CHAPTER 23

EXTERNALLY TUNED MAGNETRON OSCILLATORS

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In the types of magnetron oscillators that have been discussed in Chaps. 20, 21, and 22, the tank circuit forms an integral part of the tube. Tuning over wide frequency ranges is therefore inherently difficult. Wide tuning range may be achieved by the use of an external tank circuit in conjunction with a split-anode magnetron tube. Oscillators of this type will be discussed in the present chapter.

23-1. Externally Tuned Magnetron Oscillator Circuits.—In its simplest form the split-anode magnetron consists of a straight-wire

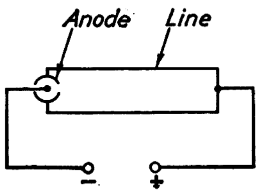

FIG. 23-1.—Basic circuit of parallel-line magnetron oscillator.

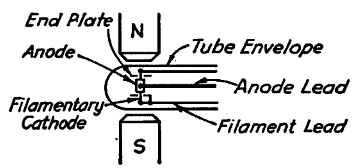

FIG. 23-2.—Method of mounting split-anode magnetron in magnetic field.

cathode surrounded by a coaxial cylindrical electrode, which is split longitudinally to form two semicylindrical anodes. The tank circuit, which is usually a parallel-line resonator one or more quarter wavelengths long, is connected to the anodes, as shown in Fig. 23-1. The tube is mounted between the pole pieces of a magnet, in such a manner that the anode-cathode region is in a magnetic field that is parallel to the axis and of essentially uniform density, as illustrated in Fig. 23-2. Direct voltage is applied between the cathode and the anodes.

Electronically, the behavior of the split-anode magnetrons discussed in this chapter appears to be in most respects similar to that of multicavity magnetrons (see Sec. 20-5). Except at frequencies considerably lower than those at which the tubes are normally operated, it does not seem to depend upon static negative resistance,[1] nor is it apparently

[1] BRAINERD *et al.*, "Ultra-high-frequency Techniques," Sec. 10-11, D. Van Nostrand Company, Inc., New York, 1942.

related to the radial transit time of electrons in the cathode-anode space.[1]

The tank circuit of an externally tuned magnetron oscillator may consist of either a lumped-constant parallel *LC* circuit shunted between the anodes, or a parallel-line resonator. In practice, however, the lumped-constant oscillator usually tends to oscillate at a frequency much higher than that of the *LC* circuit. The reason for this phenomenon is that lumped capacitance serves as an effective short circuit at frequencies considerably higher than the resonant frequency of the lumped-constant tank. In conjunction with the anode leads, therefore, it provides a quarter-wave parallel-line resonator that may act as an alternative tank circuit. Which type of oscillation takes place depends upon the relative values of loaded *Q* of the two tank circuits. The remainder of this chapter will be devoted to parallel-line oscillators.

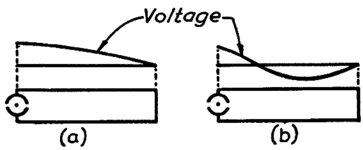

FIG. 23-3.—Voltage distribution in parallel-line oscillator in the $\lambda/4$ and $3\lambda/4$ modes of oscillation.

Oscillations in parallel-line oscillators may take place at any resonant frequency of the resonator, provided that the electrodes are at or near a voltage antinode of the resonator. In Fig. 23-1, the anode segments are connected to the open end of a parallel-wire line short-circuited at the other end. When unloaded, this circuit normally oscillates at the fundamental resonant frequency of the line. At this frequency of oscillation the anodes are at a voltage antinode, and there is a single voltage node, which is at the short-circuited end of the line. Because the length of the line is approximately ¼ wavelength, this mode of oscillation is called the $\lambda/4$ mode. The voltage distribution in the $\lambda/4$ mode of oscillation is shown in Fig. 23-3*a*. The next higher mode of oscillation is one for which the electrical length of the line is ¾ wavelength and there is a second voltage node between the anodes and the short-circuited end of the line, as shown in Fig. 23-3*b*. In general, oscillation is possible at any frequency for which the electrical length of the line is $(2n - 1)\lambda/4$, where n is any integer and λ is the line wavelength corresponding to the frequency. Because the lumped capacitance of the anodes is across the open end of the line, the physical length of the line is somewhat less than $(2n - 1)\lambda/4$. Factors that determine the mode in which oscillation takes place will be discussed in Sec. 23-7.

