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Simple low-noise power supply for electrical transient measurements

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A very simple means is described for rapidly applying and briefly maintaining a large, essentially noiseless, dc voltage across a capacitive load. The technique is suitable for various nonrepetitive electrical transient measurements, such as carrier mobility determination, occurring over timescales ranging from tens of microseconds to several seconds; it essentially eliminates capacitive currents caused by noise in the power supply voltage, which can interfere with measurement of the true transient current. In an example, the noise on a 10-ms transient current (driven by 2000 Vdc, and observed as a voltage across a 100-kΩ load resistor) was barely more than the Johnson noise ($\sim 2\times 10^{-11}$ A rms) to be expected from the resistor.

For many electrical transient measurements such as charge carrier mobility determinations, a large rather noiseless source of dc voltage must be applied rapidly to a capacitive sample and maintained for perhaps a fraction of a second. With conventional voltage sources, the capacitive currents arising from noise and ripple in the dc voltage can easily prevent accurate measurement of the "true" transient current. Measurements of this kind are therefore sometimes made differentially using one real cell, and one similar dummy capacitance; such techniques may still not completely suppress the noise, and they are inconvenient if a range of samples with various capacitances is to be tested. Multishot signal averaging techniques can be used, but they too can be inconvenient and can cause sample polarization problems.

We wish to describe a very simple arrangement by means of which such sources of noise can be eliminated almost entirely, without signal averaging. The "power supply" (Fig. 1) consists of high quality foil capacitors C_1 (Balco Electronics, 5×0.05 μF 600 V, in series), which have a much higher capacitance than the $\sim$50 pF sample cell C_2 and possess an insulation resistance approaching 10^{12} Ω. The capacitors are charged within a few microseconds when required by a single pulse from a high voltage, high current source (Cober model 606); this is capable of delivering single or multiple pulses up to 2500 V at up to 12.5 A. Naturally, if lower voltages, longer charging times or lower capacitances were used, a much simpler pulse source would suffice, especially since we only need single pulses; the noise level of this source is not critical. The current-limiting resistance R_1 is a pair of 400-Ω Caddock precision 3 W noninductive, high-voltage, oxide film resistors (MG750N) in parallel. At the conclusion of the voltage pulse, the Cober voltage drops to near zero, which back-biases the diode D_1; the Cober (and any associated noise) is thus now isolated from the rest of the circuit. D_1 is a Semtech high voltage silicon rectifier (SCF2500), having a stated reverse impedance of at least 2.5×10^{10} Ω at the peak inverse voltage of 2500 V. During this charging procedure, the measuring oscilloscope (Tektronix 7623 A, with 7A22 amplifier, one channel grounded) is protected by two fast-acting switching diodes D_2 and D_3 (G.E. 1N4608); soon after the conclusion of the charging pulse, their impedance rises to a roughly constant small-signal value of $\sim$10 MΩ, which does not significantly shunt the load resistance R_3 (1–100 kΩ).

The voltage applied to the cell is now simply determined by the charge on the capacitor C_1, and is essentially noiseless. A slow decay of this voltage occurs, which is determined for small cell currents by the insulation resistances ($>2.5 \times 10^{10}$ Ω) mentioned above; this causes a small "false," roughly constant, measured current, which is just the leakage current leaving C_1 divided by the ratio C_1/C_2 ($\sim$200). Thus, for a voltage of say 1000–2000 V, this false current is at most in the 10^{-10} A range, and is easily allowed for. If the true cell

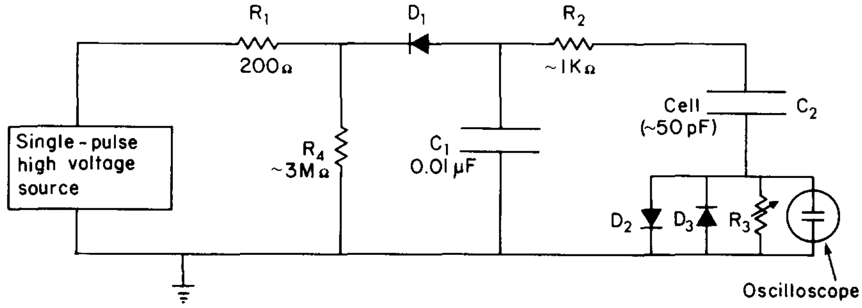

FIG. 1. Circuit diagram for the power supply described in the text.

