SIMPLE IMPROVEMENTS IN SMALL HIGH-VOLTAGE DC POWER SUPPLIES

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Figure 1 is a schematic diagram of a symmetrical voltage-doubler dc power supply incorporating two features not usually found in similar rectifiers. First, the transformer primary is sufficiently insulated to permit connecting its iron core A, as shown, to the mid-point B between charging capacitors C_1 and C_2. Second, a small capacitor C_5 is connected directly across the transformer secondary. The first feature reduces ripple voltage on the output, and the second improves regulation.

Ordinarily the core of a transformer must be connected so that its potential is close to that of the source of power because the insulation between it and the primary winding is insufficient to withstand a large voltage difference. Then the distributed capacitance C_7 between the secondary and the core and primary is in series with C_2, across the secondary. As a result, a ripple voltage $VC_7/(C_2 + C_7)$ appears at point B, where V is the ac voltage produced by the secondary. Part of this ripple, at line frequency and independent of load current, will appear at output point F. The circuit shown in Fig. 1 eliminates this ripple because the capacitive current through C_7 does not flow through C_2. In order that this connection may be fully effective in keeping ac from passing through C_2, a capacitive shield is placed between primary and secondary and connected to the core. The peak-to-peak ripple voltage of this power supply is about 0.1% of the dc output voltage at full load current. About half of this ripple is the inevitable load-dependent part at 800 Hz. The other half is at 400 Hz. This latter ripple is mainly due to a small ($\sim$ 0.01 pF) capacitive coupling C_8 between the secondary and the output point F. This ripple is appreciable because the load resistance R_L is high ($\sim$ 30 MΩ); it could be practically eliminated by improving the shielding between the transformer and the components electrically near to point F. In an earlier model of this power supply, in which a conventionally insulated transformer was employed, C_7 was in effect connected from point J to local ground. Then a neutralizing capacitor C_6, about equal in value to C_7, and located as indicated in Fig. 1, reduced the 400 Hz ripple by about a factor of three. Although a suitable resistor R_6 in series with C_6 permitted adjusting the phase of the correction to give a nearly perfect neutralization of the remaining 400 Hz ripple, R_6 dissipated such an excessive power that its use was not practical.

Figure 2 shows the improved regulation of this power supply when a capacitor C_5 is placed across the transformer secondary. The data were taken at about 10% of full voltage. Similar results are obtained at proportionally higher voltages and currents. The value of 75 pF for C_5 seems to be sufficient; 150 pF gave nearly the same regulation curve as 75 pF. At sufficiently small load currents, C_5 seems to perform no useful function, presumeably because then the distributed capacitance across the transformer is sufficient without any additional capacitance. Oscilloscope observations of the charging pulses through the rectifiers show that the function served by C_5 is to establish a larger current flow more quickly at the beginning of these pulses. That is, this capacitor eliminates the delay in rise of charging-pulse current otherwise caused by the large leakage reactance (100 H) of the secondary. In effect, C_5 establishes a sufficient flow of current through the secondary prior to the start of the charging pulse; then this current can smoothly switch from flowing into C_5 to flowing into C_1 or C_2 without any sudden demand for change of current from the secondary. Obviously C_5 must not be so large that the increased current overheats the transformer; in this transformer the wire size is more than adequate to handle the increased current through a 75 pF capacitor because for mechanical reasons it is already considerably larger than is required for sufficient conductivity in the absence of this capacitor. A capacitor C_5 also serves another useful function. It reduces RF interference generated by shock-excited ringing of the transformer secondary.

Actually the major effort in building this power supply was expended not upon the above features of the circuit, but in choosing components and designing the complete package (which occupies 1.1 ft^3 excluding only R_L of Fig. 1). The approach taken was dictated by the intended conditions of use, facilities, and prior experience: The supply was designed for use in the HV terminal of an electrostatic generator where it supplied a voltage to control the focusing of an ion beam. For precise control of the energy of this beam the ripple voltage had to be small. Gas insulation was preferred to oil immersion for convenience and lesser weight because the normal environment was to be N_2 + CO_2 gas at about 100 psig. To protect the components of the rectifier from violent surges, spark-over, etc., experience had shown that the output should be through resistors (the 0.5 and 5MΩ resistors in Fig. 1) and should be provided with a spark gap. Under pressure the supply has already operated over 6000 hours with no failure. This performance was achieved by testing in open air until a layout was found that operated at 60 kV in this situation. The most serious problem encountered during these tests was corona from varnish-coated carbon-film high-voltage resistors. The solution was to use epoxy-jacketed resistors, carefully placed (as were all other components) to minimize the maximum electrical stresses everywhere in the assembly. In the final design, the insulation within the secondary windings of the transformer is clearly the most marginal item; an improved transformer would be necessary if this supply were to be employed to its 60 kV rating in open air.

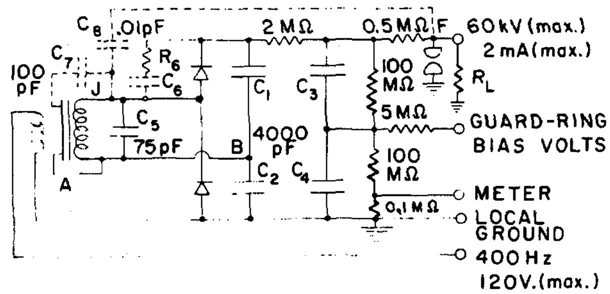

Fig. 1. Voltage-doubler power supply. The rectifiers are selenium cartridge type rated for 5 mA dc, assembled to give a rated piV of 75 kV. Capacitors C_1 through C_5 are epoxy-encapsulated ceramic rated 30 kV. Resistors (except the 0.1 MΩ) are epoxy-jacketed carbon-film on ceramic base, 19 cm long. C_7 and C_8 are distributed capacitances of the transformer secondary. Electrical connections to its core are shown explicitely since this is important to the explanation of operation of the circuit. The "guard ring bias volts" output is connected to an intermediate electrode in the ion accelerating assembly, which draws no appreciable current. C_6 and R_6 are not part of the final circuit (see text for discussion).

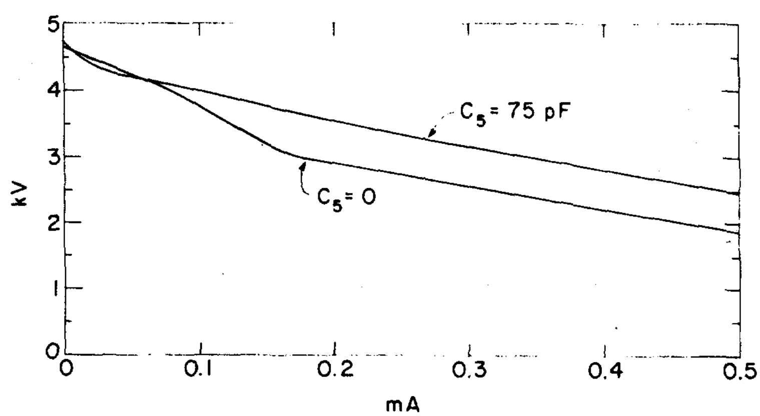

Fig. 2. Regulation curves for the power supply. The curves show output dc voltage versus output dc current at a fixed input ac voltage, with and without a capacitor C_5 connected across the secondary of the transformer. The data were taken at reduced voltages; full-voltage operation may be approximated by multiplying both scales by 12.