# DEFLECTOR POWER SUPPLY FOR SECTOR-FOCUSED CYCLOTRONS(*)

B.H. Smith
Lawrence Radiation Laboratory, Berkeley

The state of the cyclotron art demands well-regulated, ripple-free voltages for the new high-gradient electrostatic deflectors. Higher electric field gradients can be achieved if the deflector power supply provides a simple means of adjusting the energy supplied to the sparks during the deflector bake-in period. The power supply described here meets these requirements remarkably well. Two such supplies have been built and installed in the Berkeley 88-Inch Cyclotron[1]. Each supply (Fig. 1) consists of a six-stage Cockcroft-Walton rectifier built from silicon diodes mounted on printed-circuit boards, a 100 kc/s oscillator to excite the rectifier, a hard-tube modulator to control the oscillator output voltage, an electronic regulator, a reference, and a precision voltage divider.

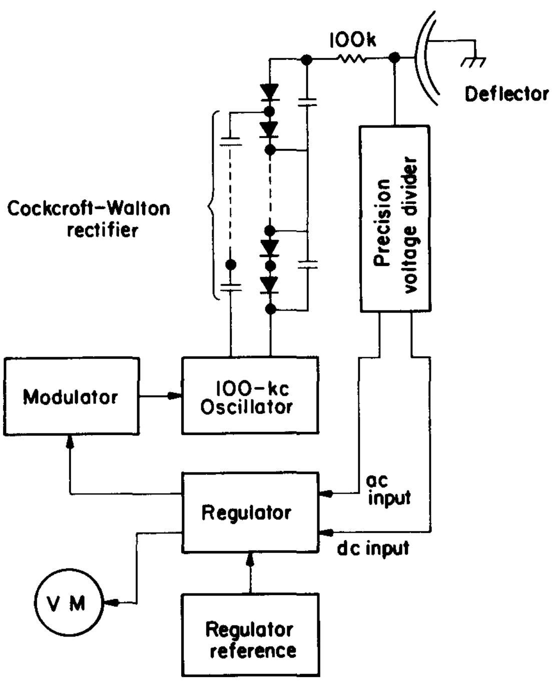


Fig. 1 Master schematic of deflector power supply.

The rectifier consists of 12 circuit boards mounted in lucite tube of outer diameter 8 in . The overall length of the assembly is 27 in. The rectifier extends from slightly above the deflector bushing to the ceiling of the deflector cage. The 100 kc/s oscillator is mounted directly above the rectifier on the roof of the deflector cage. It connects to the rectifier through a fiberglass insulator. The rest of the electronic equipment is installed in the electronic racks.

## Rectifier

Each circuit board consists of 100 Unitrode, Type UT71, silicon diodes connected in series. Each diode is shunted by a 250 pF, 500 V ceramic capacitor to divide the inverse voltages equally. The diode pattern on the circuit board is arranged to minimize the voltage gradient across the board (Fig. 2). The boards are connected electrically at two points; by a metal post at one point and by the between-decks capacitor at the other. In the vicinity of the metal post, where the potential

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difference is small, the capacitors and diodes face one another, while in the vicinity of the between-deck capacitors, where the potential difference is as much as 20 kV, the capacitors and diodes are on opposite sides of the boards. The spacing between boards is about 2 in. and provides a nominal maximum design gradient of 10 kV per in.

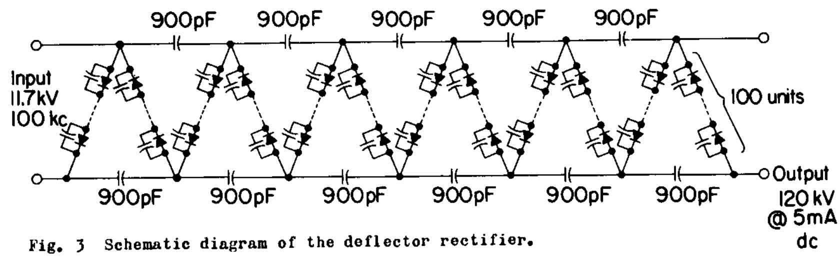


Fig. 3 Schematic diagram of the deflector rectifier.

The between-decks capacitors are 900 pF, 30 kV, ceramic, TV type capacitors. The manufacturer of the diodes rates each diode at 600 V, inverse peak, and 750 mA for 60 c/s operation. The schematic of the rectifier is shown in Fig. 3.

Since no data were available about the diodes at 100 kc/s, we set up a test for this purpose. Using a single diode rectifying negatively into a 10 kΩ unbypassed load resistor, we obtained oscillograms like the one shown in Fig. 4 for the Unitrode diode (which was the best of the diodes tested). The overshoot is caused by the stored charge in the diode junction. Apparently the storage time is about two μs at this voltage (150 V peak). We found that the diode charges a capacitive load to the peak value, and the stored charge does not subtract (appreciably, at any rate) from the output voltage. Therefore, in the type of service for which this power supply is designed, the charge stored in the junction seems to have no appreciable effect.