The circuit of Fig. 23-1 is ordinarily tuned by means of an adjustable short-circuiting bar, which may be moved along the line. The highest frequency of oscillation is obtained when the short-circuiting

[1] BRAINERD *et al.*, *op. cit.*, Sec. 10-12.

bar is adjacent to the tube envelope. Design considerations limit the extent to which the length o the anode leads with n the tube may be reduced, and in tubes designed to deliver an output of 150 watts or more, the maximum frequency obtainable in the $\lambda/4$ mode with the circuit of Fig. 23–1 is of the order of 400 Mc.

Higher frequency may be obtained by using within the tube envelope an additional short-circuiting loop, called a *back-loop*, as shown in Fig. 23–4. The higher frequency results both because of the shorter length of line and because the interelectrode capacitance is in effect divided between the two halves of the line. As in the circuit of Fig. 23–1, tuning is accomplished by means of a movable short-circuiting bridge on the external portion of the line. Oscillation may occur at any frequency for which the electrical length of the line is $n\lambda/2$, where n is an integer and λ is the wave-length. The anodes should, however, preferably be at or near a voltage antinode. An unloaded, or lightly loaded, symmetrical circuit normally oscillates in the $\lambda/2$ mode.

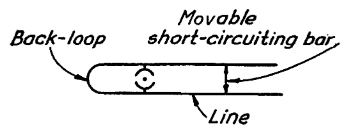

FIG. 23–4.—Double-ended parallel-line oscillator.

23–2. Types of Tube.—Figure 23–5*a* shows the structure of a single-ended magnetron designed for use in the single-ended circuit of Fig. 23–1. The anodes of this tube are cooled by water fed through the lines, as shown in Fig. 23–7. In order to afford circulation, the water is brought in through a small tube inside each line and flows out through the line.

The highest frequency at which useful output may be obtained with the 5J30 tube shown in Fig. 23–5*a* is approximately 385 Mc. The lowest usable frequency of oscillation is determined by tube failure resulting from electron bombardment of the glass in the vicinity of the anode seals. Electrons that escape from the interaction space through the anode gaps spiral around the anode leads, moving toward the seals. The direction of motion is, however, reversed between half cycles. At high frequency the length of a half period is insufficient to enable electrons to escape from the interaction space and reach the seals. As the frequency is reduced, a value is reached at which sufficient bombardment of the glass occurs to result in strains in the glass and rapid failure. Tube failure from this cause has been eliminated in recent tube models by the use of improved shielding baffles at the gaps between the anode segments and of electrically floating shields on the anode leads near the seals (see Fig. 23–5*a*).

Aside from tube failure resulting from electron bombardment of the glass, the lower frequency limit of oscillation appears to be determined by the length of line that can be conveniently used. The physical length of the line at a given frequency can be reduced by the use of lumped capacitance across the line at the anode terminals, but such capacitance is likely to result in operation in a higher mode, since the capacitance provides a low-impedance shunt across the line and thus tends to produce a voltage node at that point. The amount of capacitance that can be used is therefore limited.

Figure 23–5*b* shows the structure of the 5J29, a tube with an internal back-loop designed for the circuit of Fig. 23–4. Cooling of such a tube is simplified by the fact that the back-loop makes it possible to carry water in through one line and out through the other. The maximum frequency of oscillation of the 5J29 tube is approximately 800 Mc, although power cannot be coupled out efficiently above about 770 Mc.