current is not small, the observed current differs from the true value by the factor $(1 + C_2/C_1)$. This system is obviously suitable only for experimental time scales much less than R_iC_1, where R_i is the overall insulation resistance of the system, including that of the cell; in our case, this is at least many seconds.

We have used this arrangement[1] to apply voltages up to 2500 V to our cell and to measure current transients down to $\sim 10^{-9}$ A with time scales from ~ 50 μs to beyond 10 ms. Within the first 100 μs or so after application of the voltage, the current detection limit is set by the time for the charging transients to die away (which is in turn dependent on the values of C_1 and R_3), while for longer times the limit is set by 60-Hz pick-up and residual circuit noise; these are typically below 10^{-10} A and are somewhat dependent on the timescale of the transient, since this determines how low a frequency cutoff can be selected on the oscilloscope.

To give an example of the performance of this technique, consider a measurement of a 10^{-9} A, 10 ms transient which we made under an applied voltage of 2000 V, with $R_3 = 100$ kΩ and a high-frequency cutoff of 3 kHz. We observed $\sim 3 \times 10^{-11}$ A rms of 60-Hz pick-up, which was unchanged even with C_1 grounded, and which could no doubt be reduced by better shielding. In addition, there was $\sim 2 \times 10^{-11}$ A rms of high-frequency noise, *which is just equal to the Johnson noise to be expected from a 100 kΩ resistor and a 3-kHz bandwidth*. Thus, with no signal averaging, our simple technique reduced the noise essentially to the level set by Johnson noise.

[1] P. S. Vincett, J. Colloid Interface Sci. **69**, 354–357 (1979).

Open vacuum tube in space

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After having reviewed briefly the reliability of vacuum tubes on spacecraft, it is shown that the operation in space of a vacuum tube with an open structure is possible provided adequate measures are taken. The tube considered here is a multielectrode electron gun emitting electrons into space, in order to control the potential of a satellite. To avoid the failure of the most sensitive element of the gun, namely the impregnated tungsten cathode, the gun design includes such characteristics as a slow warming up of the heater element, a reactivation program used in case of cathode contamination, and a clean opening system which is not contaminant. Similarities with communication tubes are considered and the advantages of open tubes are mentioned.

Vacuum tubes have almost disappeared from the electronic systems of modern spacecraft and the travelling wave tube (TWT) is one of the very few vacuum tubes still in use in communication satellites; it is unlikely that it can be replaced by any solid state device in the near future. The lifetime of a properly designed TWT is determined by the depletion of emissive material from the cathode, but failure analysis[1,2] have shown that the cathode is the most sensitive element of the tube.

Among the different causes of failure are

—A snap turn on of a very cold heater element[1];
—A broken window seal which leads to cathode contamination[1];
—Outgassing of electrodes and subsequent cathode poisoning.[2]

Sometimes the failure of the ion pump associated with powerful tubes can also be the cause of the tube failure.[2]

This short note describes how some of the above mentioned failure problems have been successfully solved in the design and the operation of an open structure electron gun emitting electrons into space.

Artificial emission of electrons has been proposed for a long time as a means to control spacecraft potential in space. At different distances from the earth and sometimes at different positions along the orbit (eclipses), the potential of a satellite varies with respect to the surrounding medium. Malfunctions of spacecraft systems and degraded performances of scientific experiments can result from these potential differences and their variations. On the International Sun Earth Explorer 1 (ISEE-1), two open electron guns can be used to stabilize the potential at a value slightly positive with respect to the ionized medium by emitting a beam of electrons into space.

A cross-sectional view of the electron gun is shown on Fig. 1 taken from Ref. 4; the main parts of the