A POSSIBLE LOW FREQUENCY POWER SOURCE
(Power Compression by virtue of a Thyratron)

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ISSUES

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Charge – discharge waveform on each component

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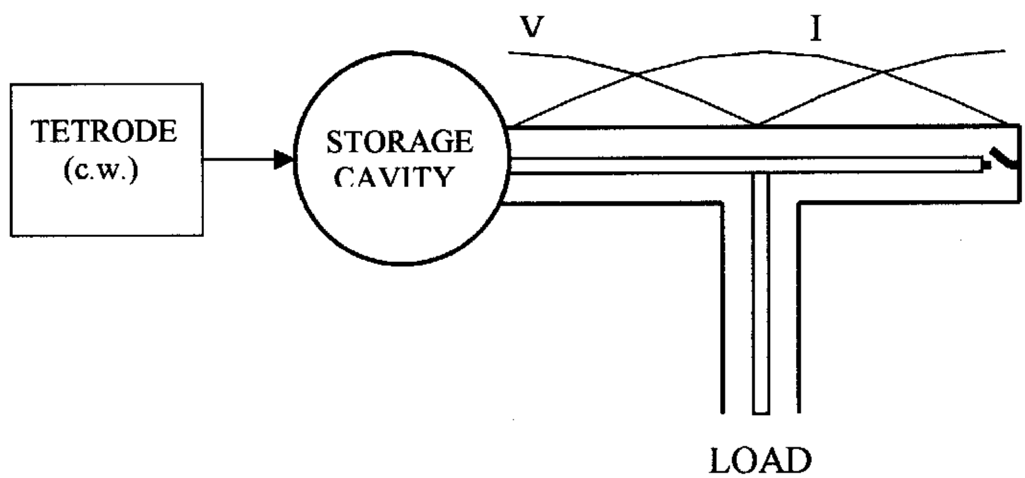
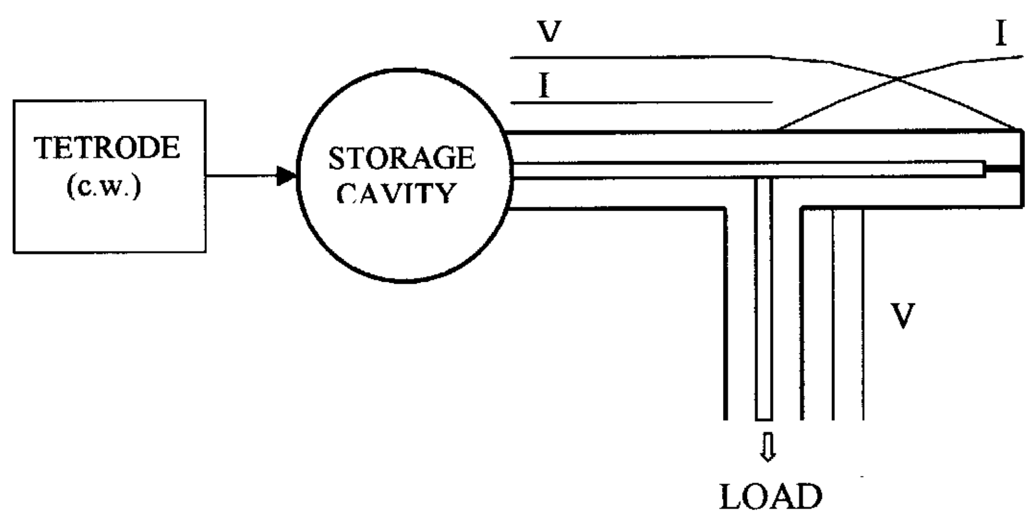
PRINCIPLE SCHEME

A storage cavity is charged by a cw tetrode. Its output is connected to a half-wavelength cable with a switch at the other end and a load at middle point. When the switch is open, there is no power go to load and the storage cavity sees an open circuit. When the switch is closed, the right one-quarter wavelength cable plays as an open circuit, thus the storage cavity connects to the load (i.e the accelerator) to which the energy drains. A thyratron is considered applicable at low RF, though it is usually only used at video frequency.

