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A CURRENT MIRROR CIRCUIT TO BIAS BEAM INTERCEPTING PICK UP ELECTRODES

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ABSTRACT

Beam properties are often determined by measuring the current induced on intercepting electrodes. To collect the full signal current, it is desirable to bias the electrodes. The system discussed in this note makes use of a current mirror circuit to allow the use of a shared bias supply while dispensing with the need for isolation amplifiers. Low power, high voltage bipolar transistors, matched for best performance, form the mirror. The circuit has a wide dynamic range, which can exceed 10^4. Though it is unipolar, versions can be made for either positive or negative polarity. Spark protection is provided by including a current limiting circuit. A current mirror system has been constructed and used in a TRIUMF H^- ion source. The device provides eight measurement channels and supplies 400 V at up to 1 mA.

INTRODUCTION

Skimmer plates and targets intercepting 12 keV H^- ions require a positive bias exceeding 50 V to collect scattered and thermionic electrons. As the bias level is increased from zero the signal increases until a plateau region is reached. Bias voltages of 300 V to 400 V are often used to ensure operation in the plateau region and with H^- ion beams of higher energy. The current mirror circuit provides the required clearing fields while avoiding the disadvantages of other commonly used methods which are discussed next [1].

Pick up electrode bias can be provided by a floating bias supply in series with the amplifier input, which remains near ground level. This requires one independent bias supply per channel and is often implemented with batteries. The amplifier is prone to damage because a spark at the pick up electrode momentarily connects the supply across the amplifier input. Another biasing scheme uses isolated amplifiers and a shared bias supply. Isolation of the amplifier output, power, and gain ranging control are all required. This can become expensive and the amplifiers are again prone to spark damage. Instead of biasing the pick up electrode, it can be held near ground voltage and surrounded by biased electrodes. This can complicate the construction of the device, however, by requiring extra plates, insulators, and feedthrus. The current mirror circuit avoids these problems.

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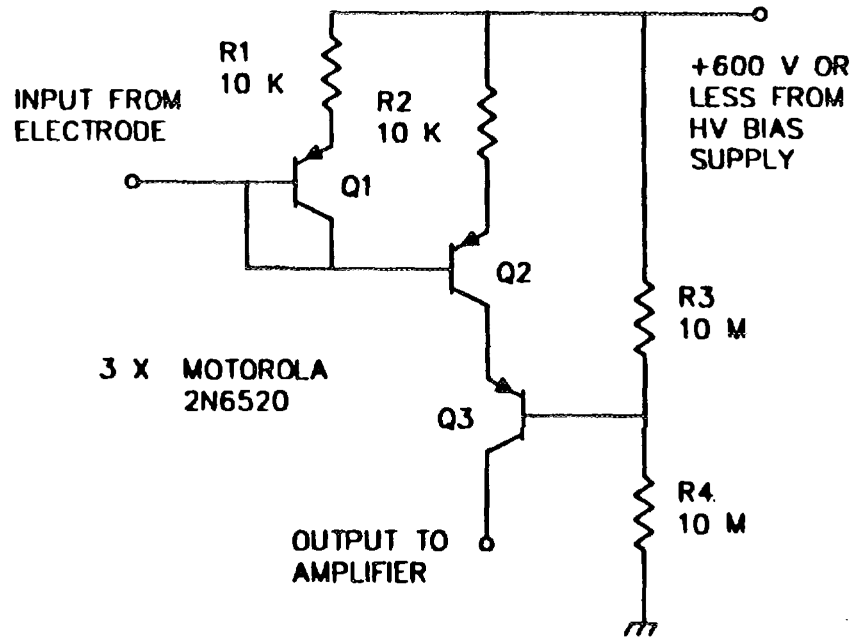

Figure 1. Current mirror circuit.

