8. Pulse Modulators

For many designers, the most technically challenging subsystem of any high-power transmitter is its pulse modulator. Even though not all transmitters require one, the compleat transmitter engineer can't know too much about them.

To begin, there are some system-level considerations that govern which of the two basic types of pulse modulators are appropriate for a given high-power microwave tube application: cathode pulsers and control-electrode pulsers. Of course, in the latter case it is necessary that the microwave tube have a control electrode in its electron gun. Such control electrodes include

- a modulating anode (sometimes called an isolated anode),
- a focus electrode, and
- a control grid.

A brief description of each of the major types of pulse modulators follows in this chapter, along with a discussion of the various considerations to keep in mind about electron guns (e-guns).

8.1 Cathode-controlled electron gun

Figure 8-1 shows the cross section of a diode (or cathode-controlled electron gun), which is the simplest of all electron guns. It consists of a thermionically emitting cathode, a heater, a focus electrode, and an anode. The heater raises the cathode temperature high enough for it to become an efficient emitter of electrons. The focus electrode is electrically connected to the cathode, and its shape

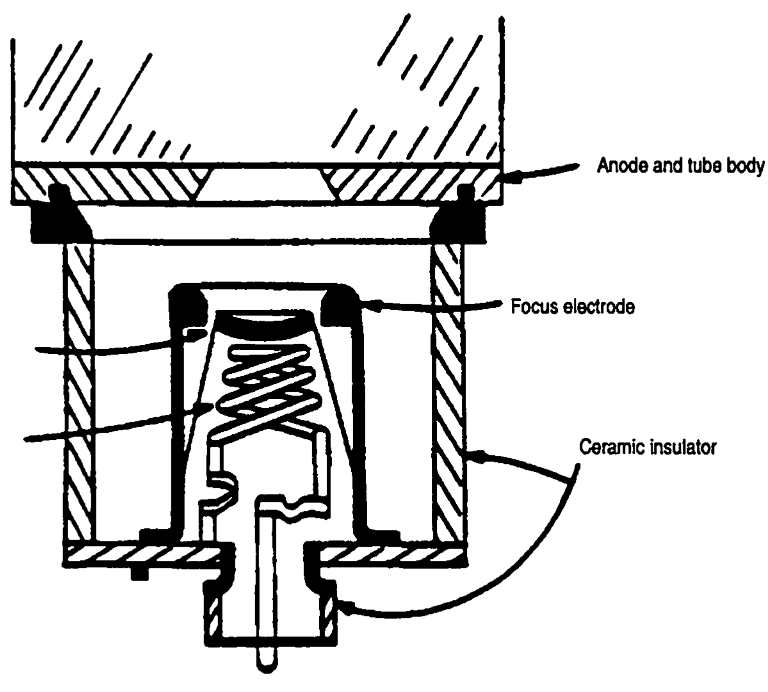

Figure 8-1. Cross-section view of a diode, or cathode-controlled electron gun.