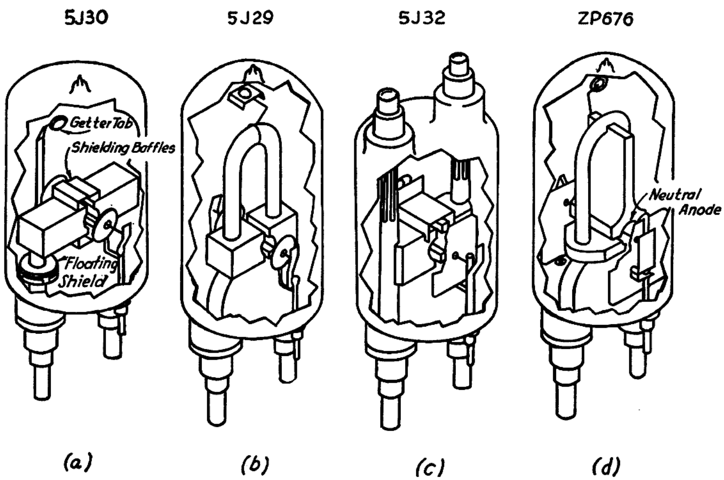

FIG. 23–5.—Typical glass split-anode magnetrons.

In order that a high upper frequency limit may be attained, the back-loop must be made short. It is evident, therefore, that only when the movable external short-circuiting bar is near the anode terminals of the tube will the anodes be near the mid-point of the line. As the frequency is reduced by lengthening the external line, the position of the anodes departs more and more from that of the voltage antinode. Finally, a position is reached for which the anodes are in a more favorable position in the λ mode than in the $\lambda/2$ mode of oscillation. Operation therefore jumps abruptly to the λ mode, with a corresponding increase of frequency. Further lengthening of the line again causes reduction of frequency until conditions are more favorable to the $3\lambda/2$ mode than to the λ mode. The frequency then again jumps to approximately the same value as in the preceding jump. It is apparent that this phenomenon *limits the frequency range* at the low-frequency end.

Mode jumping of the type just discussed can be prevented by the use of the double-ended tube shown in Fig. 23–5*c*. With this tube both sections of the line may be adjusted in length and the anodes thus kept near the voltage antinode at the center of the line. This tube may also be used in a single-ended line. In single-ended-line operation, a capacitor may be shunted across the "back" terminals (those to which the line is not connected). Lower frequencies may thus be obtained without the tendency toward mode jumping that is observed when the capacitor is connected between the line terminals of the anodes.

Another type of tube is the *neutral-anode tube* or *neutrode* illustrated in Figs. 23–5*d* and 20–2. In this tube the anode is divided into three segments, one of which connects to the mid-point of the internal loop. The latter segment covers 180 deg or more of the total anode circumference, and each of the others covers 90 deg or less. Since the mid-point of the loop is a voltage node, the r-f potential of the large anode is neutral relative to the other two. The electronic behavior of the tube resembles that of a multicavity magnetron even more closely than does the two-anode type. Operation appears to be more stable, and a higher frequency limit is obtained than in the two-anode type. The neutrode is, however, more adversely affected by unbalanced loading (see Sec. 23–6), since unbalanced loading displaces the voltage node from the mid-point of the internal loop.

23–3. Performance.—Outputs in excess of 1 kw at efficiencies ranging up to 70 per cent have been obtained with tubes of the type shown in Fig. 23–5 and tubes of similar structure. A production model of a transmitter using interchangeable 5J29 and 5J30 tubes to cover the frequency range from 150 to 585 Mc gives a power output in excess of 180 watts in the range from 150 to 700 Mc. The output falls approximately linearly to 50 watts as the frequency is increased from 700 Mc to 785 Mc. Figure 23–6 shows curves of power output and efficiency of an oscillator using a ZP599 tube. Operating data for 10 types of split-anode magnetrons are listed in Table 23–1.

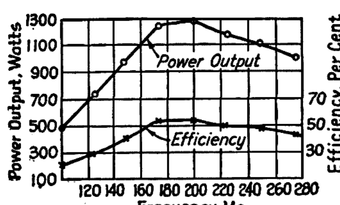

FIG. 23–6.—Curves of power output and efficiency of a ZP599 magnetron used in a single-dial parallel-line oscillator.

In order to prevent undesirable radiation from the tube and the lines, the system must be shielded. A satisfactory type of shielded oscillator is shown in Fig. 23–7.

