10-4 BACKWARD-WAVE CROSSED-FIELD OSCILLATOR (CARCINOTRON)

The backward-wave crossed-field oscillator of *M*-Carcinotron has two configurations: linear *M*-carcinotron and circular *M*-carcinotron.

Linear *M*-Carcinotron. The *M*-Carcinotron oscillator is an *M*-type backward-wave oscillator. The interaction between the electrons and the slow-wave structure takes place in a space of crossed field. A linear model of the *M*-Carcinotron oscillator is shown in Fig. 10-4-1.

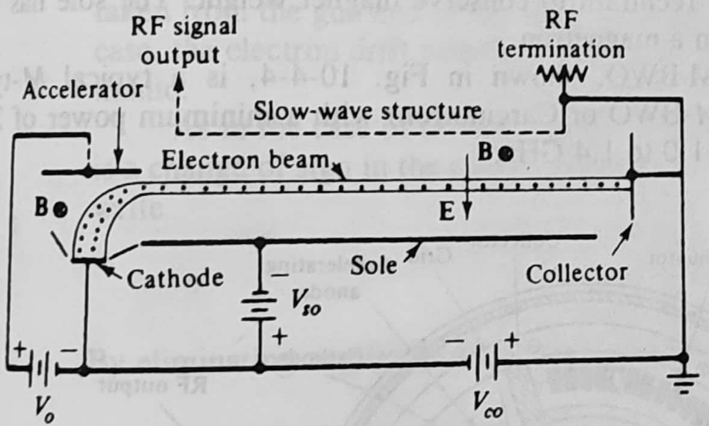


Figure 10-4-1 Linear model of an *M*-Carcinotron oscillator. (*From J. V. Gewartowski and H. A. Watson [6]; reprinted by permission of Van Nostrand Company.*)

The slow-wave structure is in parallel with an electrode known as the sole. A dc electric field is maintained between the grounded slow-wave structure and the negative sole. A dc magnetic field is directed into the page. The electrons emitted from the cathode are bent through a 90° angle by the magnetic field. The electrons interact with a backward-wave space harmonic of the circuit, and the energy in the circuit flows opposite to the direction of the electron motion. The slow-wave structure is terminated at the collector end, and the RF signal output is removed at the electron-gun end. Since the *M*-Carcinotron is a crossed-field device, its efficiency is very high, ranging from 30 to 60%.

The perturbed electrons moving in synchronism with the wave in a linear *M*-Carcinotron are shown in Fig. 10-4-2.

Electrons at position *A* near the beginning of the circuit are moving toward the circuit, whereas electrons at position *B* are moving toward the sole. Farther down

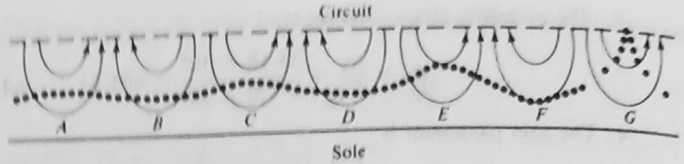


Figure 10-4-2 Beam electrons and electric field lines in an M-Carcinotron.

the circuit, electrons at position C are closer to the circuit, and electrons at position D are closer to the sole. However, electrons at position C have departed a greater distance from the unperturbed path than have electrons at position D. Thus, the electrons have lost a net amount of potential energy, this energy having been transferred to the RF field. The reason for the greater displacement of the electrons moving toward the circuit is that these electrons are in stronger RF fields, since they are closer to the circuit. Electrons at position G have moved so far from the unperturbed position that some of them are being intercepted on the circuit. The length from position A through position G is a half cycle of the electron motion.

Circular *M*-Carcinotron. The *M*-Carcinotrons are generally constructed in the circular reentrant form as shown in Fig. 10-4-3. The slow-wave structure and sole are circular and nearly reentrant to conserve magnet weight. The sole has the appearance of the cathode in a magnetron.

The Litton L-3721 M-BWO, shown in Fig. 10-4-4, is a typical *M*-type backward-wave oscillator (*M*-BWO or Carcinotron) with a minimum power of 200 W at frequency range from 1.0 to 1.4 GHz.