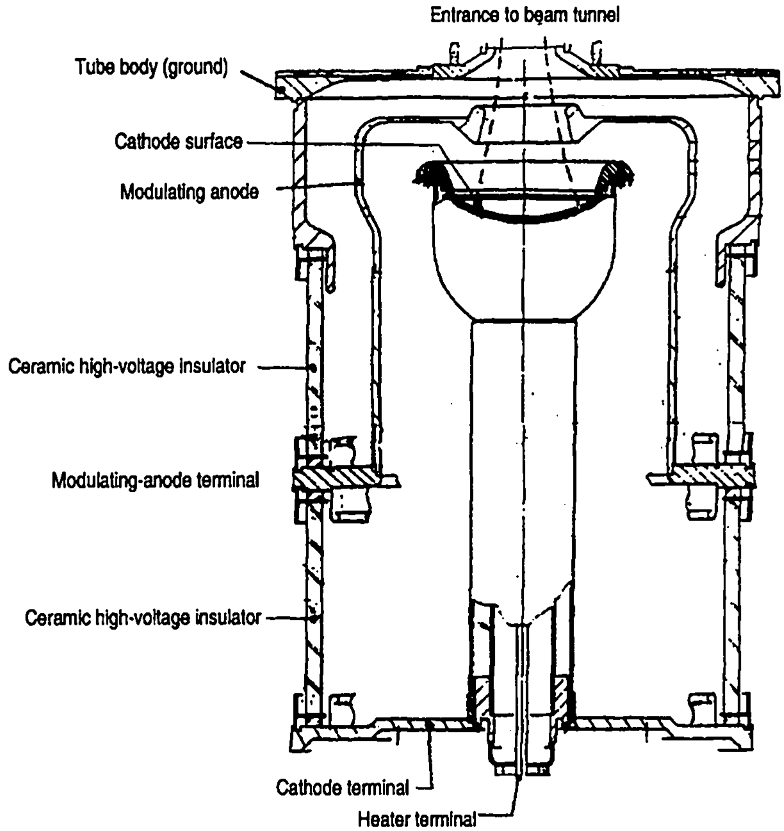

Figure 8-2. High-power microwave-tube electron gun with modulating anode.

is important to the electrostatic lens formed between cathode and anode. (It is also the terminus of most of the high-voltage arcs, reducing the likelihood of arc damage to the cathode surface itself.) The anode is usually the entrance to the beam tunnel of the amplifier device. There is only one electrode to which pulse modulation can be applied and that is the cathode. (The cathode heater power source must, of course, be capable of being floated atop the cathode modulation pulse.)

8.2 Modulating anode

Some time ago, it occurred to engineers at EIMAC, who designed and built large CW klystrons for UHF television service and tropospheric-scatter communications, that if the electrode serving the function of the anode in the diode gun were insulated from both the cathode and the body of the tube, some interesting properties might be obtained. The original intent of their "isolated anode" was to mitigate the effects of internal gun arcing. If, for instance, the anode was maintained at a voltage near ground by connecting it to ground through a resistor, an arc between cathode and the isolated anode would simply pull the anode down to cathode potential and result in nothing more than the shutting off the beam current. If the electrode can be used to shut off beam current, it can also be used to turn it on, hence the alternative appellation "modulating anode."

The modulating anode is an electrode of cylindrical geometry placed between the cathode and drift-tube entrance. The example shown in cross-sectional view

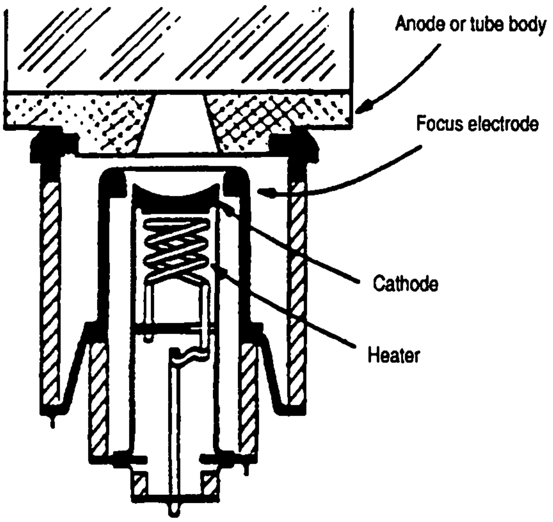

Figure 8-3. Cross-section view of electron gun with insulated focus electrode.