SWITCH OPEN --- NO ENERGY GO TO LOAD



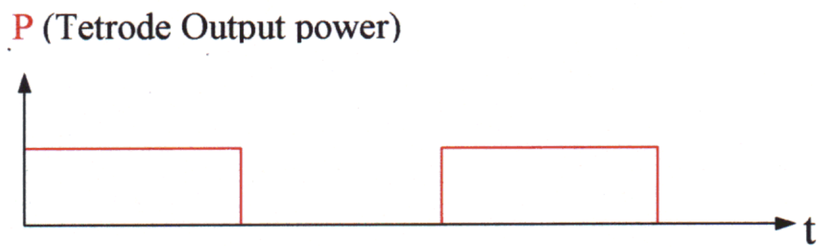
SWITCH CLOSED --- ENERGY DISCHARGES TO LOAD



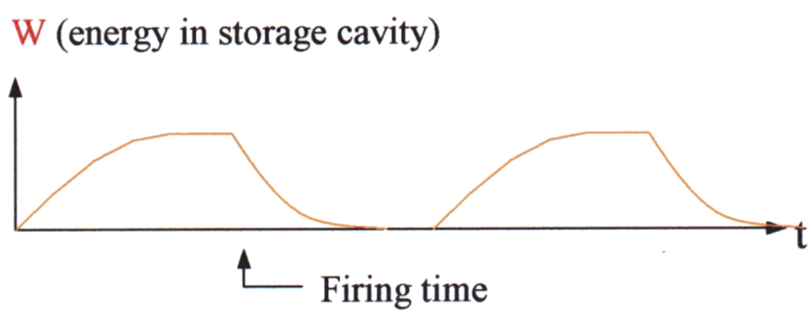
CHARGE-DISCHARGE WAVEFORM OF EACH COMPONENT

(not scaled)

The tetrode is operated with long pulse (cw alike status).

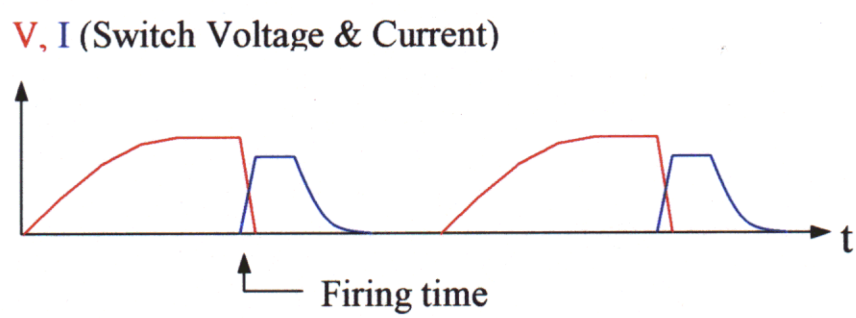


The storage cavity is charged by the tetrode with long pulse and discharged rapidly.

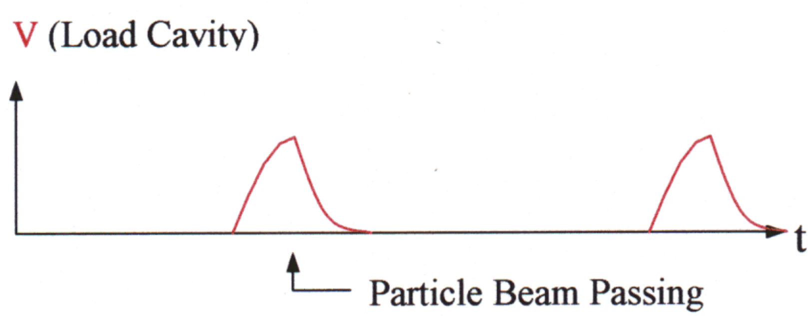


The voltage on the switch keeps pace with charging and dropdown after firing.

(see next page for detail)



Charging waveform on the accelerator structure. Particle beam is phased on the peak.