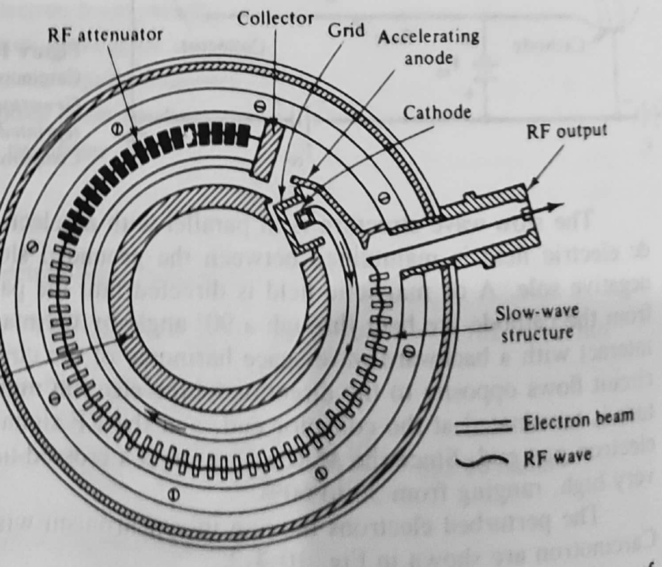
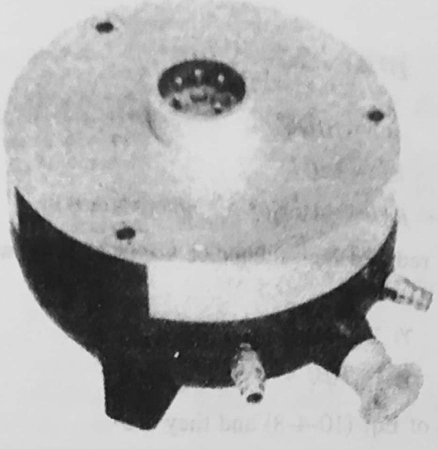


Figure 10-4-3 Schematic diagram of a circular M-Carcinotron. *(Courtesy of Raytheon Company, Microwave Tube Operation.)*



L-3721 7⅝" Wide

Figure 10-4-4 Photograph of Litton L-3721 BWO. (*Courtesy of Litton Company, Electron Tube Division.*)

In the circular configurations, the delay line is terminated at the collector end by spraying attenuating material on the surfaces of the conductors. The output is taken from the gun end of the delay line which is an interdigital line. Clearly, in this case, the electron drift velocity has to be in synchronism with a backward-space harmonic.

As in the case of O-type devices, the only modification in the secular equation is a change of sign in the circuit equation. If this change is made in Eq. (10-3-1), we write

$$\gamma_0 = j\beta \tag{10-4-1}$$

$$\gamma = jk + \epsilon \tag{10-4-2}$$

By eliminating negligible terms, we obtain for the Carcinotron

$$(\beta^2 - k^2 + j2k\epsilon)\,[j(\beta_e - k) - \epsilon][\beta_m^2 - (\beta_e - k)^2 - j2(\beta_e - k)\epsilon]$$
$$= j\beta\beta_e k^2\left(\beta_e - k + \frac{2\alpha}{1+\alpha^2}\beta_m\right)H_2 \tag{10-4-3}$$

A solution of Eq. (10-4-3) for synchronism can be obtained by setting $\beta = \beta_e$ and $\beta_e - k = \beta_e b'$, where b' is a small number so that terms like b'^2 and $b'\epsilon$ may be neglected. This yields

$$2\epsilon(j\beta_e b' - \epsilon) = \beta\beta_e k\left(\frac{b'}{\beta_m^2} + \frac{2\alpha}{1+\alpha^2}\frac{1}{\beta_m}\right)H^2$$
$$\doteq \beta_e k\,\frac{2\alpha}{1+\alpha^2}\frac{\beta}{\beta_m}H^2 \tag{10-4-4}$$
$$= 2\beta_e k D^2$$

where

$$D^2 = \frac{\alpha}{1 + \alpha^2} \frac{\beta}{\beta_m} H^2 \tag{10-4-5}$$

$$\epsilon = \beta_e D \delta \tag{10-4-6}$$

$$b' = bD \tag{10-4-7}$$

$$\delta(\delta - jb) = -1 \text{ or } \delta^2 - jb\delta + 1 = 0 \tag{10-4-8}$$

