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PART 5. KLYSTRON AND MAGNETRON

By the Engineering Department, Aerovox Corporation

The limitations of conventional negative-grid oscillators and of the tubes commonly employed in these circuits become very apparent at the microwave frequencies. Tube interelectrode capacitances, lead inductances, and corresponding impedances and resonant frequencies are important characteristics which restrict high-frequency operation of negative-grid oscillators. Most important consideration of all is electron transit time.

VELOCITY MODULATION

This is a process for converting d. c. energy into radio-frequency oscillations by alternately accelerating and retarding the electrons of a beam. In the simplest application of this principle, an electron beam is generated by an electron gun similar to the gun system of an oscilloscope tube. After acceleration, the beam then is caused to pass through suitably biased grids. If the controlling grid is biased negatively, the beam electrons are slowed down in proportion to the bias voltage. Conversely, the electron velocity is increased when the bias is positive. If the bias is alternating, those beam electrons that passed through the grid during the negative portion of the grid voltage cycle will move into the space beyond the grid at a slower speed than those later electrons which pass through during the positive half-cycle. The faster electrons tend to overtake their slower predecessors. This leads to a movement of the electrons in groups or bunches in the space beyond the grid. If a "collector" electrode is placed an appropriate distance from the grid, the electron beam will impinge upon it, delivering energy in periodic pulses corresponding to the bunches, and the pulsations may be conveyed to an external circuit.

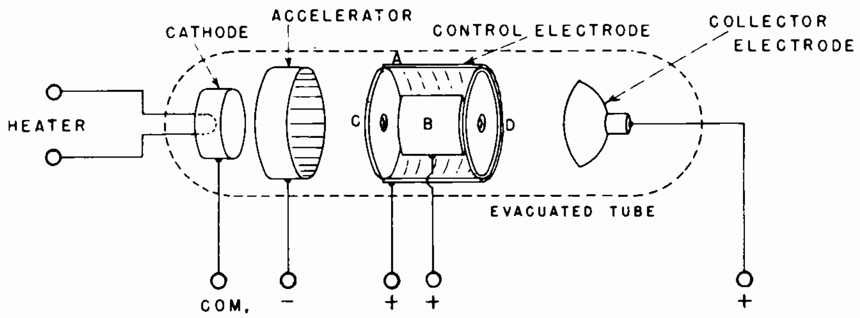
The process of velocity modulation thus is one for converting the relatively smooth flow of electrons in a beam into one of periodically intermittent velocity. One possible method for accomplishing the bunching action consists of establishing a radio-frequency field between two adjacent grids in the path of the beam.

Figure 1 shows the arrangement of electrodes in one rudimentary type of velocity modulation tube. The heater, cathode, and accelerator (focus electrode) comprise the electron gun. This portion of the tube generates the electron beam which travels in the direction of the collector electrode. The cylindrical control electrode consists of two concentric metal cylinders or sleeves, A and B. The external cylinder is provided with end discs, C and D, which have small holes at their centers for the passage of the beam. These holes may be provided with grid meshes. The two cylinders are not connected. Along the axis of the other electrodes, but at some distance beyond the end of the control electrode, is placed the collector electrode.

THE KLYSTRON

The klystron is a special velocity modulation tube making use of cavity resonators or *rhumbatrons*. One form of klystron is illustrated by Figure 2.

The tube shown contains (1) an electron gun, composed of heater, cathode, and focusing ring (sometimes referred to as the control grid); (2) a first re-entrant type cavity resonator, called a "buncher," with grids inserted into its two opposite walls; (3) a second re-entrant type cavity resonator, called a "catcher", with grids inserted also into its two oppo-



VELOCITY MODULATION TUBE

FIG. 1

site walls; and (4) a collector electrode, also called a deflector. The two cavities are butted together with a so-called *drift space* between them.

In Figure 2, both buncher and catcher rhumbatrons are shown in cross section. Figure 3-A is a radial section of one of these cavities drawn to show the re-entrant shape and the spoke-like construction of the radial grids. 3-B is a bottom view of the same cavity to show the complete grid structure. Both cavities are modified cylinders of metal.

Operation of the klystron is explained in the following manner: The beam from the electron gun is directed through the two grids of the buncher cavity, the drift space, and the two grids of the catcher cavity, and in the absence of any electrical action in the cavities would pass with comparative freedom to the collector electrode. If, instead, the buncher cavity is excited by means of radio-frequency energy (applied, for example, through the coupling loop shown entering the buncher in Figure 2), the beam will be acted upon by the parallel electric field which then will be present between the two buncher grids. The beam velocity will be stepped up by positive half-cycles and cut down by negative half-cycles. The average number of electrons in the beam will remain constant, however.