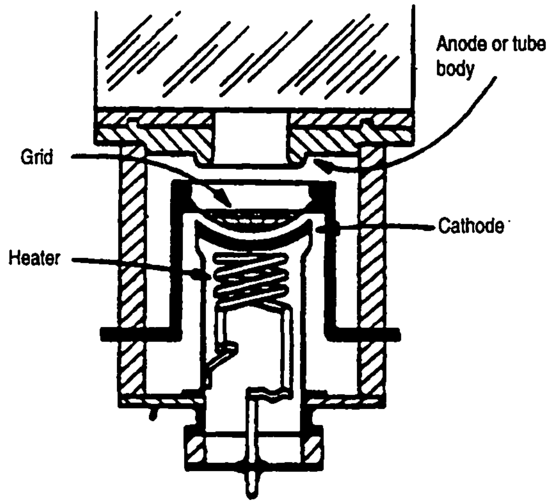

Figure 8-4. Cross-section view of electron gun with intercepting grid.

in Fig. 8-2 is of an electron gun whose cathode operates at approximately 100 kV negative with respect to body (ground). The pulse voltage applied to a modulating anode is usually a large fraction of the cathode voltage (50% or more) and is often pulsed to within a few hundred volts of ground during the beam-current pulse. The particular geometry illustrated is typically operated at 70% cathode voltage (70-kV pulse with respect to cathode, 30-kV negative with respect to ground). The convergent electron beam, the outer edges of which have been shown with dashed lines, is magnetically and electrostatically focused so that only a tiny fraction (0.1%) of the total beam current is intercepted by the modulating anode. Therefore, it takes virtually no power to drive it. The load the anode presents to the pulsed-voltage source is predominantly capacitance, made up of its internal capacitance and the self-capacitance of the modulator itself (which, as we will see, can be the largest component).

8.3 Insulated-focus electrode

As shown in Fig. 8-1, the focus electrode in a diode-type electron gun is connected to the cathode. As shown in Fig. 8-3, it can also be insulated from the cathode, in which case a voltage can be applied between the focus electrode and cathode. During the interpulse interval, this voltage can be sufficiently negative to inhibit the flow of electrons leaving the cathode, and during the pulse it can either be at cathode voltage or even positive with respect to the cathode. As with the modulating-anode electron gun, the cathode voltage in this device is continuously applied. The voltage swing required between beam cutoff and full-beam conduction is less for the focus electrode than for the modulating anode, but the effect on beam shape during the rise-and-fall intervals is greater.

8.4 Intercepting control grid

Requiring even less voltage swing between beam cutoff and full conduction is the intercepting control grid, illustrated in Fig. 8-4. The grid is a radially connected mesh of concentric circles that is set directly in the path of the electron

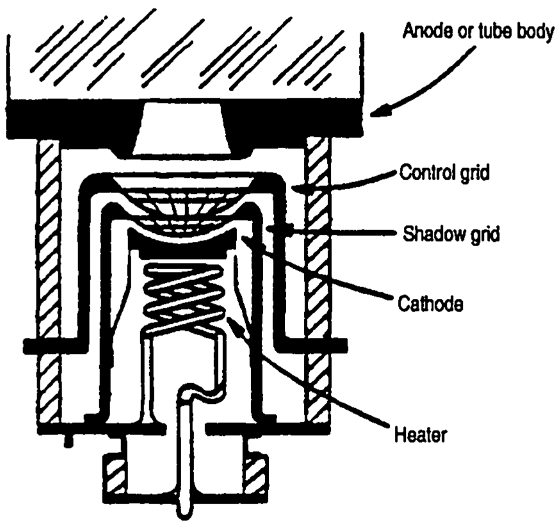

Figure 8-5. Cross-section view of electron gun with control and shadow grids.