Typical curves of direct anode voltage as a function of direct anode current at fixed filament current and wavelength at three values of magnetic flux are shown in Fig. 23–8*a*. Throughout the ranges in which the curves are dotted, the oscillation is unstable (see Sec. 23–10). Figure 23–8*b* shows the manner in which the form of the current-voltage curves is affected by filament current. Reduction of frequency affects the form of the anode current-voltage curves at low values of anode current in a similar manner to reduction of filament current. The small slope of the current-voltage curves at low filament current is in part the result of *back-heating*, which is the heating of the cathode by electrons that return to the cathode with increased kinetic energy.

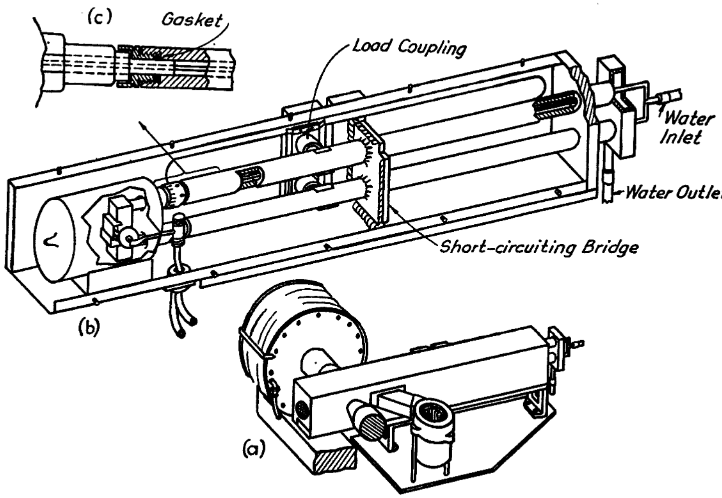

FIG. 23–7.—Structure of a practical parallel-line split-anode magnetron oscillator.

As the anode voltage is increased from a low value, very little anode current flows until the voltage reaches the value corresponding to the voltage intercept of the anode current-voltage curve. Because of the reduction of voltage with increase of current at low values of anode current, particularly at low frequency, the current then jumps abruptly to a higher value, which depends upon the resistance of the power supply and the shape of the current-voltage curve. If the dotted portion of the curve covers a considerable range of anode voltage, if the slope of the curve at higher currents is low, and if the impedance of the power supply is small, the anode current may jump to such a high value as to result in damage to the tube. For this reason it is usually necessary to provide some means of limiting the anode current.

The anode current may be stabilized by (1) the use of an anode power supply having high internal resistance; (2) the use of a constant-current network in the a-c line of the power supply; (3) the use of a constant-direct-current device, such as a pentode, in series with the anode power supply; (4) the use of the direct anode current to excite the electromagnet that supplies the magnetic flux; and (5) the automatic reduction of filament current with increase of anode current. In the fourth method

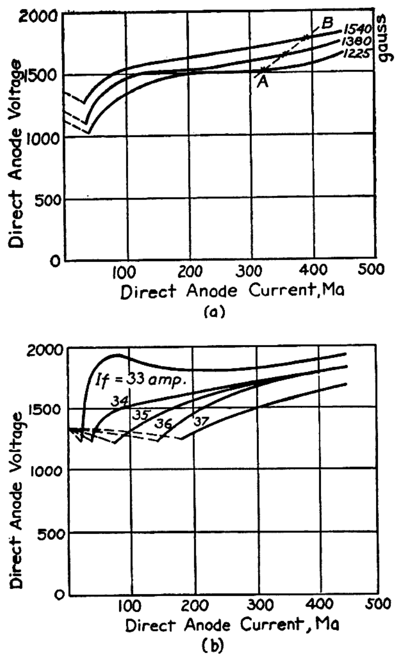

FIG. 23-8.—Anode current-voltage curves of a 5J30 magnetron at a frequency of 250 Mc: (*a*) at a filament current of 34 amp and (*b*) at a flux density of 1540 gauss.

the effect of making the magnetic flux proportional to the anode current is to increase the slope of the anode current-voltage characteristic. Thus, if the electromagnet is designed to produce a flux density of 1540 gauss at an anode current of 400 ma, flux densities of 1380 and 1225 gauss will be obtained at approximately 358 and 318 ma, respectively. The resultant curve is shown by the dashed line *A-B* in Fig. 23-8*a*. In the fifth system, the anode current is limited by limiting the cathode emission. This method is useful in partly compensating for the effect of back-heating, but will obviously fail if the back-heating is more than sufficient to supply the necessary emission. In some high-power tubes the back-heating is great enough so that the filament heating current may be turned off when the tube is oscillating.

