_1 and L_2 represent the inductance associated with the off-axis portion of the cavity. These same inductances are "seen" by the π -mode, but the capacitive effect between the nibs 11 and 12 and the cylindrical wall 19 of the cavity, FIG. 2b, is represented by the capacitors C_1' and C_2' , FIG. 4b. Because of the geometry of the cavity, the capacitances C_1' and C_2' will be smaller in value than C_1 and C_2 . Because the resonant frequencies of the O-mode and π -mode are expressed by the relationships $1/2\pi\sqrt{L_1C_1}=1/2\pi\sqrt{L_2C_2}$ and $1/2\pi\sqrt{L_1C_1'}=1/2\pi\sqrt{L_2C_2'}$, respectively, it is seen that the resonant frequency of the π -mode will be higher than that of the O-mode. I am able to lower the resonant frequency of the π -mode to a frequency range closely adjacent that of the O-mode by adding additional capacitance to the cavity, this additional capacitance being "seen" substantially only by the π -mode, thereby lowering the frequency of the π -mode without substantially affecting the resonant frequency of the O-mode. The added capacitance effect may be achieved by shortening the electric field lines of the π -mode of FIG. 2b.

This increased capacitance for the π -mode is achieved by the cavity construction illustrated in FIGS. 5 and 6, wherein the basic asymmetrical cavity of FIG. 2 is altered by the addition of the cup-shaped apertured member 25 which is positioned coaxially about the beam path. The shaped surface of member 25 is arranged so that in the region of gap 20 where the axial field lines are strongest, the surface is substantially normal to the O-mode field lines, thereby having negligible effect on the O-mode. However, the shaped surface of member 25 has a large component of its direction parallel to the π -mode field lines in the region of the gap, so that the π -mode field lines will terminate on the conductive member 25, thereby shortening their lengths to increase the capacitance for this mode. Not only must this capacitive effect be achieved by the member 25, but it must not appreciably disturb the altered π -mode electric field pattern illustrated in FIG. 2b. This altered π -mode field pattern must be preserved in order to assure that appreciable electric field reversal and the negative beam loading effects will not again occur. With the added capacitance for the π -mode provided by conductive member 25, the resonant frequency of the π -mode will be lowered and can be brought into the portion of the frequency spectrum adjacent the resonant frequency of the O-mode so that now the combined resonances of the two modes will include a continuous broad range of frequencies, see FIG. 7, thereby achieving in one cavity of a klystron a bandwidth of amplification formerly achieved in two separate cavities successively disposed along the beam path.

As may be seen from FIGS. 5 and 6, the cup-shaped apertured capacitive member 25 is positioned so that its convex side is nearer the shorter reentrant nib 12. The exact location of this capacitive member 25 relative to the nib is best determined experimentally. I have found, however, that it cannot be positioned too close to nib 12 without disturbing the altered π -mode to such an extent that it reintroduces appreciable electric field reversal of the axial component of the π -mode, thus reintroducing the negative beam loading that is to be avoided. Attempts to use a planar apertured capacitive member have proven to be unsuccessful.

In order to successfully practice the present invention, it is not necessary that the capacitive member 25 have the exact shape that is illustrated in the accompanying drawings. Various different shapes for capacitive member 25 may be employed, always keeping in mind that the shaped surface should be substantially normal to the electric field lines of the O-mode in the region of the gap, and should have a large component of its direction parallel to the electric field lines of the π -mode in the region of the gap. Further, it may be possible to achieve the desired

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capacitive loading effect for the π -mode by employing more than one capacitive member 25 in the gap region between the nibs.

Although it is conceivable that the capacitive member 25 of FIGS. 5 and 6 might be employed in a symmetrically positioned gap to perform the dual function of adding capacitance for the π -mode and also altering the electric field pattern of the π -mode to substantially eliminate the electric field reversal in the gap region 1 presently preferred to employ the asymmetrically positioned gap as the means for altering the electric field pattern of the π -mode. This places less stringent requirements on the design of capacitive member 25 and allows greater flexibility in the design of the cavity.

While the invention has been described in its preferred embodiments, it is to be understood that the words which have been used are words of description rather than limitation and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of the invention in its broader aspects.

What is claimed is:

1. A broadband resonant cavity tube comprising, a hollow conductive cavity member having first and second end walls, first and second aligned reentrant nibs on the respective end walls of said cavity and forming a gap therebetween said cavity being adapted to support standing electromagnetic waves at a first frequency in a first cavity mode characterized by electric field lines that extend across said gap between said nibs, and supporting standing electromagnetic waves at a second frequency in a second cavity mode characterized by electric field lines in the gap that extends between the respective nibs and the side wall of said cavity member, an apertured conductive cup-shaped member coaxially disposed in said gap adjacent one of said nibs, said cup-shaped member being positioned in the region of said gap to intersect substantially normally the electric field lines of said first mode.
2. The combination claimed in claim 1 wherein said first and second end walls of said hollow conductive cavity member are apertured for passing an electron beam axially therethrough.
3. A broadband resonant cavity comprising, a closed conductive member having first and second end walls, first and second aligned conductive nibs respectively disposed on said end walls and extending inwardly into said conductive member, said nibs being separated by a gap in the interior of said cavity, said cavity supporting standing electromagnetic waves at a first frequency in a first mode and at a second frequency in a second mode, said first mode being characterized by electric field lines that extend between said nibs in said gap region and the second mode being characterized

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by electric field lines in the region of said gap that extend between the respective nibs and the surface of said conductive member,

a conductive apertured member disposed coaxially between said nibs and nearer one of said nibs, said member having a shaped surface in the region of said gap that is substantially normal to the electric field lines of said first mode and having at least a component direction of its surface parallel to the electric field lines of the second mode.

4. The combination claimed in claim 3 wherein, said conductive apertured member is cup-shaped and extends to the walls of said cavity and the convex side of the member is adjacent the shorter one of said nibs.

5. A broadband resonant cavity for use in an electron beam tube comprising

a cylindrically shaped cavity having first and second apertured end walls for passing an electron beam axially through said cavity,

first and second axially-aligned tubular conductive nibs of unequal lengths extending inwardly from the respective apertured end walls and forming a gap therebetween that is positioned asymmetrically between said end walls,

said cavity being adapted to support standing electromagnetic waves at a first frequency in a first cavity mode characterized by electric field lines that extend across said gap between said nibs, and supporting standing electromagnetic waves at a second frequency in a second cavity mode characterized by electric field lines in the gap that extend between the respective nibs and the inner wall of the cavity,

a conductive apertured member disposed coaxially between said nibs and nearer the shorter one, said member having a symmetrically shaped surface that extends to the inner wall of said cavity,

said shaped surface being substantially normal to the electric field lines of said first mode in the region of said gap and at least the portion of its surface nearest said shorter nib having a component of its direction parallel to the electric field lines of the second mode in the region of the gap.

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