At the suggestion of E. Diebold of the International Rectifier Corp., we bombarded some of the diodes with electrons in our 5 MeV electron linear accelerator. This improved rectification, as shown in Fig. 5. The beam-current density was 400 $\mu A/cm^2$. The optimum bombardment time with this beam was 17 min.

We wondered whether the electron irradiation had any effect on the inverse characteristic of the diode. We found that it reduced the apparent resistance by a factor of 10. It had no appreciable effect on the avalanche breakdown voltage, which was about 900 V for these diodes. The back resistance was reduced to about 200 MΩ for each diode. This is still enormously high compared with any load that the rectifier might be called upon to feed, so there appears to be no reason why irradiated diodes cannot be used. It appears that rectifiers can be built to operate at much higher frequencies than the 100 kc/s if desired. We decided that in our application we did not have to irradiate the diodes; we used them as they came from the manufacturer. Irradiation is mentioned here for those who might want to operate at frequencies above 100 kc/s.

## Conclusion

Apparently, integration of the spark current starts on the dark current

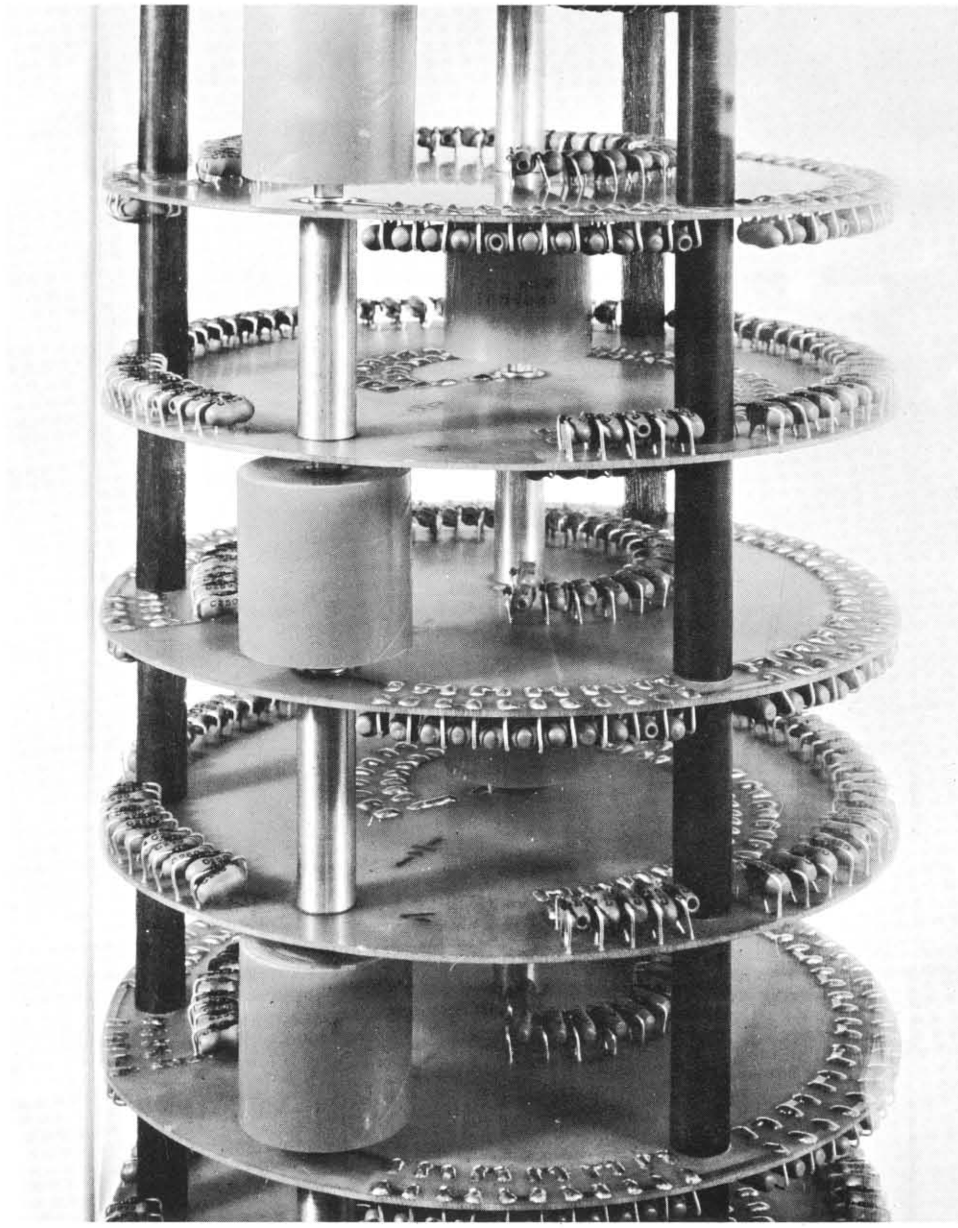

Fig. 2 Close-up view of the rectifier assembly, showing the details of the construction.