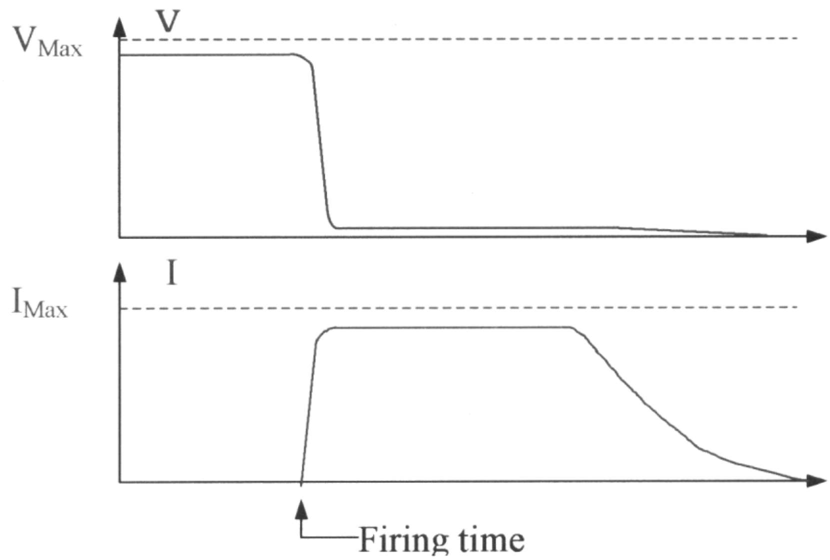
A CLOSE VIEW OF THE THYRATRON

Thyratrons are normally used in modulators with video frequencies.

IS A THYRATRON WORKABLE AT RF?

A thyratron before firing functions as an open circuit except a capacitance. After firing it functions as a short-circuit from viewpoint of low frequency. The plasma inside the thyratron reflects RF waves so that it looks as a metallic wall. For high RF, it can not see an open circuit because of capacitance. For low RF (say 30-100MHz) it is considered applicable.

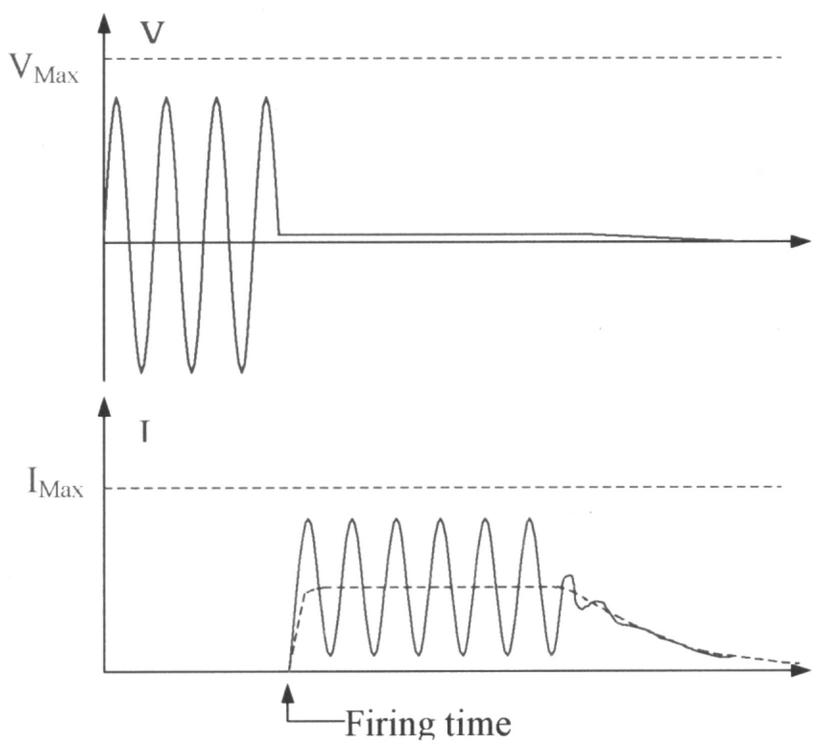
In a normal modulator, the voltage and current of a thyratron is shown in the right figure.



In the present scheme, the figure shows that there exists both video and RF components with the conditions that:

