KLYSTRON

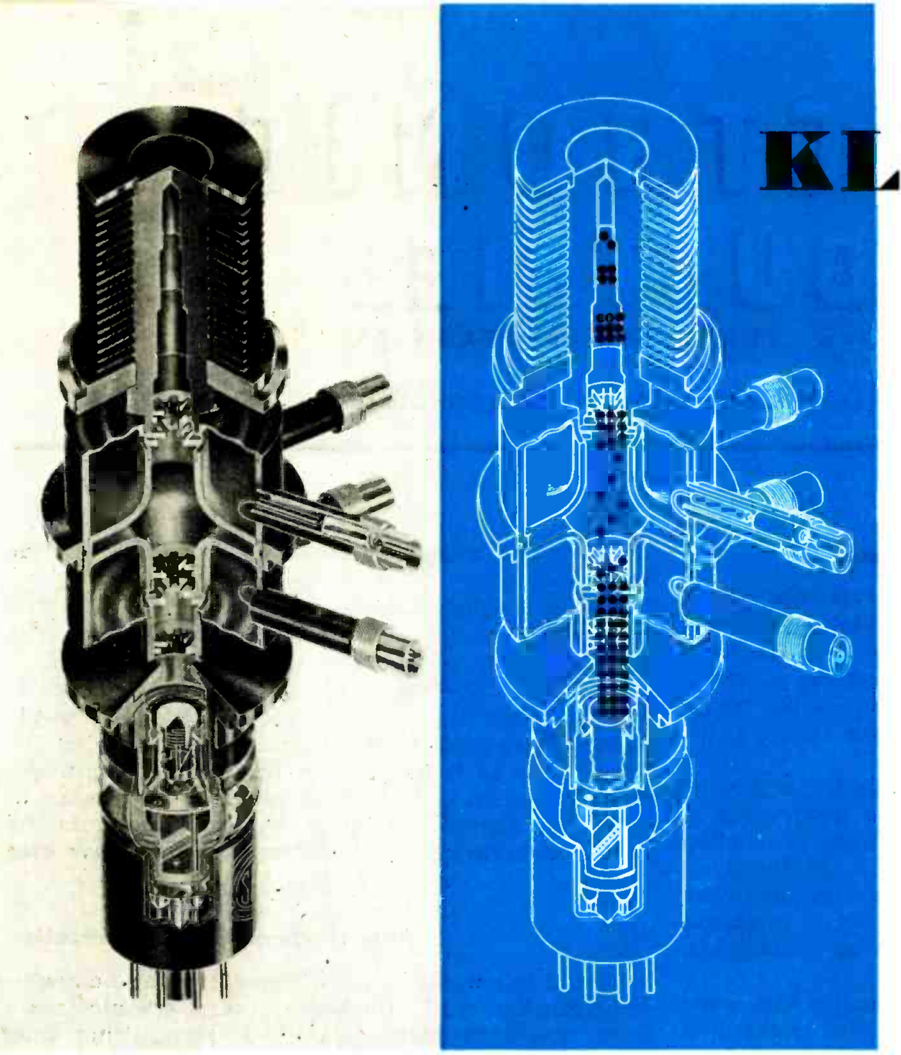

Fig. 1—Sectional view of 410R showing electron gun at bottom, lower (buncher) cavity, upper (catcher) cavity, pickup loops with seals, and heat radiating collector at top. At right, buncher action is shown altering electron velocity. Groups form at catcher and deliver energy

Operating principles, electrical and mechanical details of type 410R Klystron. Performance curves and data

● The generation of voltages at frequencies above 1000 mc/sec. by conventional grid-control tubes is difficult as well as low in efficiency and power output. One of the principal reasons for these conditions is the relationship of the transit time of the electrons from the cathode to the grid in the ordinary tube as compared to the time for one cycle of the frequency being generated.

Thus in a common triode or pentode, with its normal plate voltage, a certain definite time is required for the electrons to make the trip from cathode to the plane of the grid. This time is a fraction of a microsecond. However, at a frequency of 1000 mc. the time for one cycle is 10^{-3} microseconds and in all but special tubes such as the acorn type, etc., electrons cannot reach the plane of the grid in this short space of time and consequently the grid voltage passes through a large portion of its cycle during the time the electron is in flight. Only a few if any get beyond the plane of the grid since when the grid voltage is great enough to allow electrons to proceed toward the plate this voltage will pass through half or more of its cycle and repel the electrons which have not yet reached the grid. In most instances, the transit time must be less than 1/10th the time for one signal cycle for satisfactory operation. Excessive transit time reacts as increased input loading.

