OPERATION OF PULSED MILLIMETER WAVELENGTH
EXTENDED INTERACTION OSCILLATORS

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ABSTRACT

This paper discusses the problems of pulsing Extended Interaction Oscillators (EIO's), summarizes some experience gained in operating EIO's in several experimental systems with pulse lengths from ten to several hundred ns, and contrasts EIO operation with operation of conventional millimeter wave magnetrons.

SUMMARY

The Extended Interaction Oscillator (EIO) is a source of millimeter wave RF energy which has recently become available which is capable of considerable peak power (1 to 10 kw) when operated in the pulsed mode. A cross section schematic diagram of an EIO given as Figure 1,

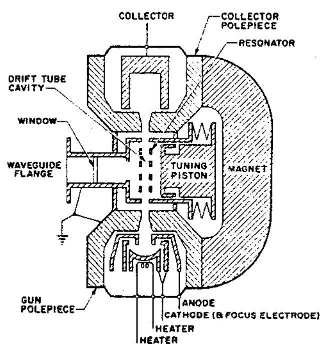

Figure 1. Schematic cross-sectional view of a pulsed EIO[1].

with connections to a typical EIO shown as Figure 2.

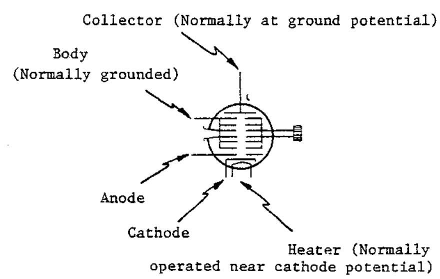

Figure 2. Schematic diagram of an EIO with various electrodes identified[1].

There are anode, cathode, and filament voltages which must be provided for proper operation of the tube. The anode may be operated with either a negative dc or pulsed voltage, the cathode voltage is pulsed negative with respect to the anode and to ground, while the filament is operated at cathode potential. Variation in anode or beam voltage can provide a degree of electronic tuning, but larger amounts or tuning require mechanical adjustment of the EIO. Representative characteristics of an EIO operating near 95 GHz are summarized in Table I.

TABLE I

Representative Characteristics
of an EIO Operating Near 95 GHz[2]

Center Frequency	95 GHz
Tuning Range	94-95 GHz
Peak Power	1 kW
Beam Voltage	21 kV
Peak Beam Current	650 mA
Anode Voltage	13 kV*
Peak Anode Current	10 mA
Duty Cycle	0.005
Electronic Tuning Range (Anode)	150 MHz
Cathode Modulation Sensitivity	0.15 MHz/Volt
Anode Capacitance	30 pF
Cathode Capacitance	15 pF

When comparing EIO operation with that of a pulsed millimeter wave magnetron, a number of significant differences are soon apparent. The most obvious difference is the ease of operating an EIO; arcing and moding problems often association with magnetrons were not evident. While one prototype tube did exhibit two low voltage, low power modes as beam voltage was varied, these were well separated and presented no problems; final versions of this tube only evidenced a single mode. Another striking difference is that the EIO behaves like an almost resistive load (being a space-charge limited diode for which $I = KV^{3/2}$), which is significantly different from the biased diode characteristic of magnetrons. However, no RF output is produced by an EIO until approximately 70% of the operating beam voltage is reached. Finally, unlike a magnetron, operating frequency is a quite sensitive function of electrode voltages, requiring extremely flat pulses if excessive frequency shifting is to be avoided. While the EIO has proven to be a rather easy device to pulse, nevertheless, satisfactory operation (particularly for short pulses) requires careful selection and design of the modulator.

As is the case with most high power tubes, occasionally momentary arcs may develop in the tube structure. With millimeter wave tubes, the small physical size of the device makes serious damage to the tube likely if large amounts of energy can be dissipated in the tube during such arcs. In order to limit the energy dissipated on a per-pulse basis, use of a line-type modulator is quite desirable.

Conventional line-type modulators use a pulse-forming network (similar to an artificial transmission line), a switch (such as a hydrogen thyratron), and a pulse transformer (to step-up the output voltage supplied to the EIO) (see Figure 3).

*Recent tubes operate at approximately 8kV.

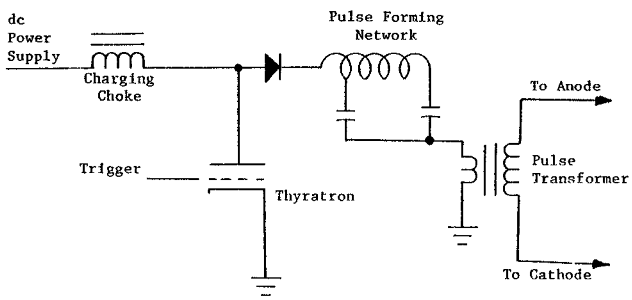

Figure 3. Simplified schematic diagram of a line type modulator for use with an EIO.