1. The voltage is always below the high limit to avoid breakdown before trig.

2. The current is always below high limit and above zero. (As negative current is not allowed in thyratrons).

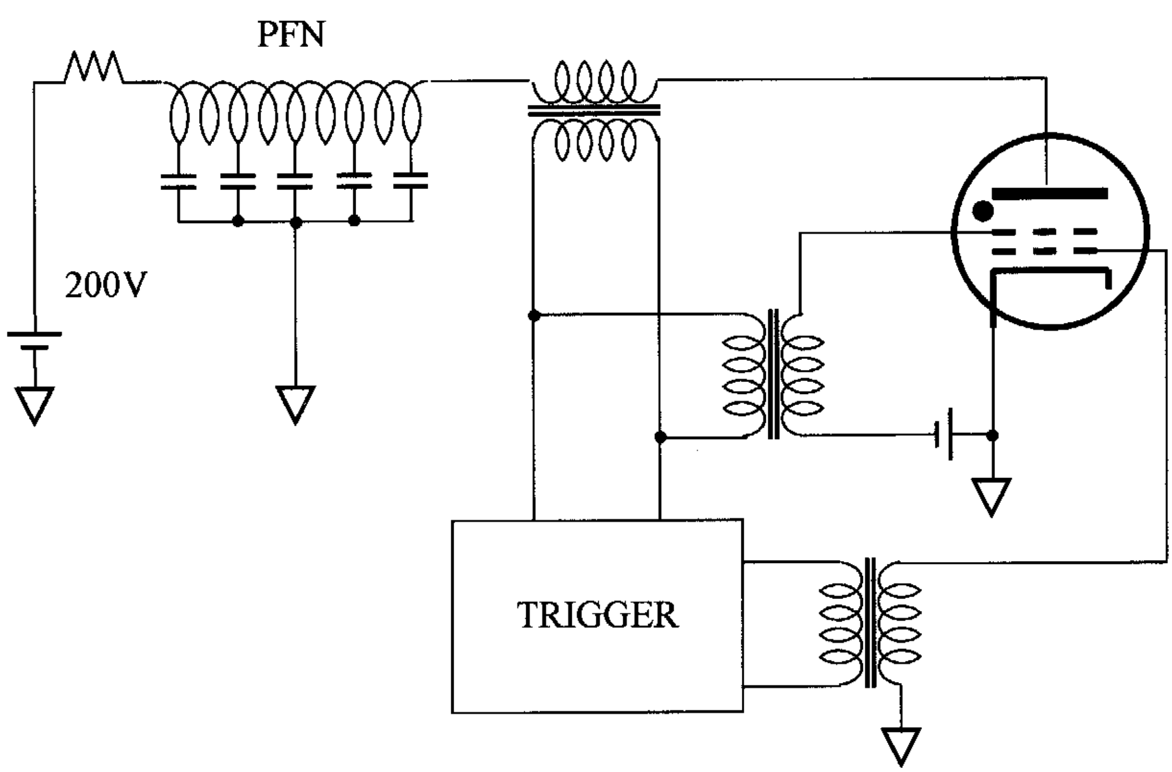


HOW TO HANDLE A THYRATRON

Two fold:

Radio Frequency: It should be mounted mechanically in a RF circuit (in present case it terminates a cable) as a part of RF. (see next page)

Electronics: It should be fired by a trig pulse (not fired by RF voltage) and able to sustain adequate bias current in order to avoid negative current. A possible circuitry is shown below.



The trigger: supplies high voltage pulses to the anode and screen grid and a modest pulse to the control grid with proper phases so as to trig the thyratron.

The PFN: generates a long pulse to sustain adequate bias current. High voltage and high quality of flatness are not required.

STORAGE CAVITY ISSUES

Basic requirements: **High Q – small loss during charging**
High energy storage capability – no breakdown

How high a Q of the storage cavity is required?

Assuming the accelerator is a cavity with known maximum stored energy W_{ac} and intrinsic Q factor of Q_{ac}.

Then the power required is: $P_{ac} = \dfrac{\omega W_{ac}}{Q_{ac}}$

Filling time: $\tau = \dfrac{Q_L}{\pi f} = \dfrac{Q_{ac}}{1+\beta}\dfrac{2}{\omega} = \dfrac{Q_{ac}}{\omega}$ $(assume\ \beta = 1)$

Charging time: $\sim 3\tau$

Total energy required: $W_L \approx 3\tau P_{ac} = 3W_{ac}$

Stored energy: $W_s > W_L = 3W_{ac}$

Minimum drive power: $P_{dr} = \dfrac{\omega W_s}{Q_s} > 3\cdot\dfrac{\omega W_{ac}}{Q_s} = 3\cdot\dfrac{Q_{ac}}{Q_s}P_{ac}$

(Note: Q_s is the system Q, which includes the cavity intrinsic loss and the external loss due to the imperfection of the output circuit)

Power Gain: $G = \dfrac{P_{ac}}{P_{dr}} < \dfrac{1}{3}\dfrac{Q_s}{Q_{ac}}$

Q of the storage cavity: $Q_s > 3GQ_{ac}$

If desire: $G = 20$, and $Q_{ac} = 10k$

then $Q_s > 60\ Q_{ac} = 600k$

This value is hard to reach with a normal conducting cavity. An investigation of TE01-mode cavity indicates that the size is too big to be practicable.