There are a number of other limitations to conventional tubes at ultra high frequencies, radiation losses, internal circuit parameters, etc.

In order to develop frequencies much in excess of 1000 mc. it becomes necessary to use a tube in which the transit time need not be limited to a fraction of the time required for one cycle of the frequency to be generated. One solution is velocity modulation of the electron stream from a gun similar to that employed in cathode ray tubes. The basic principle is that of periodically changing the velocity of electrons passing a certain point in a tube and allowing these electrons of different velocities to form bunches by drifting through the required distance. These bunches will form due to the faster electrons catching up with the slower ones at a given point in the tube. They occur once each cycle of the frequency to be generated if they are allowed to travel through the tube for some convenient distance since time is required to form the bunches or groups. Internal forces in the beam cause de-bunching through repulsion but in practical tubes good design holds this to a minimum.

These bunches of electrons can be made to deliver their energy to a resonant circuit of a special type. The groups of electrons, coming as they do at periodic intervals, act in a manner similar to a periodic impulse applied to a pendulum causing it to oscillate at a regular frequency and amplitude.

One group of tubes employing velocity modulation is known as the Klystron.* These tubes are a development of R. H. Varian and S. F. Varian and the Sperry Gyroscope Co., Inc., Brooklyn, N. Y.

A typical model type 410R made by Sperry is shown in the cut-away view Fig. 1. This tube consists of a cup-shaped cathode and internal heater element which is noninductively wound, and a control grid both near the base of the tube. The control grid of the tube is so constructed as to aid in focusing the electrons into a beam. Both of these structures, the cathode and the control grid, are quite similar to those found in cathode ray tubes.

The next electrode in the stream is a "smoother" grid similar in some respects to a screen grid in a cathode ray tube. A pair of grids which are separated approximately 0.030 in. are located a little beyond the smoother grid. These grids are connected to the side walls of a cavity resonator. These resonators, which will be described in more de-

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* Trademark of Sperry Gyroscope Co., Inc.

CHARACTERISTICS

by **WILLIAM E. MOULIC**
Associate Editor, Electronic Industries

tail later, are basically a resonant circuit similar in electrical action to the common parallel coil-capacitor tuned circuit.

These cavities are hollow metal cylinders and in the case of the Klystron shown, are under vacuum with the rest of the tube. The cavity resonator nearest the cathode is commonly called the buncher since it is the action of this tuned circuit and its associated grids to group the electrons of the stream into the required bunches.

Note that the grids in this tube are radial fins similar to spokes of a wheel in which the hub has been removed. This construction permits a more uniform field between the grids and at the same time offers a minimum physical obstruction. The next section of the tube is an evacuated chamber commonly known as the drift space. In this drift space, the electrons whose velocity has been increased by the buncher "catch-up" with those which were slowed down by buncher action.

A second cavity resonator, commonly called a catcher, follows the drift space and is identical (in the tube shown in Fig. 1) to the buncher. The catcher resonator grids are identical in construction to those of the buncher and are spaced by the same amount. Beyond the buncher is a collector electrode, which in the case of the tube shown in Fig. 1, consists of a metal cylinder with heat radiating fins and a series of different