Many EIO applications require high range resolution, necessitating use of short pulses. However, the relatively high operating impedance of the EIO, coupled with the large stray cathode capacity, make it difficult to achieve satisfactory operation for short pulse lengths. In particular, there are several criteria which must be satisfied by the transformer if reasonable pulse fidelity is to be achieved. If good waveform fidelity without excessive overshoot is to be achieved, then the condition

$$Z \approx \sqrt{\frac{L_\ell}{C + C_D}}$$

should be satisfied[3], where

Z is the ratio of operating voltage to operating current

L_ℓ is the leakage inductance of the transformer

C is the tube element capacitance of the EIO

C_D is the distributed capacity of the transformer.

If one assumed $C_D = 0$, $C = 15$ pF, and that $Z = 8$ kV/.65 A, then one can solve for the desired value of L_ℓ as 2.3 mH. The risetime achievable with such a transformer is[3]

$$t_r = 1.78\sqrt{L_\ell(C + C_D)}$$

or the minimum risetime is approximately 0.33 us.

There are several methods by which risetime may be reduced while still perserving reasonable pulse shape, the most straightforward approach being to parallel the cathode with a low resistance to reduce the operating impedance, permitting lower values of L_ℓ and reduced risetime. Unfortunately, this approach results in the consumption of appreciable amounts of power. A second approach is to eliminate the transformer entirely and pulse the tube directly; unfortunately, this approach necessitates the use of rather high voltages in the modulator.

The use of the Blumlein modulator configuration[4] permits the use of lower voltages in the modulator; a schematic diagram of such a modulator is given as Figure 4.

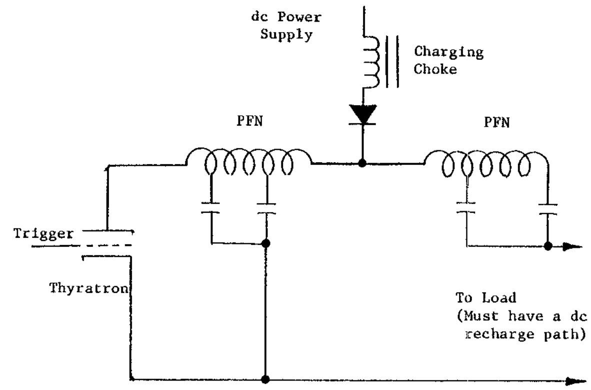

Figure 4. Blumlein modulator for directly pulsing an EIO. The pulser may be capacitively coupled to the cathode, but a dc recharge path must be provided.

The PFN's may be lumped constant networks, or for short pulses, open circuited coaxial cable sections may be utilized.

When operating magnetrons at short pulse lengths, so-called "pedestal" modulator techniques are sometimes utilized. This approach involves the application of a slowly rising voltage pedestal with a short pulse superimposed on top to place the tube at its operating point. When using magnetrons, this approach helps the magnetron to oscillate in the proper mode. While EIO's exhibit no such moding problems, nevertheless such an approach does have some merit when pulsing EIO's, since reduction of the required voltage swing of the short pulse reduces the effective load impedance, thus simplifying modulator design problems.

When using the various line-type modulators at short pulse lengths (less than 10 ns), the switching time of the device used may become significant. The switching time of hydrogen thyratrons (the most commonly used switch) varies with tube type and among thyratrons of the same type. Representative switching time of from ten to fifteen ns were achieved with conventional thyratrons, permitting generation of pulses approximately ten ns in width. Other candidate switching devices include multiple grid thyratrons and triggered spark gaps in order to achieve rapid switching times.

When an EIO is pulsed, there is only a limited portion of the beam voltage over which appreciable RF energy is generated, thus producing RF pulse risetimes substantially shorter than the risetime of the applied voltage pulse. In addition, a delay of from 15-20 ns between application of full voltage and generation of the RF output pulse was typically observed. When operating at 10 ns pulse width, generation of the RF output pulse was coincident with removal of the applied voltage.

Some current areas of research involve the possibility of phase and injection locking the EIO, and frequency modulating the device for use in pulse compression systems. In addition, development of Extended Interaction Amplifiers (EIA's) is under consideration. Careful control of both the anode and beam voltages will be required in order to achieve the desired frequency and phase stabilities for these applications. In order to achieve the desired degree of electrode voltage control, it will probably be necessary to utilize non-saturating hard tube modulators with grid drive control and complex coupling networks[5].

REFERENCES

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