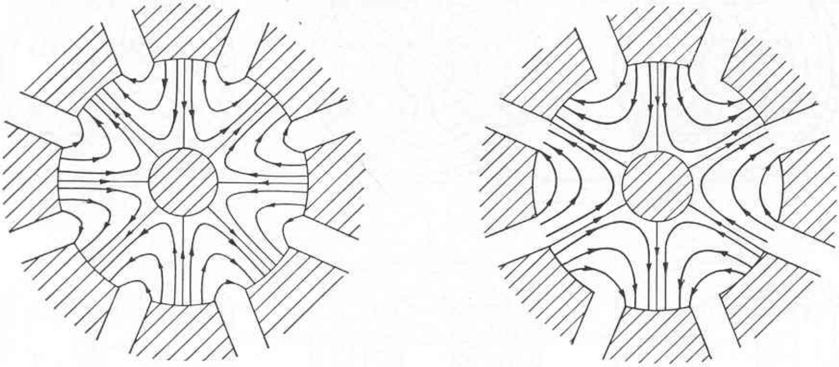
For magnetron resonators having more than four cavities, mode designation by names such as "push-pull-parallel" is awkward, but the number n, signifying the number of cycles of variation along a path around the cathode, can always be used to designate the modes. For a magnetron having any even number N of cavities, the modes correspond to $n = 0$, $n = 1$, $n = 2$, . . . , $n = N/2$, and the $n = N/2$ is the desired π mode for magnetron operation. For an eight-cavity magnetron, the $n = 4$ mode is the π mode and has the electric-field pattern in the interaction space (the space between cathode and anode where electrons and fields interact) illustrated in Fig. 14*A*. The pattern of the next-simpler mode ($n = 3$) of the eight-cavity magnetron is shown in Fig. 14*B*.


(A) n = 4 (π) MODE

(B) n = 3 MODE

FIG. 14. Interaction-space electric fields of eight-cavity magnetron.

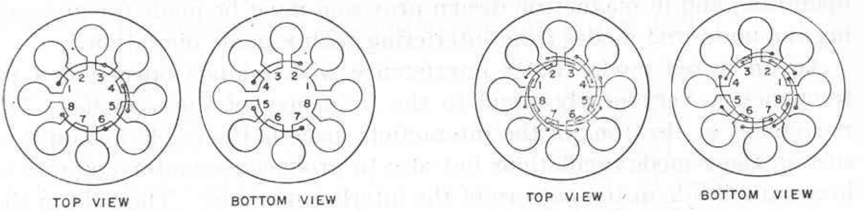
The $n = 0$ mode is not employed in a resonant-cavity magnetron because the fields of this mode do not enter the individual anode cavities, and thus the cavities do not control the frequency of the mode. The other modes, with the exception of the π mode, are undesirable because they are degenerate (see Art. 4, Chap. IX); that is, each is a combination of two modes having identical resonant frequencies. The two component modes are present simultaneously, and the resultant pattern may take a variety of forms depending upon the relative amplitudes of the components. For magnetron resonators, the various patterns of a degenerate mode differ only by a rotation about the tube axis. For example, for the $n = 1$ mode of Fig. 13*A*, the pattern is rotated 90 deg if different pairs of anode segments operate in parallel. A combination of two patterns 90 deg apart yields a pattern shifted by less than 90 deg from the position of the figure. Similar rotations of the $n = 3$ pattern of Fig. 14*B* are possible.

Degenerate modes are undesirable in magnetron operation, for one reason, because the load is ordinarily coupled to only one cavity of the

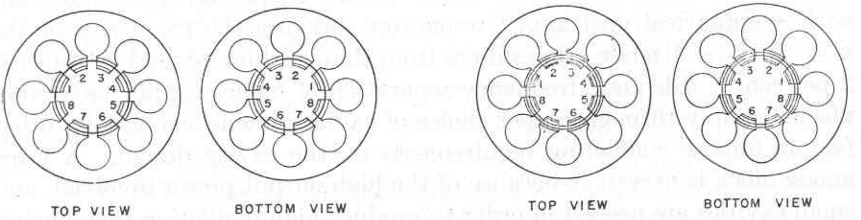
An undesired mode causes interference with π-mode operation if its frequency is very nearly equal to the frequency of the π mode. The movement of electrons in the interaction space is then able not only to sustain the π-mode oscillations but also to produce resonator voltages of lower amplitude in the pattern of the interfering mode. The field in the interaction space is consequently distorted from the π-mode form, and the electron motions are altered in such a way that the efficiency of the oscillator is decreased. This effect occurs frequently in magnetrons with symmetrical unstrapped resonators, because the frequency of the $n = (N/2) - 1$ mode often differs from that of the π mode by less than 2 per cent. Adequate frequency separation of modes cannot be accomplished simply through proper choice of cavity dimensions because other factors impose conflicting requirements on the cavity design. A large anode block is necessary because of the high output power involved, and small cavities are needed in order to produce high oscillation frequencies. The impedance presented to the interaction space depends upon the ratio of the width of segments between adjacent cavities to the width of the cavity slots, and this ratio must be kept reasonably low. Thus a large number of small cavities is required, with the result that undesired modes occur at frequencies very near that of the π mode. However, the frequency separation can be made 10 per cent or more, with considerable improvement in magnetron efficiency, through use of anode straps or a rising-sun type of resonator.