Conclusion

A superconducting cavity is necessary.

POTENTIAL POWER COMPRESSION RATE

The power gain or compression rate depends on how much the energy can be stored with a given source and how fast it can be released.

The former depends on how high is the loaded Q achievable when the switch is open. The higher the Q, the more energy stored.

The latter depends on how low is the loaded Q is achievable when the switch is closed. The lower the Q, the faster the energy released.

It turns out a question: How much On-Off Ratio (Q_{eo}/ Q_{ec}) is Achievable?

where Q_{eo}= Loaded Q when Switch open

Q_{ec}= Loaded Q when Switch close

From the equivalent circuit

$$\frac{Q_{eo}}{Q_{ec}} = \frac{Z_{eO}}{Z_{eC}}$$

Assume a 12" copper cable, ignore the loss due to the switch, one can find:

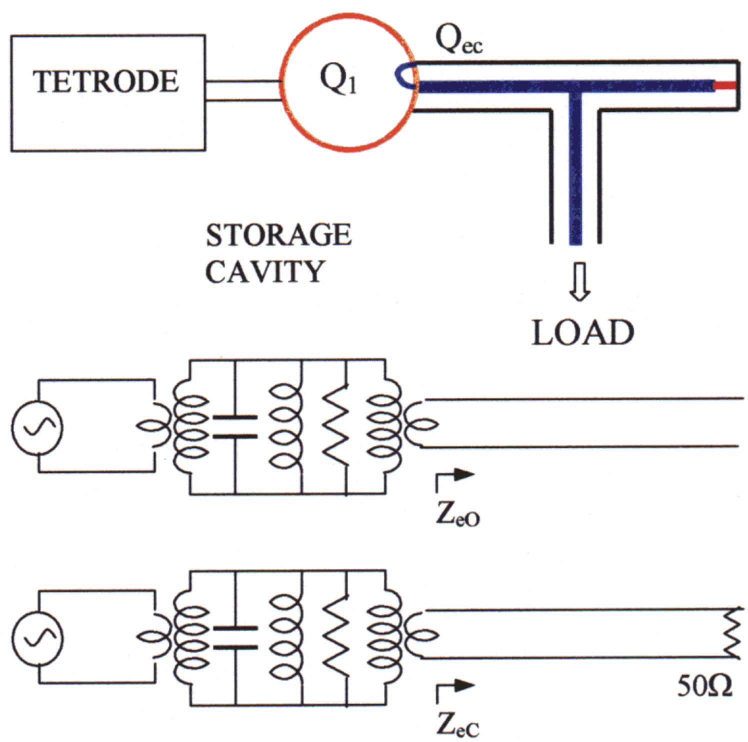
$$\frac{Q_{eo}}{Q_{ec}} = \frac{1}{k_2 l} = 4100$$