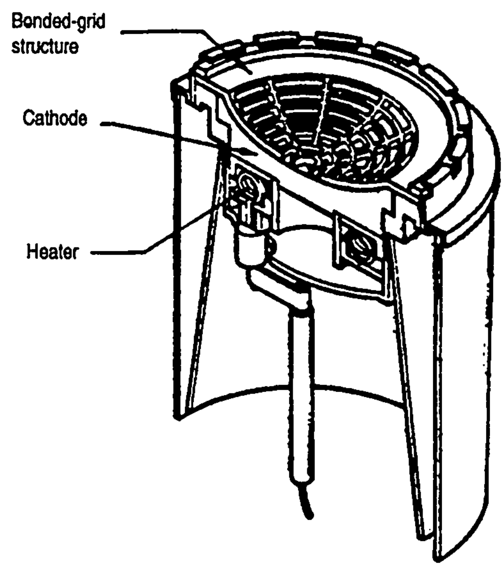

Figure 8-6. Cut-away view of electron gun with bonded-grid control electrode.

beam. Therefore, it is going to intercept some fraction of the total cathode current whenever its voltage is positive with respect to the cathode. This interception current not only subtracts from the available interaction beam current, but it causes the grid wires to heat and, eventually, to become secondary electron emitters, which severely limits the pulse energy and average-power capabilities of tubes that use them.

8.5 Shadow-gridded gun

The shadow-gridded gun, illustrated in Fig. 8-5, uses an electrode called the shadow grid that is at cathode potential, has the same pattern as the control grid, and is positioned between the control grid and the cathode so as to inhibit electrons whose paths would cause them to strike the control grid.

8.6 Bonded-grid gun

An extension of the shadow-grid concept is the bonded-grid structure, shown in Fig. 8-6. Here, an integrated assembly consisting of the grid and an insulating substrate having the same shape is directly bonded to the cathode surface. In some cases, it is even embedded in the cathode surface so that the plane of the grid is virtually flush with that of the cathode.

8.7 E-gun considerations

What, then, are the considerations that determine which type of microwave-tube electron gun is appropriate and what type of pulse modulator should go with it?

The choice is simple if the power levels involved exceed those that can be achieved with a tube that can operate with continuously applied cathode voltage. The theoretical upper limit of this voltage is approximately 150 kV. However, there are few practical systems that operate reliably at much more than 100 kV. The gray region, therefore, is between 100 kV and 150 kV. Above 150 kV there is no choice but to use a diode gun with a cathode pulser (and the shorter the pulse, the greater the voltage that can be applied before the interval between gun arcs becomes the limitation). Between 150 kV and 200 kV, cathode pulses, whose durations can range from 40 µs at the high-voltage end to 100 µs at the low-voltage end, have proven practical. Between 200 kV and 300 kV, practical pulse durations shrink from 40 µs down to 1-2 µs. In the submicrosecond-pulse range, cathode voltages up to 1 MV are not necessarily outrageous.

On the other hand, there are situations where cathode pulsing is most inappropriate, such as for a microwave tube that is unstable if its cathode voltage is less than its intended operating voltage. (The coupled-cavity TWT is a notorious example.) Cathode pulsing of such a tube can give rise to "rabbit ears," which are periods of RF oscillation during the rise-and-fall intervals of cathode voltage as the voltage passes through regions of instability. Tubes of such power—greater than 100 kW peak power is a fuzzy criterion—almost always have electron guns with modulating anodes. Even though these modulating anodes have pulse voltages applied to them that may be less than the total beam voltage, the electrons that enter the drift region of the tube will all have the same initial velocity. This velocity is determined only by the total accelerating voltage, which is the voltage between cathode and ground. (Guns whose modulating-anode voltage is significantly smaller than the cathode voltage—say, 50% or so—are called velocity-jump guns because the electron-beam velocity jumps as it enters the drift space beyond the modulating anode.)

The tube with the modulating-anode gun and pulser is also superior to the cathode modulator in high-duty-factor, high-average-power applications because the modulator, as we will see, handles only a small fraction of the total beam power. These advantages shrink as the system pulse repetition rate increases, and at some point greater than 5000 pps—another fuzzy criterion—the microwave-tube gun must have a low-voltage control grid and a grid modulator to go with it. Worthy of consideration in the gray region between high-PRF grid control and high-average-power, high-duty-factor modulating-anode control is control by means of the focus electrode, which is located physically and electrically between them.