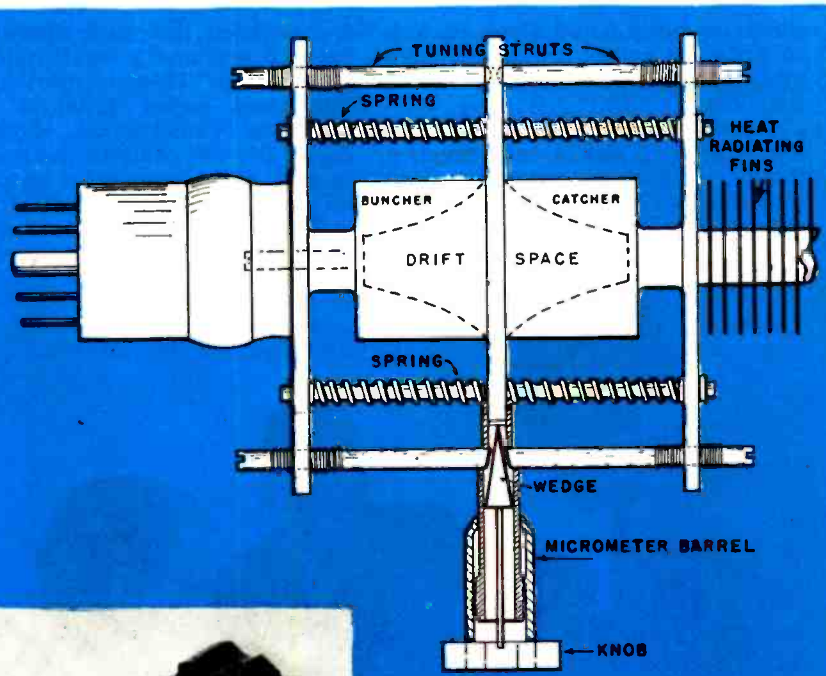

Fig. 3 (Right)—Basic features of cavity tuning mechanism in 410R. Wedge expands one strut only to alter distance between grids

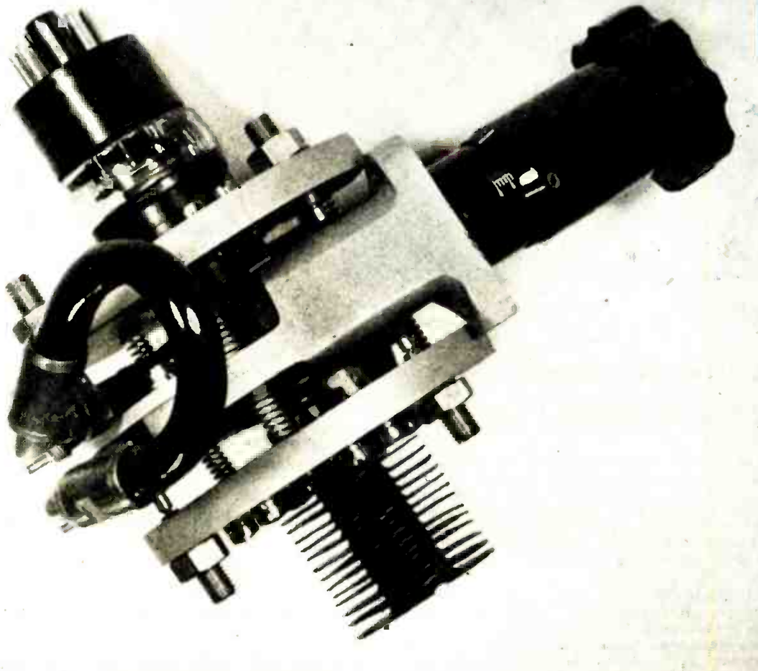

Fig. 2 (Below)—410R Klystron showing tuning knob and coaxial feedback cable. Note springs and struts of tuning mechanism

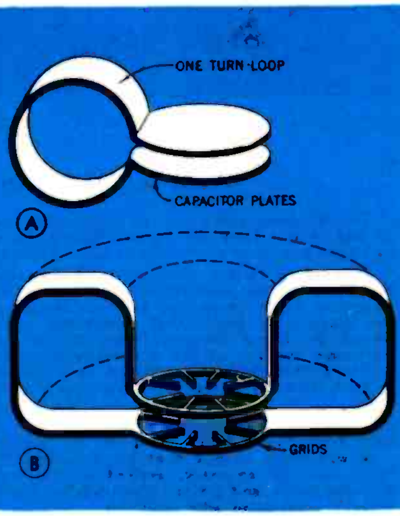

Fig. 4—Simple tank circuit at A has low Q at uhf because of radiation of energy. Increasing number of loops as at B develops into cavity as used in Klystron and other tubes