CURRENT MIRROR CIRCUIT

In figure 1, the current mirror consists of Q_1, Q_2, R_1, and R_2. Q_1 holds the electrode at a voltage close to the high voltage bias voltage. R_1 and R_2 are chosen so that their voltage drop is small compared to the supply voltage at the highest signal current (1 mA in this example). If the transistor gains are high, most of the electrode current will flow through the collector of Q_1. Disregarding R_1 and R_2 for the moment, it is evident that Q_1 and Q_2 must have the same base to emitter voltage and, if they are matched, the same collector current. Applying the Ebers-Moll equations to the current mirror yields two limiting cases [2]. At low electrode currents, the base to emitter voltage of the transistors is large compared to the voltage across their emitter resistors. If Q_1 and Q_2 are matched and at the same temperature, the transfer function is as shown in equation 1.

$$\frac{i_{c2}}{i_{electrode}} = \frac{\beta_2}{2 + \beta_2} \qquad (1)$$

where: i_{c2} is the collector current of Q_2

$i_{electrode}$ is the current from the beam intercepting electrode

β_2 is the current gain of Q_2

Over the highest two decades of electrode current, the voltage drop across the emitter resistors swamps the base to emitter voltages of the transistors. The resistors can be adjusted at the highest current to make $i_{out} = i_{electrode}$ as shown in equation 2.

$$\frac{R_2}{R_1} = \frac{\beta_2 - 1}{\beta_2 + 1} \qquad (2)$$

The collector of Q_2 can be at a much lower voltage than its base, allowing it to be connected to a current amplifier whose input is near ground voltage. Readily available low leakage transistors, such as the Motorola 2N6520, can withstand up to 350 V.

Q_3, R_3, and R_4 can be included to double the voltage safety margin of the circuit. Q_3 is connected in a common base configuration with its base biased at half the supply voltage. If Q_3 has high gain, its collector current is nearly equal to its emitter current. Q_2 and Q_3 will share the supply voltage allowing a bias of 400 V with a 300 V safety margin.

TRANSISTOR SELECTION

The gain of a Motorola MPSA44 transistor can range from 40 to 200 at 1 mA of collector current. The gain decreases with decreasing current falling to about 20 % of its 1 mA value at 100 nA. The leakage of the current mirror circuit is twice the I_{CBO} (collector cutoff current) of Q_2, which ranged from 0.5 to 1.3 nA at 23 °C and 300 V for the sample of 10 transistors which were tested. The leakage doubles for every 10 °C increase in temperature, indicating that the circuit offset could reach 8 to 21 nA at 53 °C. Q_1 and Q_2 must be at the same temperature for equation 1 to hold and should be epoxied together to insure good thermal contact. Heating of Q_2 sets an upper limit on the signal current of about 1 mA. The maximum allowable device dissipation for these transistors in a TO-92 plastic case is 625 mW at 25 °C ambient, derated at 5 mW/°C.

Transistors can be selected to give improved performance. Q_2 should be selected for high gain and low leakage. Q_1 should then be chosen to best match Q_2 in the mirror configuration at low current. It was found that pairs of transistors could easily be selected to yield an absolute accuracy of ±10 % in the low current region and ±3 % in the high current region.

For a negative bias supply, NPN transistors must be used instead of PNP in the current mirror. Table I lists some inexpensive devices of both types.

Table I. Suitable current mirror transistors.

Transistor	Type	Breakdown (V)	Package
MPSA44	NPN	400	Single
MPSA45	NPN	350	Single
2N6516	NPN	350	Single
MPQ7043	NPN	250	Quad
2N6520	PNP	350	Single
MPSA92	PNP	300	Single
2N6519	PNP	300	Single
MPQ7093	PNP	250	Quad

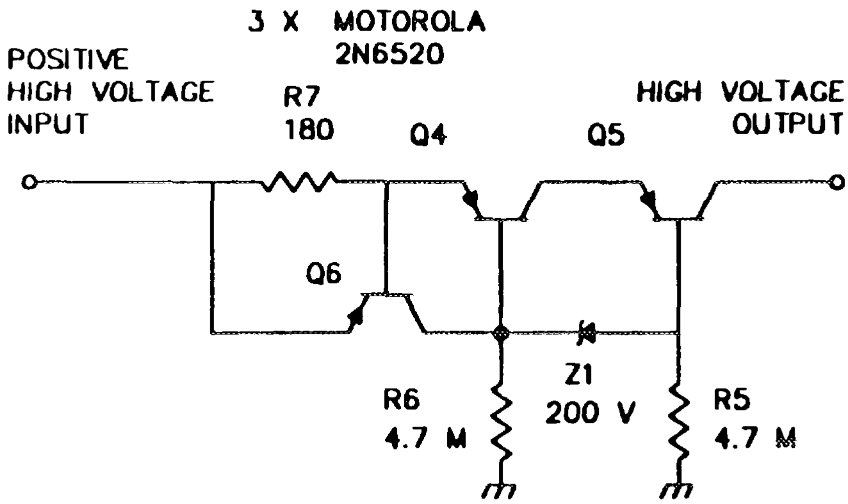

Figure 2. Current limiter circuit.