As a result, we have reduced the number of waves to two, with propagation constants given by

$$\gamma_1 = j(\beta_e + b) + \beta_e D \delta_1 \tag{10-4-9}$$

$$\gamma_2 = j(\beta_e + b) + \beta_e D \delta_2 \tag{10-4-10}$$

where the δ's are the roots of Eq. (10-4-8) and they are

$$\delta_1 = j \frac{b - \sqrt{b^2 + 4}}{2}$$

$$\delta_2 = j \frac{b + \sqrt{b^2 + 4}}{2}$$

To determine the amplification of the growing waves, the input reference point is set at $y = 0$, and the output reference point is taken at $y = \ell$. It follows that at $y = 0$, the voltage at the input point can be computed as follows:

$$V_1(0) + V_2(0) = V(0) \tag{10-4-11}$$

$$\frac{V_1(0)}{\delta_1} + \frac{V_2(0)}{\delta_2} = 0 \tag{10-4-12}$$

Solving Eqs. (10-4-11) and (10-4-12) simultaneously we have

$$V_1(0) = \frac{V(0)}{1 - \delta_2/\delta_1} = \frac{\delta_1 V(0)}{\delta_2} \tag{10-4-13}$$

$$V_2(0) = \frac{-V(0)}{1 - \delta_1/\delta_2} = \frac{-\delta_2 V(0)}{\delta_1} \tag{10-4-14}$$

Then the voltage at the output point $y = \ell$ is given by

$$\begin{aligned} V(0) &= V_1(0) \exp(-\gamma_1 \ell) + V_2(0) \exp(-\gamma_2 \ell) \\ &= V(0)[\delta_1 \exp(-\gamma_1 \ell) - \delta_2 \exp(-\gamma_2 \ell)]/(\delta_1 - \delta 2) \end{aligned} \tag{10-4-15}$$

The term in the square bracket is the inverse of the voltage gain of the device. Oscillation takes place when this is zero. That is,

$$\delta_1 \exp(-\gamma_1 \ell) = \delta_2 \exp(-\gamma_2 \ell) \tag{10-4-16}$$

or

$$\delta_1/\delta_2 = \exp(\gamma_1 \ell - \gamma_2 \ell) \tag{10-4-17}$$

$$= \exp[-\beta_e D \ell(\delta_2 - \delta_2)]$$

From Eq. (10-4-8) we have

$$\delta_1/\delta_2 = \frac{b - \sqrt{b^2 + 4}}{b + \sqrt{b^2 + 4}} \tag{10-4-18}$$

and

$$\delta_2 - \delta_1 = j\sqrt{b^2 + 4} \tag{10-4-19}$$

Then

$$\delta_1/\delta_2 = \exp\left(-j\beta_e D \ell \sqrt{b^2 + 4}\right) \tag{10-4-20}$$

Equations (10-4-18) and (10-4-20) can only be satisfied simultaneously if $b = 0$ and $\delta_1 = -\delta_2$. Then

$$2\beta_e D \ell = (2n + 1)\pi \tag{10-4-21}$$

where n = any integer numbers. If we introduce N as usually defined through $\beta_e \ell = 2\pi N$, the oscillation condition becomes

$$DN = \frac{2n + 1}{4} \tag{10-4-22}$$

Example 10-4-1: Carcinotron Characteristics

A circular carcinotron has the operating parameters:

Anode voltage:	$V_0 = 20$ kV
Anode current:	$I_0 = 3.5$ A
Magnetic flux density:	$B_0 = 0.3$ Wb/m^2
Operating frequency:	$f = 4$ GHz
Characteristic impedance:	$Z_0 = 50\ \Omega$
D factor:	$D = 0.8$
b factor:	$b = 0.5$

Compute:

a. The dc electron velocity
b. The electron-beam phase constant
c. The delta differentials
d. The propagation constants
e. The oscillation condition

Solution

a. The dc electron velocity is

$$\mathcal{V}_0 = 0.593 \times 10^6 \times (20 \times 10^3)^{1/2} = 0.8386 \times 10^8 \text{ m/s}$$

b. The electron-beam phase constant is

$$\beta_e = \frac{\omega}{\mathcal{V}_0} = \frac{2\pi \times 4 \times 10^9}{0.8386 \times 10^8} = 300 \text{ rad/m}$$

c. The delta differentials are

$$\delta_1 = j\frac{0.5 - \sqrt{(0.5)^2 + 4}}{2} = -j0.78$$

$$\delta_2 = j\frac{0.5 + \sqrt{(0.5)^2 + 4}}{2} = j1.28$$

d. The propagation constants are

$$\gamma_1 = j(\beta_e + b) + \beta_e D\delta_1$$

$$= j(300 + 0.5) + 0.5 \times 0.8 \times (-j0.78) = j300.20$$

$$\gamma_2 = j(300 + 0.5) + 0.5 \times 0.8 \times (-j1.28) = j301.00$$

e. The oscillation occurs at

$$DN = 1.25 \qquad \text{for } n = 1$$

then

$$N = 1.5625$$

and

$$\ell = \frac{2\pi N}{\beta_e} = \frac{2\pi \times 1.5625}{300} = 3.27 \text{ cm}$$