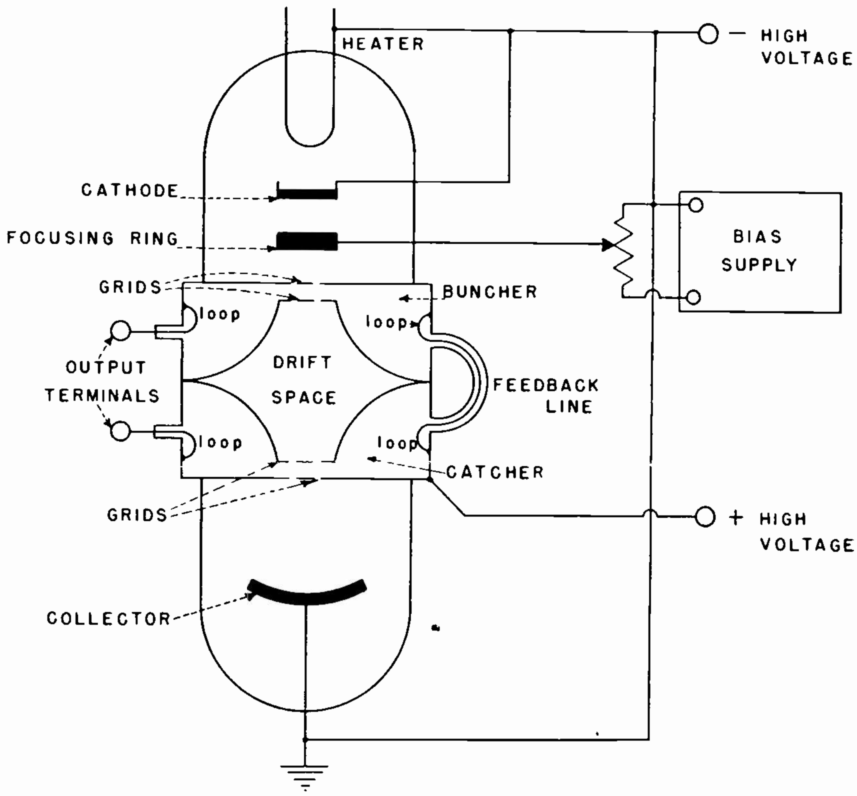
There is no charge in the drift space. Fast-moving electrons which were accelerated by the positive field accordingly will overtake the slower electrons which entered this space after being decelerated by the negative field. This action produces electron bunching in the drift space.

As the electron beam completes its passage through the drift space, the bunched groups pass through the two grids of the catcher cavity, delivering some of their energy to these grids in corresponding pulses. The field which is set up is periodic and it establishes oscillations of corresponding frequency within the catcher cavity. Some of this oscillating energy may be coupled out of the catcher by means of a coupling loop, such as the one shown in Figure 2, inserted into the chamber through a concentric line. For maximum efficiency, the position of the catcher cavity coincides with the position of maximum bunching action.

Since the amount of r. f. energy required to excite the buncher is small compared to that which may be extracted from the catcher, the klystron tube is an amplifier. If a short feedback loop, consisting of a concentric line terminated by coupling loops in buncher and catcher cavities, as shown in Figure 2, is connected between the two cavities, a self-excited klystron oscillator is obtained.

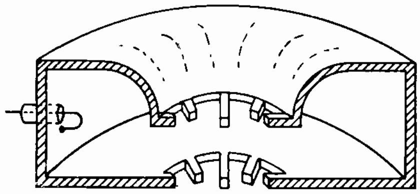
Klystron tubes have been produced for microwave power outputs up to several hundred watts. Oscillator and amplifier efficiencies are somewhat less than the theoretical 58 percent given in the literature. When employed as an oscillator, the klystron has high harmonic output. In addition to transmitter use, klystrons are employed also as detectors and oscillators in microwave receivers.

The resonant frequency of a klystron is governed largely by the shape and dimensions of the cavities, and is influenced to some extent by elec-



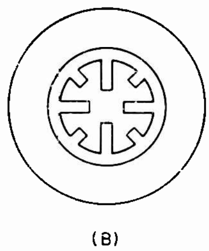
KLYSTRON TUBE

FIG. 2



(A)

KLYSTRON CAVITY

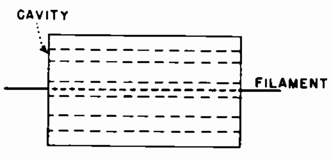


(B)

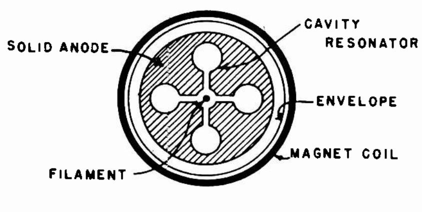
BOTTOM OF CAVITY, SHOWING GRID

FIG. 3

trode voltages. Tuning is possible over a narrow range by altering the cavity dimensions. This usually is accomplished by altering one or more of the cavity dimensions. One tunable type of klystron employs pressure applied to the cavities by means of a mechanical system operated by a threaded shaft. The effect of the pressure is to reduce the separation between the grids of both cavities. In this way, the frequency may be varied a few percent from the fundamental.