Because of the extreme complexity of the problem, no complete theoretical analysis of performance has so far been made. A number of useful approximate relations have been derived, however. Slater has shown that oscillation cannot take place unless the magnetic flux density exceeds a minimum value which depends upon the number of anode gaps and the wavelength. For a two-segment split-anode magnetron the minimum required flux density is given by the relation

$$\lambda \mathcal{B} > 31{,}800 \tag{23–1}$$

in which λ is the wavelength and $\mathcal{B}$ the flux density.

Hartree has shown that oscillation cannot start spontaneously unless the anode voltage exceeds a minimum value. For a two-segment split-anode magnetron the minimum voltage is given by the equation

$$2\frac{e}{m}\left(\frac{\lambda}{2\pi c}\right)^2 \frac{E_b}{r_a^2} = \frac{e}{m}\frac{\lambda}{2\pi c}\mathcal{B}\left[1 - \left(\frac{r_c}{r_a}\right)^2\right] - 1 \tag{23–2}$$

where E_b is the anode voltage; $\mathcal{B}$ the flux density in gauss; λ the wavelength in centimeters; r_c and r_a the cathode and anode radii, respectively, in centimeters; c the velocity of light in centimeters per second; and e and m the charge and mass, respectively, of an electron.

The voltage at which most efficient operation should be expected has been derived by Slater. For a two-segment split-anode magnetron the relation for best operation is

$$r_a = 0.0345\sqrt{\frac{\lambda E_b}{\mathcal{B} - \frac{10{,}600}{\lambda}}} \tag{23–3}$$

In the derivation of Eq. (23–3) the assumption was made that the ratio of the anode radius to the cathode radius has a theoretical optimum value.

It has also been shown theoretically that oscillation should cease when the anode current exceeds a certain maximum value. This phenomenon is observed experimentally.

23–4. Tube Life.—At the time of writing, the tube life of this series of magnetrons has not been long. Thirty hours represents a typical life expectancy, and many tubes fail much earlier.[1] Tube life is greatly shortened by no-load operation and by nonuniform cooling of the envelope. Unless the filament is destroyed by a rapid increase of anode current and resulting back-heating, the tubes invariably fail by cracking as the result of strains set up in the glass. A contributing factor to

[1] Satisfactory tube life can be achieved by the use of a cylindrical shields surrounding the electrode structure.

failure appears to be the tungsten that is deposited on the inside of the envelope. It is possible that this coating causes cxcessive losses and localized heating of the glass. In order to conserve tube life, the filament should be operated at as low a temperature as is consistent with required power output and with ease of starting of oscillation.

Not only must the anodes of split-anode magnetrons be water-cooled, but the filament leads and the entire envelope must be cooled by air. It is important to cool the envelope as uniformly as possible. In order to ensure proper circulation of water within the anodes of tubes not having an internal loop, the inner tubes that carry the water into the anodes must extend as far into the anodes as possible. If this precaution is not observed, boiling may take place within the anodes.

23-5. Modulation.—Figure 23-9 shows a circuit that has been found satisfactory in modulating split-anode magnetrons. Anode-current modulation is produced by varying the grid voltage, and hence the plate current, of the series pentodes. The pentodes serve the additional function of stabilizing the anode current, as discussed in Sec. 23-3. The peaking coil L partly compensates for the stray capacitance of the modulating circuit, which would otherwise affect the response adversely at high modulation frequencies. The effective load resistance of the modulator tubes is approximately equal to the average slope of the anode voltage-current curve of the magnetron in the operating range. From the point of view of fidelity, the output of this type of modulated oscillator is not very satisfactory, since the amplitude of oscillation does not in general vary linearly with anode current. Moreover, amplitude modulation is accompanied by appreciable frequency modulation.