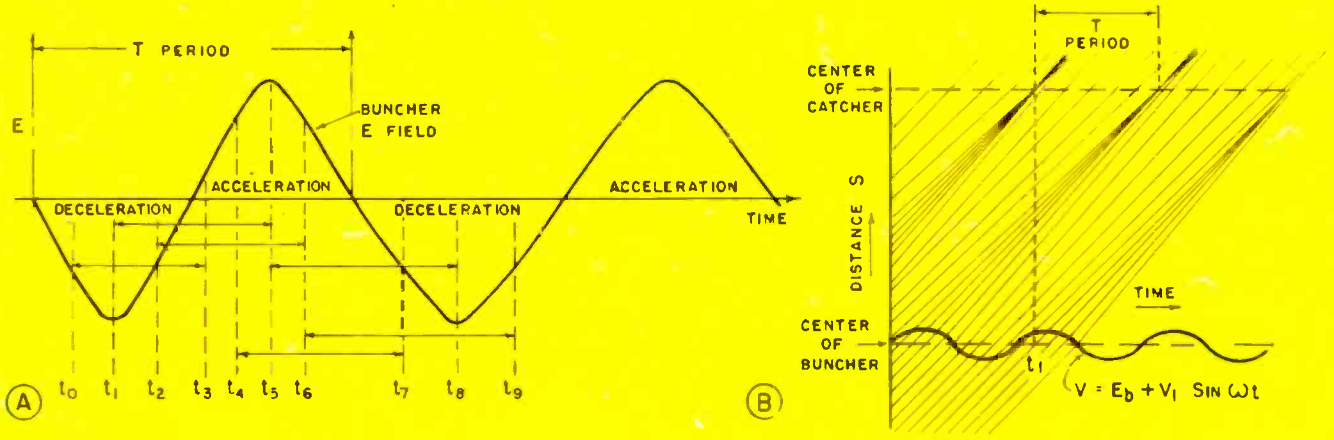

Fig. 5. Effect of buncher field on electron velocity at A and Applegate diagram of bunching at B. Slope represents velocities

diameter holes bored along its axis in order to collect the spent electrons and radiate the heat caused by them.

To take energy from the cavities and also to inject it into them, a number of pickup leads are sealed into the two chambers. They consist of a short section of coaxial transmission line with appropriate vacuum seal and a small half-turn pickup loop. These connections are sometimes called antenna seals.

In the construction shown in Fig. 1, the two cavities, the smoother grid, and the collector anode are all connected together electrically to the positive terminal of the dc power supply. The only insulation in the tube is the small glass ring at the base which insulates the cathode and grid structure from the remainder of the tube.

The ends of the cavities are made flexible by the concentric rib construction. The frequency at which the tube operates is adjustable over a range of several per cent of its fundamental frequency by means of mechanically "stretching" the tube to change the distance between the buncher grids and the catcher grids. In this tube the distance from buncher grid to catcher grid is normally very near one inch.

The tuning mechanism is shown attached to the tube in Fig. 2 and a diagram of the operation is shown in Fig. 3. The frequency of the tube may be altered over a rather wide range by means of the three tuning struts for each cavity. These three struts operate against the center ring midway between the two resonators and stretch the anode end and the cathode end away from the center thus altering the distance between the buncher

RUSSELL H. VARIAN **SIGURD VARIAN** **DR. W. W. HANSEN**

CALIFORNIANS WHO DEVELOPED THE KLYSTRON

The Klystron came out of California; three men were responsible for the final development of the tube. They are Russell Varian, his younger brother Sigurd, and Dr. William W. Hansen, associate professor of Physics at Leland Stanford University.

Subsequent to the conception of the original idea of the Klystron, which occurred to Sigurd Varian while he was Flight Captain for Pan American Airways on the Mexican and Central American flight lanes, the brothers retired to Halcyon, Calif., to work out the basic theory and the preliminary paper work. After the idea had been worked into a practical form, they contacted Dr. David Webster, head of the department of Physics at Stanford, with the hope of obtaining the use of the University laboratories. This was a logical move because it was from Stanford that Russell graduated in 1925 with the Degree of A.B. Doctor Webster consented to take them on as research associates without pay.

It was during this period that the brothers met Doctor Hansen who worked with them in developing the final design based on the "velocity grouping principle." The final model was built from this design by Sigurd. It worked just as expected during the preliminary tests.

It was mere chance that Dr. H. Hugh Willis, vice-president, Sperry Gyroscope Co., and then chief research engineer, arrived at the Oakland airport just as the instrument was ready for demonstration, and Doctor Willis was invited to see the new instrument. That was the beginning of Sperry's association with Klystron.

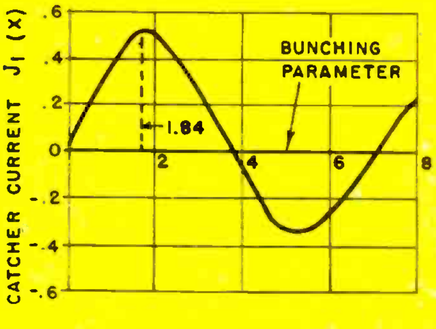

Fig. 6. (Above)—Variation of rf catcher current for bunching parameter X as given by equation 3

Fig. 8. (Right)—Experimental curves of multiple oscillation points for values of $1/\beta$

Fig. 9. (Right center)—Experimental frequency deviation with beam voltage for 410R