Design the coupler of the storage cavity such that

$$\beta_{eo} = 0.5, \quad \beta_{ec} = 2000$$

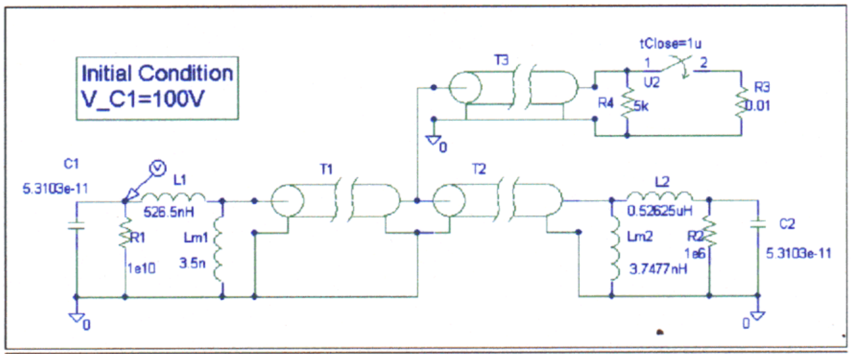
then obtains

$$G = \frac{2000}{1+0.5} = 1330$$

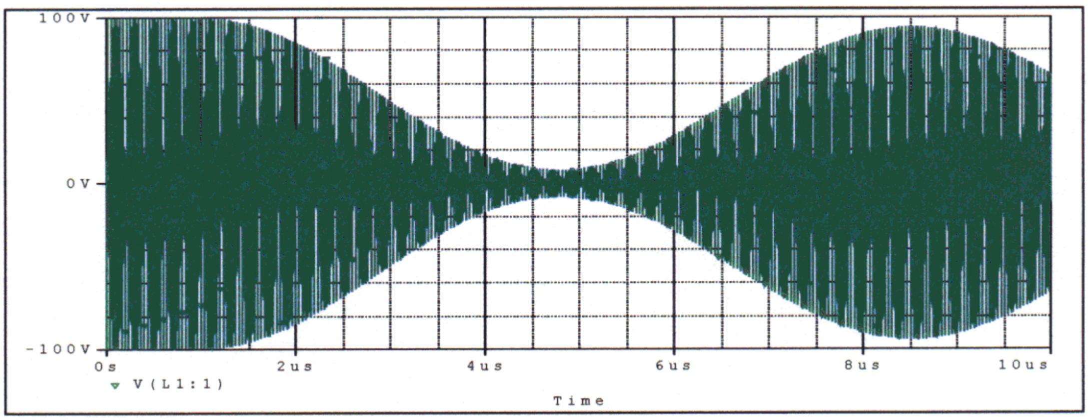


It means **the theoretic gain can be as high as > 1000**

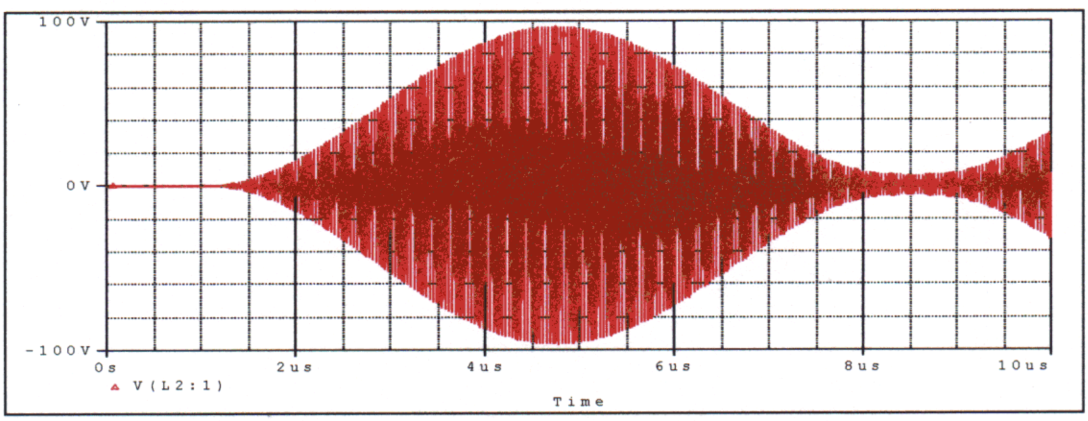
SIMULATION (Pspice)