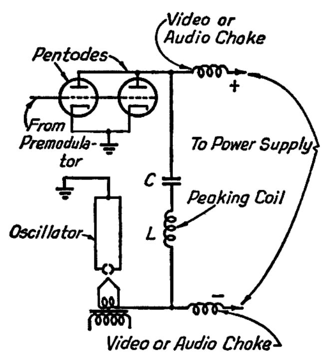

FIG. 23-9.—Amplitude-modulation circuit for split-anode magnetron oscillator.

If the frequency of oscillation is increased at constant anode current and flux density, it is found that the anode voltage rises. In order to make possible the maintenance of the correct operating voltage of the series pentodes, therefore, the power supply must be provided with means for varying the anode supply voltage.

The attainable band width increases with the tightness of load coupling, because of the reduced value of Q.

23-6. Load Coupling.[1]—The simplest method of coupling out power from a parallel-wire magnetron oscillator is by direct connection to one

[1] See also Chap. 16.

side of the line near the movable short-circuiting bridge, as shown in Fig. 16–10*a*. The tap connects to the center conductor of a coaxial cable, the outer conductor of which is connected to the shield surrounding the parallel-wire resonator. A disadvantage of this type of coupling is that it unbalances the oscillatory circuit with respect to ground and thus tends to reduce the efficiency of operation. For normal requirements, however, this effect is not serious, provided that both the outer conductor of the output line and the short-circuiting bar are solidly grounded to the shield by good low-impedance connections.

Theoretically, in order to achieve single-dial tuning with optimum coupling over the entire frequency range of the oscillator, the mechanical coupling mechanism between the short-circuiting bar and the load tap should be such that the distance between the bar and the tap is automatically reduced as the frequency is increased. In practice, however, it is found that this refinement is not justified, since the load is seldom perfectly matched and the oscillator is, moreover, rather tolerant of mismatch. The effects of lead inductances and other frequency-sensitive portions of the circuit must also be considered. By careful attention to details, it is possible to achieve a condition in which the optimum distance from the short-circuiting bar to the load tap is approximately constant when the load is matched. The oscillator of Fig. 23–7 employs this type of output coupling and has two controls. The frequency control moves both the short-circuiting bar and the coupling tap; the coupling control moves only the coupling tap. With a matched load, this oscillator is capable of operating over a range of 150 or 200 Mc with single-dial control with only a slight reduction of output and efficiency.

The unbalancing resulting from the use of a single coupling tap can be avoided by tapping both lines and connecting to the output cable by means of a balun (see Secs. 3–13 to 3–16). The limitations and complications introduced by this arrangement may, however, outweigh its advantage.

Figure 16–12*a* shows a system of coupling that is advantageous when operation is desired at the highest possible frequency. The load impedance is transformed by means of matching networks to a very low value and is in effect inserted in series between one side of the resonator line and the short-circuiting bar. Since no space is required ahead of the bar for coupling purposes, useful power may be obtained with the bar right at the tube seals. This method of coupling has the added advantage that it does not require separate coupling adjustments.

Another method that avoids the need of a separate coupling adjustment is to couple the load to the oscillator by means of a second parallel-wire line which is close to the oscillator lines, and the length of which is adjusted simultaneously with that of the oscillator lines, as shown in

Fig. 16-6*a*. By comparatively small adjustments in the relative positions of the two short-circuiting bridges, the tracking can be made sufficiently good over the entire frequency range so that a single tuning control suffices. Figure 23-6 shows curves of power output and efficiency of a single-control oscillator using this type of coupling.

23-7. Mode Jumping.—Figure 23-10 shows typical experimentally determined curves of minimum ratio of anode voltage to flux density at which oscillation starts, plotted as a function of frequency. Curves of this type vary with tube structure and with flux density [see Eq. (23-2)] and to some extent with load. After oscillation starts, operation is possible over a range of $E_b/\mathcal{B}$ that may in general extend on either side

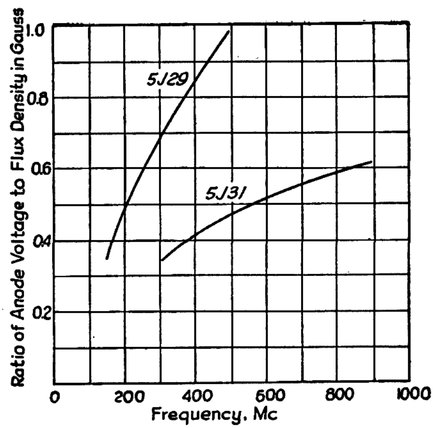

FIG. 23-10.—Minimum ratio of anode voltage to flux density for oscillation of type 5J29 and 5J31 tubes.

of the starting value. The curves shown in Fig. 23-10 were plotted from data obtained in $\lambda/4$, $3\lambda/4$, and $5\lambda/4$ operation and are, therefore, applicable to at least these three modes.