(A)



(B)

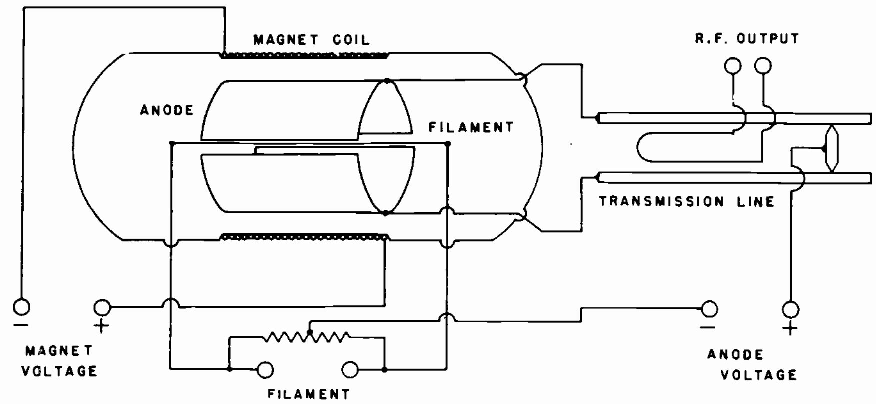
FIG. 5

THE MAGNETRON

The magnetron is a special type of diode tube having a concentric anode and cathode and an external electromagnet which sets up lines of force parallel to the axis of the electrodes. Under proper conditions of operation, the magnetron generates oscillations at extremely short wavelengths.

Operation of the magnetron is explained in the following manner: Under the influence of the strong magnetic field set up by the electromagnet coil wound outside the tube envelope, electrons no longer pass in straight lines from filament, or cathode, to anode, but follow curved paths. When the strength of the magnetic field has been increased to a proper level with respect to the positive anode voltage, the paths become circular, or very nearly so, and the electrons turn back and bombard the cathode without quite reaching the plate. The electrons moving in these curved paths set up super-high-frequency oscillations. The oscillation frequency is determined by the velocity of the electrons as they move around their paths. Extremely high frequencies have been generated in this manner by employing close-spaced electrodes, high anode voltage, and strong magnetic field.

Figure 4 shows the circuit of a simple, split-anode magnetron. The two sections of the anode are halves of a single cylinder mounted coaxially with respect to the straight filament or cathode. Each is connected to one bar or tube of a high-Q transmission-line tank circuit. Electrons leaving the cathode describe spirals, moving close to one anode and finally striking the opposite one. A fractional-turn hairpin coil, mounted close to the bars of the transmission line, serves to couple microwave energy out of the circuit. In instances where it has been feasible to employ lumped constants, variable capacitors of special design and high-Q coils have been used instead of the transmission-line tank shown in Figure 4.



SPLIT ANODE MAGNETRON OSCILLATOR

FIG. 4

For maximum tuned circuit efficiency, cavity resonators have replaced other forms of tank circuits in microwave magnetron circuits. It has been possible to build these resonators right into the tubes. Figure 5 shows one such arrangement. Here, the anode is a solid metal block into which has been cut a lengthwise central channel through which the filament or cathode is run, and four cavity resonator chambers, each of which communicates with the filament channel through a narrow slot. Figure 5-B is an end view of this ingenious anode-cavity structure.

This latter type of tube is known as a *multi-segment* magnetron. While four cavities are shown in Figure 5, more than this number have been employed in some microwave magnetrons designed for radar. In some other tubes, only one cavity is employed. Pickup loops, of the same type described earlier in this paper and in Part 4, may be sealed into the magnetron cavities. The cavities also may be made to open into wave guides for the purpose of coupling energy out.

Magnetrons have made it possible to obtain hundreds of kilowatts of power at a few centimeters wavelength. Additionally, smaller tubes of this type have been designed specifically for use as local oscillators in super-high-frequency receivers.

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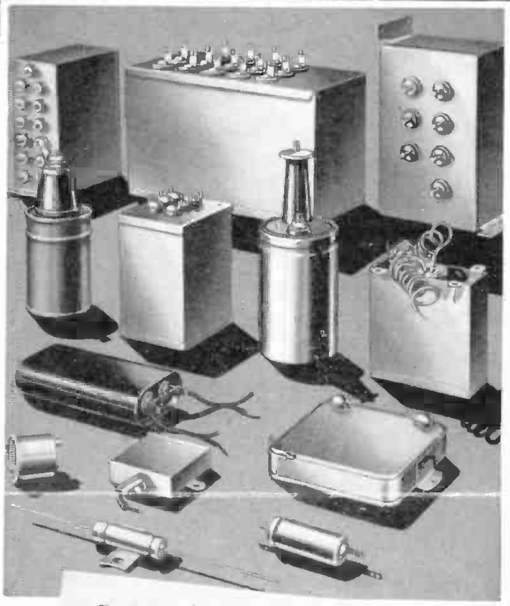

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