Four methods of strapping are illustrated in Fig. 15. The straps consist of wires of either circular or rectangular cross section connected to alternate segments of the anode block. In single-ring strapping (Fig. 15*C*), all odd-numbered segments are joined on one side of the block and all even-numbered segments are connected at the opposite side. In double-ring strapping (Fig. 15*D*), both inner rings connect to odd-numbered segments and both outer rings join even-numbered segments. The straps may extend beyond the ends of the anode structure as shown in Figs. 15*A* and *B*, or they may be run in shallow slots as in Figs. 15*C* and *D*. Embedding the straps in the block partially isolates the straps from the interaction space and thus minimizes the distortion in the interaction-field pattern caused by the presence of the straps.

The way in which straps influence magnetron operation may be explained in terms of the additional reactive elements they introduce into the resonator system. Because each strap can carry conduction current between the segments joined, the strap has the effect of connecting the two segments through an inductance. Since a displacement current can also flow between a strap and a segment it passes over, each strap is coupled to a segment through a shunt capacitance. In the π mode, each strap joins segments that are at the same voltage, so that only the shunt capacitance is important. This capacitance is effectively in parallel with the equivalent parallel *R-L-C* circuit of the resonator and hence reduces the frequency of the π mode and lowers the impedance level for this mode. For lower modes the inductance effect of the straps becomes important because for these modes the strap ends are at different voltages. The shunt-capacitance effect is simultaneously reduced because the voltage between a strap and the segment beneath it is less than for the π mode. The combined effect of strap inductance and capacitance is to reduce the resonator inductance, to increase its capacitance slightly, with a net result of an increase in the lower order mode frequencies. As a result of strapping, therefore, the resonant frequencies of all modes are shifted in a manner that increases the separation between the π-mode frequency and the frequencies of all other modes.



(A) UNSYMMETRICAL (B) ECHELON



(C) SINGLE RING (D) DOUBLE RING

FIG. 15. Methods of strapping.

The extent to which strapping increases the frequency separation of the modes depends upon the strapping system used. Of the four methods illustrated in Fig. 15, double-ring strapping provides the greatest frequency separation between the π and the next lower mode. Unsymmetrical strapping, on the other hand, yields the least improvement over an unstrapped resonator. Of the remaining two methods, single-ring strapping is the more effective.

Unwanted modes may be further suppressed by introducing an asymmetry into the strapping system. The asymmetry, which may be accomplished by breaking a strap (as in Fig. 15*D*) or by omitting a strap (as in Fig. 15*B*), interrupts current flow in the strap, thereby distorting the patterns of unwanted modes and reducing the efficiency with which energy is transferred from the electron stream to the modes. The amplitude of the oscillations of the unwanted modes is thus reduced. Since the only strap current flowing in the π mode arises from the displacement current between strap and anode segment below, a strap break has very little effect upon the π mode of operation.

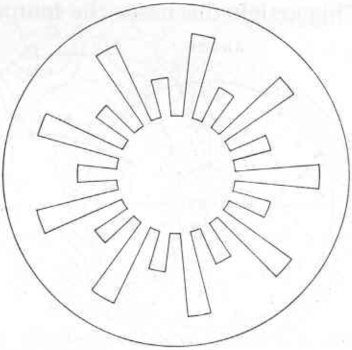


FIG. 16. Rising-sun type of resonator system.

In the absence of strap breaks, degenerate modes may assume any angular position about the resonator axis. Because these modes normally take up a position that yields least coupling to the output circuit, strong oscillations in these modes are possible. The asymmetry resulting from a strap break has the effect of separating degenerate modes into two distinct modes of slightly different frequency. Because the angular positions of the split-mode patterns are determined by the location of the strap breaks, it is possible to locate the output-coupling device so that the split modes are equally loaded. The damping provided by the load then aids in suppressing these modes.

As indicated in Art. 5, strapping is not feasible in 1-cm magnetrons because of the smallness of the anode structure. In the 1-cm region, the desired mode separation is achieved through use of the rising-sun type of resonator, consisting of an equal number of large and small cavities arranged alternately around the anode block (see Fig. 16). The effect of the two sets of resonators is to divide the modes into two groups. As alternate slots are made deeper, the resonant frequencies of modes $n = 1$ through $n = 4$ become less than the frequencies of corresponding modes in the uniform-slot-resonator system. This shift in the mode spectrum