From a curve of the type shown in Fig. 23-10, it is possible to determine in which modes oscillation is possible. Suppose, for instance, that the frequency of the resonant line used with a type 5J29 tube is 150 Mc in the $\lambda/4$ mode. The frequency in the $3\lambda/4$ mode is then approximately 450 Mc. Oscillation is possible in the $\lambda/4$ mode if $E_b/\mathcal{B}$ exceeds 0.35. If $E_b/\mathcal{B}$ exceeds 0.92, oscillation may take place in either the $\lambda/4$ mode at 150 Mc or in the $3\lambda/4$ mode at 450 Mc. If the loaded Q in the two modes is the same, oscillation will normally occur in the $\lambda/4$ mode, since $E_b/\mathcal{B}$ exceeds the value required for the $\lambda/4$ mode by a much greater amount than it does the value required for the $3\lambda/4$ mode. This is merely another way of saying that at the lower frequency the conditions are more favorable to the transfer of energy to the resonator from the source of direct voltage by electrons in the anode-cathode space. Any oscillator capable of oscillating in more than one mode will, however, tend to oscillate in the mode in which its loaded Q is highest if other operating parameters are such as to allow oscillation in that mode. In effect, the oscillator always tries to shed its load if that is possible. If the load is coupled to a parallel-line magnetron oscillator at a point on the line at which a voltage node exists in a higher mode, the loaded Q may be greater in the higher mode than in the fundamental mode. Hence, as the load is gradually increased, a value is reached at which the oscillation will jump to the higher mode if $E_b/\mathcal{B}$ is sufficiently great to support oscillation. Such an abrupt change from one mode to another is called *mode jumping.*

Mode jumping may also be influenced by the facts that the flux density required to sustain oscillation increases with frequency [see Eq. (23–1)] and that there is a maximum value of anode current at which oscillation is possible. Under operating conditions normally used, however, the ratio $E_b/\mathcal{B}$, rather than the values of flux density and anode current, determines whether oscillation can jump to a higher mode.

Mode jumping may take place at constant load if the oscillator is modulated. If the load and the operating value of $E_b/\mathcal{B}$ are such as to cause operation in the $3\lambda/4$ or a higher mode when the oscillator is loaded, modulation may cause $E_b/\mathcal{B}$ to fall to a value so low that oscillation is not possible in this mode, or that efficiency of electronic energy transfer is so low that operation shifts to a lower mode in spite of its lower loaded Q. Mode jumping as the result of modulation is obviously highly undesirable in ordinary applications of a modulated oscillator.

The tendency toward mode jumping in a parallel-line oscillator may be reduced by lowering the impedance of the load. This fact may be explained as follows. In order to maintain the load constant, the coupling point must be moved closer to the short-circuiting bridge as the load impedance is decreased. The closer the coupling point is to the short-circuiting bar, however, the higher is the mode of oscillation at which the coupling point is at or near a voltage node. Since the values of $\mathcal{B}$ and $E_b/\mathcal{B}$ are insufficient to sustain high-order-mode oscillation, there is less tendency for mode jumping.

The tendency toward mode jumping may also be reduced by the use of a form of coupling circuit in which the coupling is not made at a single point along the line. The coupling methods illustrated in Figs. 16–6*a* and 16–12*a* are therefore preferable from the point of view of avoidance of mode jumping.