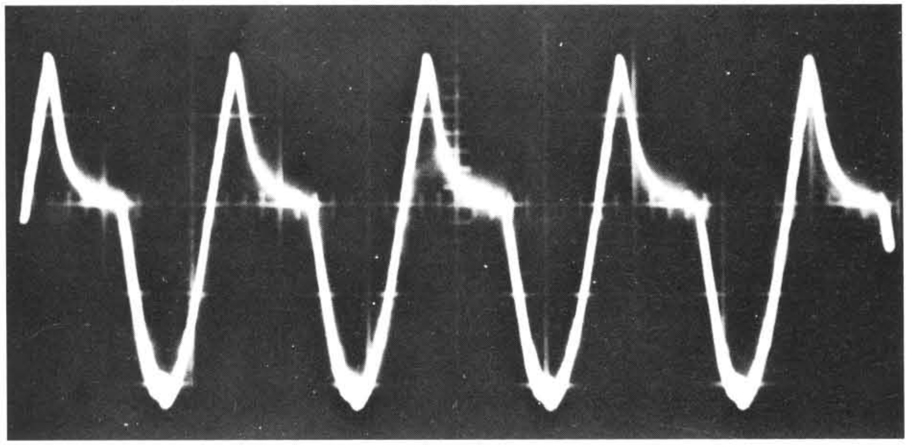

Fig. 4 Wave for obtained across a 10 kΩ load resistor for a single Unitrode UT71 diode. The peak value of the applied voltage was 150 V, and the frequency was approximately 100 kc/s. The overshoot shows the storage time of the diode junction at this voltage - about 2 μs. When the rectifier load is shunted by a sufficiently large capacitor, the capacitor charges to the peak value as though the diode-junction-stored charge were not present.

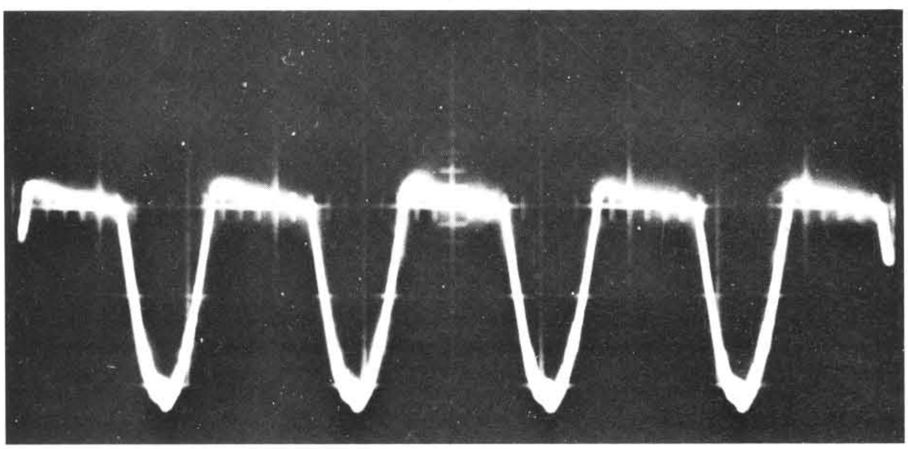

Fig. 5 The rectification characteristics of the diode were much improved after it was irradiated with 5MeV electrons; irradiation was at 400 $\mu A/cm^2$ for 17 min.

preceding the actual spark, because at the more sensitive positions of the crowbar current setting, the power supply can be turned off before a spark becomes visible. By decreasing the crowbar sensitivity slightly, one can finally see a small arc during sparking; when the sensitivity is decreased further the arc becomes much brighter; finally, when it is decreased still further, it becomes a very heavy arc. Thus, one has very good control over the amount of spark-produced heating of the electrode surfaces. A second advantage of this type of power supply is that the high carrier frequency results in a very wide bandwidth in the regulator loop, making possible a very high degree of regulation. The only limitation seems to be the stability of the resistors in the voltage divider. A third advantage of the power supply is that it withstands the short-circuit currents associated with sparking well. We had the power supply sparking virtually every second, 24 h/day for many days, without any indication of difficulty. I think, basically, the reason for this is that the stored energy is only 2.5 J and this, at most, is distributed among 1200 diodes. Even if all the energy were to end up in them, (which of course it will not) there is so little energy per diode that no damage occurs. There is so little energy in a spark from this rectifier that it will not puncture even a piece of 0.005 in. aluminum foil.

## Reference

1. For a more complete description of this system see Lawrence Radiation Laboratory Report UCRL-10655, March 25, 1963.

## DISCUSSION

LAPOSTOLLE : What would be the effect of longer irradiation than the one you used on the silicon rectifiers?

SMITH : I do not know. This was the longest bombardment we made.

SCHMIDT : How much current is drawn from the deflector power supply when the beam is passing through the deflector?

GRUNDER : About 0.5 mA as an average value.

SMITH : It is powerful and it can deliver a large amount of power to the beam. I have run the diodes up to 20 mA on a single disk and the diodes showed no appreciable heating. The little ceramic capacitors would over-heat at 20 mA. However, I am sure that if one wanted more current, one could find better capacitors.