Fig. 10. (Far right)—Dial calibration determined experimentally for 410R

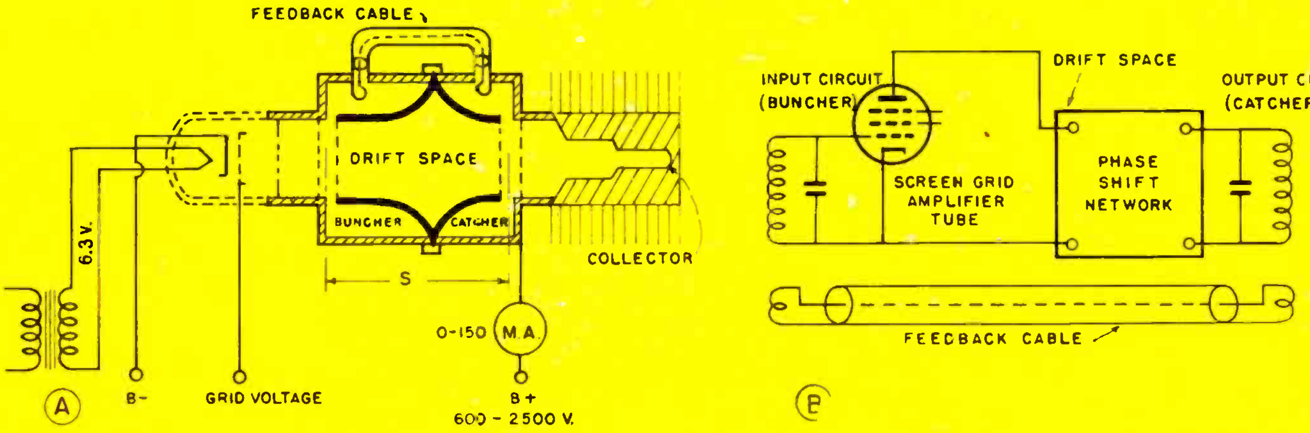

Fig. 7. Klystron tube at A showing bunching distance S and equivalent conventional tube circuit at B. Phase-shift network replaces drift space

and catcher grids. Tension springs are used to keep the end plates bearing against the struts.

A vernier tuning mechanism is employed and the control knob and graduated scale on the 410R are shown in Fig. 2. A micrometer type barrel operates a screw and wedge to expand or contract the length of one of the three tuning struts.

The extension of the analysis of ordinary lumped constant circuits (circuits including inductance, capacitance and resistance), to the ultra-short wavelengths obtained with Klystrons presents a number of difficulties. Consider the single wire loop and capacitor shown in Fig. 4 (A). As the size of the loop is decreased to reduce the wavelength, the losses become tremendous and the loop practically vanishes before the desired wavelength is reached. By adding a number of larger loops in parallel to decrease the inductance; this would lead to the shape shown in Fig. 4 (B) which resembles the resonators actually used in Klystrons.

Cavity resonators, like transmission lines, have more than one resonant frequency. A simple coil and capacitor circuit, in which all dimensions are negligible compared with the wavelength, has only one resonant frequency. A long transmission line has an infinite number of resonant frequencies which occur when the length is an integral number of quarter or half wavelengths, and a single number suffices to specify the order of a harmonic.

In a cavity resonator all three dimensions are in general comparable with a wavelength, and nodes can exist in three different directions. Not only are three numbers now required to specify the order of a certain "harmonic", but the higher resonant frequencies are no longer integral multiples.

It is possible to divide the fields within a cylindrical cavity resonator into two main types: one type has the electric field E parallel to the axis. The second type is a similar family with the electric and magnetic fields interchanged. The relations are analogous to the fields in waveguides (c.f. Slater-Microwave Transmission), but the usual waveguide notation will be replaced in the discussion below by the Bessel function describing the boundary conditions, since this allows convenient computation of the resonant wavelength of a cylindrical cavity. If b is the length of the cavity and a is the radius:

$$\frac{1}{\lambda^2} = \left(\frac{m}{2b}\right)^2 + \left(\frac{k}{2\pi a}\right)^2 \qquad (1)$$