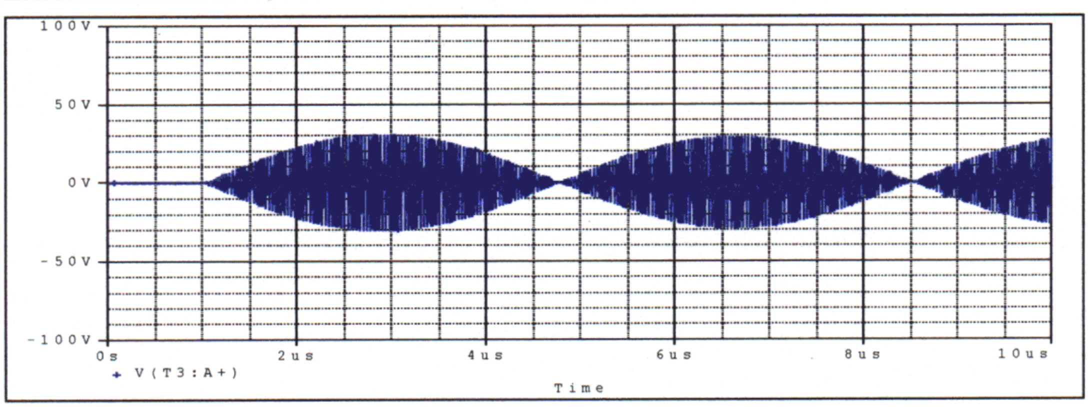
V_{C1}



V_{R2}



V_{T3}

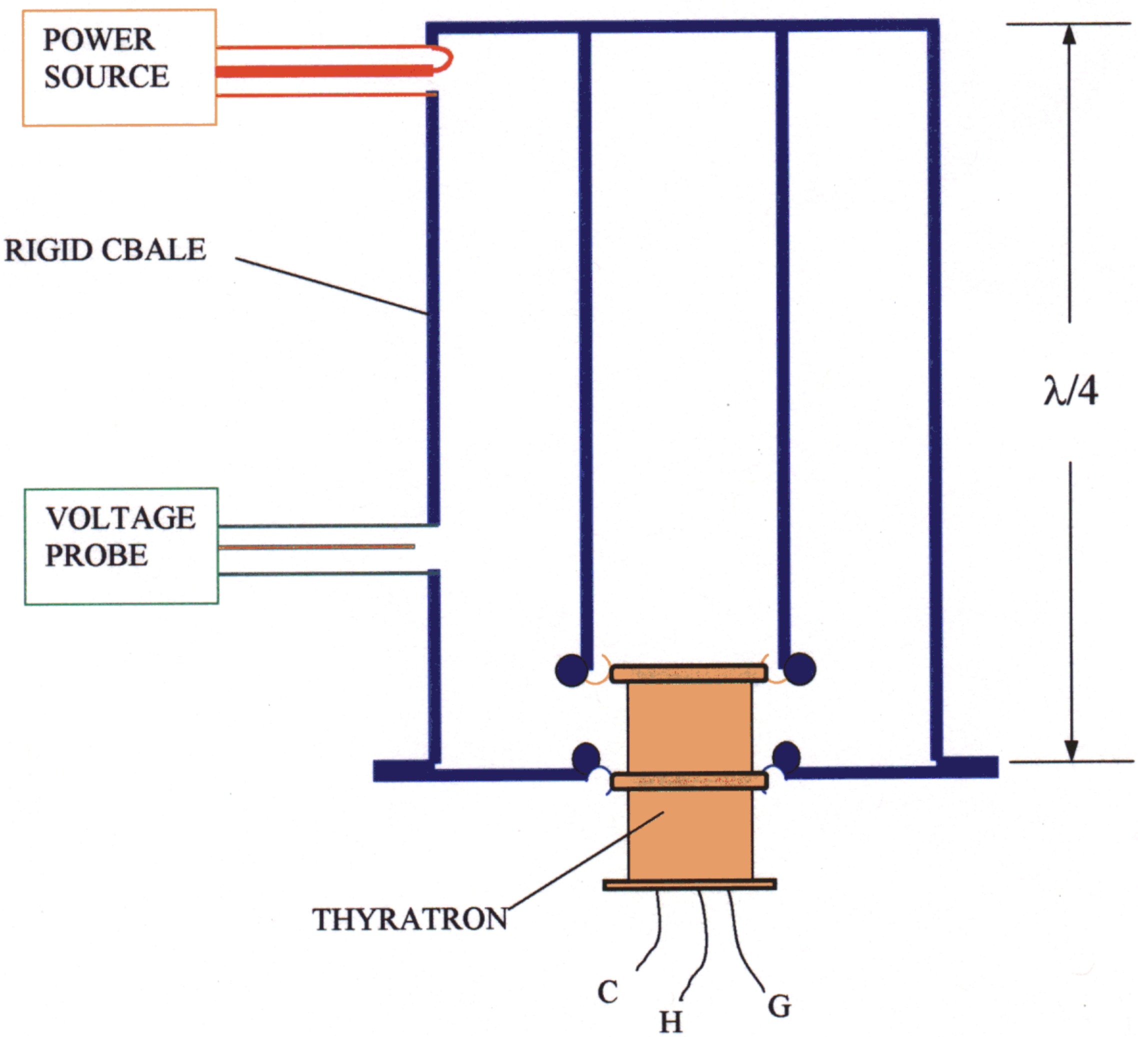


CONCERNS AND EXPERIMENTS

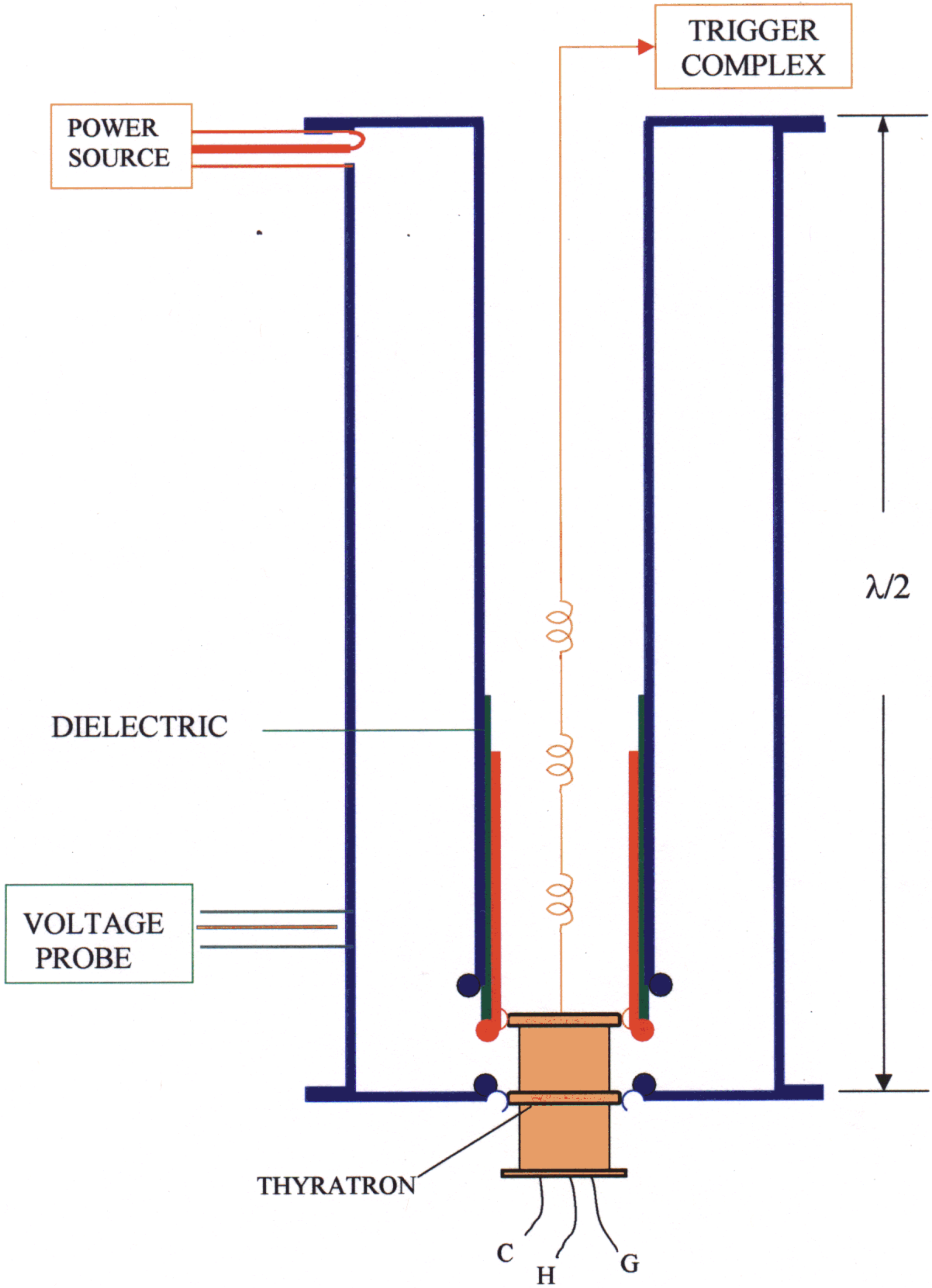
Concerns about thyratrons:

1. Can a thyratron endure high RF voltage like video pulse? (30-100MHz is very low frequency in comparison with microwave, but is too high for thyratron usage.)
2. When both RF and video current exist in the thyratron, will it be okay or cause extra loss?
3. Others – loss due to displacement current, loss by choke or capacitance contact, pulse duration capability, life time etc.

An experimental set up (test the 1st concern only)



2nd EXPERIMENT SETUP



RF STRUCTURE OF THE THYRATRON

(Schematic)

Key issue: The thyratron is working on both RF and video pulse. In the view of RF, both anode and screen grid must be grounded, while in the view of video pulse they must be insulated each other. In the following option (see Figure), a choke is employed to short RF current. Another option is "capacitance contact" forming RF shorting. The latter is simpler and may also be less lossy.