23–8. Frequency Pulling.—Like other self-excited oscillators, split-anode parallel-line oscillators exhibit frequency pulling, or change in frequency with load impedance (see Sec. 21–6), and are subject to the long-line effect. The long-line effect *is the presence of frequency discontinuities* over the tuning range of the oscillator and is observed if the load is tightly coupled to the oscillator through a long transmission line that is not matched to the load (see Sec. 21–8). The long-line effect is merely an example of the frequency discontinuities that may be observed over the tuning range of any oscillator having two or more tightly coupled oscillatory circuits. The transmission line acts as one oscillatory circuit. When the load cannot be matched to the coupling line throughout the entire frequency range, frequency jumping may be prevented by making the transmission line so short that it cannot resonate within the tuning range of the oscillator, or by coupling the transmission line loosely to the oscillator. When frequency jumping does exist, the frequencies at which jumping occurs may be shifted away from a desired portion of the tuning range by means of a line-stretcher inserted in series with the transmission line.

23–9. Frequency Pushing.—Frequency pushing, or change in frequency with direct anode current, is observed in split-anode magnetron oscillators. It is caused by change of impedance presented to the tank circuit at the anodes as the result of electronic action within the tube (see Sec. 21–4). Frequency pushing causes amplitude modulation to be accompanied by frequency modulation.

23–10. Pulsing.—Under certain conditions of operation, particularly at low values of anode current, the amplitude of oscillation of split-anode magnetrons jumps periodically between two values, one of which may be zero. This action is called *pulsing*. The pulsing frequency may be changed from the order of once a second to as much as 1 Mc per sec by variation of the circuit constants of the power supply. It is not prevented by the use of a constant-current supply. In at least some types of split-anode magnetrons, pulsing does not occur at high values of anode current, but to date no way has been found to ensure that it will not occur at low currents. Pulsing therefore limits the usefulness of this type of oscillator as a generator of amplitude-modulated waves when large percentages of modulation are desired, unless the modulation introduced by the pulsing is not objectionable.

Pulsing is probably explained by the presence of regions of the anode current-voltage diagram in which the anode current-voltage curves have a negative slope, the action in some respects resembling that of a glow-tube relaxation oscillator. It is of interest to note that pulsing is not ordinarily encountered in multicavity magnetrons.

23–11. Modulation by Filament Field.—Split-anode magnetrons now available make use of single-wire filamentary cathodes. Computation of the magnetic flux produced by the filament current discloses that the density of the flux at the surface of the cathode is of the order of one-tenth that of the main applied magnetic flux. Although the flux produced by the filament current in a straight filament is normal to the main flux, it does affect the electron paths. When the filament current is alternating, as is usually true, the effect of the filament-current flux is to modulate the oscillation at twice the supply frequency. This effect, which is very objectionable in the generation of modulated waves for communication purposes, can be prevented by the use of direct heating current or of tubes having bifilar reversed-helix filaments or filaments resembling a short-circuited length of coaxial cable. Such tubes are not at present available, but tests have shown that they are feasible.

Table 23–1

Developmental number	Type number	Frequency, Mc	Power output, watts	Effic. per cent	Direct anode voltage	Direct anode current, ma	Flux density, gauss	Filament volts	Filament amp	Structure
ZP579	5J29	350–770	75–150	..	2500	450max	1500	2.2	35	Internal loop
ZP584	5J31	700–1200	75–150	..	2500	450 max	2640	2.5	40	Internal loop
ZP590	5J30	150–385	75–150	50	2500	450 max	1500	2.2	35	Single-ended
ZP599	....	90–300	750 min	..	2300	1000	1750	7	32	Single-ended
ZP646	5J32	90–450	80–150	..	2500	450 max	1500	2.2	35	Double-ended
ZP647	....	225–500	1000	50	2300	1000	1200–1500	10	32	Neutrode
ZP675	....	425–775	> 150	50	1500	400	....	....	..	Neutrode
ZP676	5J33	750–1150	200	40	1800	400	1500	2.2	35	Neutrode
ZP677	....	1100–1650	> 200	50	....	....	....	7	32	Neutrode-tropotron*
ZP685	....	450–700	1000	50	2300	1000	1500	7	32	Tropotron*
RCA A-133	....	700–1050	1000	50	2500	1000	1500	7	32	Tropotron*

* The tropotron is a recently developed multisegment tube in which the resonant line makes one or more complete turns about the anode structure, the various segments being connected to the line in such a manner that the tube behaves like a multicavity magnetron.