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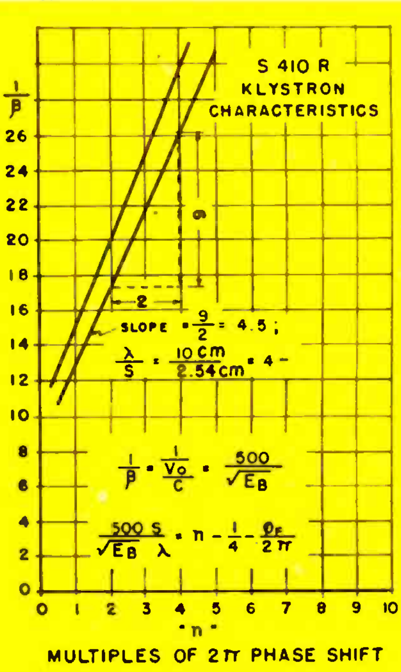

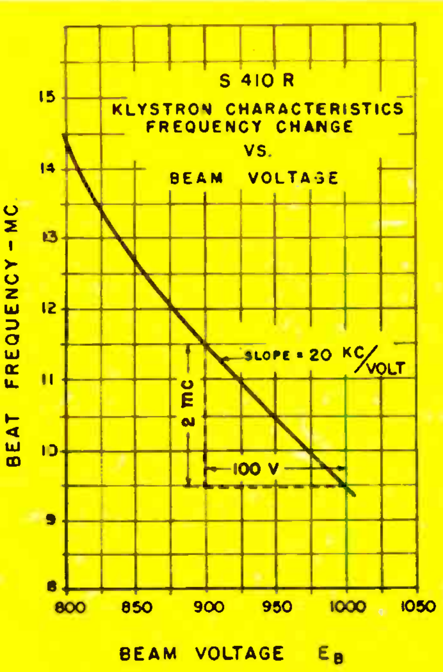

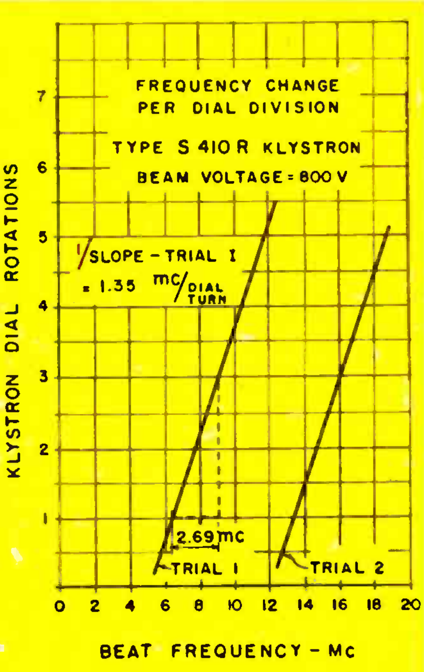

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KLYSTRON CHARACTERISTICS

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for the TM (transverse magnetic) modes where k is defined by:

$$J_n(k) = 0$$
$$n = 0,1,2,3,..$$
$$m = 0,1,2,3,....$$

For the TE (transverse electric) modes the resonant wavelength is determined by Bessel function derivatives, J'n (K')

$$\frac{1}{\lambda^2} = \left(\frac{m'}{2b}\right)^2 + \left(\frac{k'}{2\pi a}\right)^2 \qquad (2)$$

$$J'_n(k') = 0$$
$$n = 0,1,2,3,....$$
$$m' = 1,2,3,...(m' \neq 0)$$

Resonator characteristics

Shape and size obviously determine the resonant wavelength of a cavity resonator. The losses in the inner wall of the metal cavity and the ratio of volume to surface area determines Q, so that in general a shape which provides an increased ratio of the volume to the surface area improves the Q of the cavity. It is also true that the same shape with larger dimensions and longer resonant wavelength has a higher value of Q. A sharp reentrant point in a resonator may increase the current concentration tremendously and greatly reduce the Q.

The electron beam passing the grids of a Klystron resonator also influences Q. Since the space charge between the resonator grids depends on both current and velocity, both the beam current and the acceleration voltage affect the amount that Q is reduced by the presence of an electron beam in a resonator. Secondary electrons, if present, may have a considerable effect on the Q of a resonator.

Losses in a resonator are not only introduced by the resistivity of the conducting material of which it is constructed, but may be introduced by circuits coupled to the resonator and by losses in the load and input coupling loops. Losses in the conducting material are not proportional to the first power of the resistivity of the conductor, since rf resistance depends on the depth of penetration of the current, or the skin depth, as well as the resistivity itself.

Actually, losses in a cavity resonator of nonmagnetic material are proportional to the square root of resistivity. A resonator of brass with a resistivity four times that of copper may have a Q one-half as great if no other losses are

(Continued on page 154)