CURRENT LIMITER CIRCUIT

The current limiter circuit is shown in figure 2. The basic circuit consists of Q_4, Q_6, R_6, and R_7. The value of R_7 has been selected so that when more than 2 mA passes through it, Q_6 conducts preventing Q_4 from passing more current. The current limit must be twice that of the total electrode current as an equal current flows in the current mirror output. Q_5, Z1, and R_5 may be added to double the withstand voltage. The heat dissipation in Q_4 and Q_5 can be halved by paralleling them with two more transistors and adding emitter resistors to force current sharing.

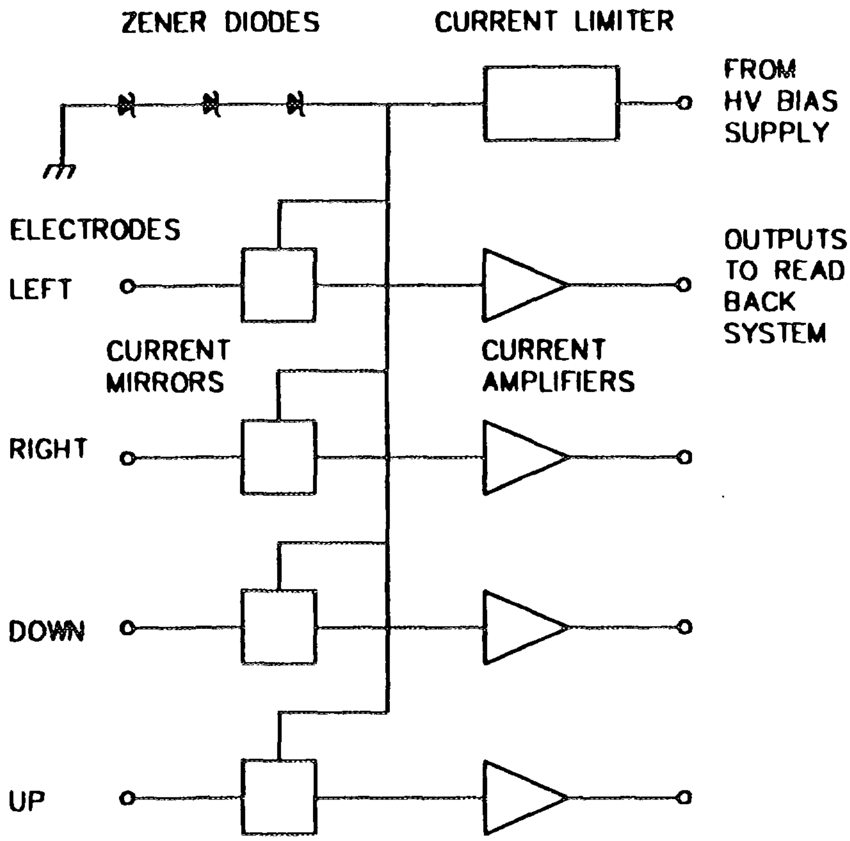

Figure 3. System layout.

STEP RESPONSE

A measure of the speed of the current mirror was made by replacing the electrode by another transistor of the same type used in the current mirror to switch the input current on and off. The current was switched from zero to various levels from 10μA to 1 mA. The rise and fall time of the output current was less than about 1 μS.

SYSTEM LAYOUT

Figure 3 shows a possible configuration consisting of four current mirrors and a single current limiter. This layout is less complex than one using a current limiter in series with each pick up electrode, though an electrode short to ground would lower the bias to all four channels. Standard operational amplifiers are used in the current amplifiers.

The power supply must have low ripple to be useful in a current mirror system. It was found that a high voltage switching supply module, the MIL Electronics VH10, generated a 20 V P/P ripple at 3 kHz. This caused current pulses due to charging and discharging of the coaxial cables connecting the electrodes to the current mirrors. The pulses were triangular shaped, 60 μS FWHM, and 300 μA from base to peak. The pulses can be reduced to acceptable levels by using a well filtered high voltage bias supply or short connecting cables.

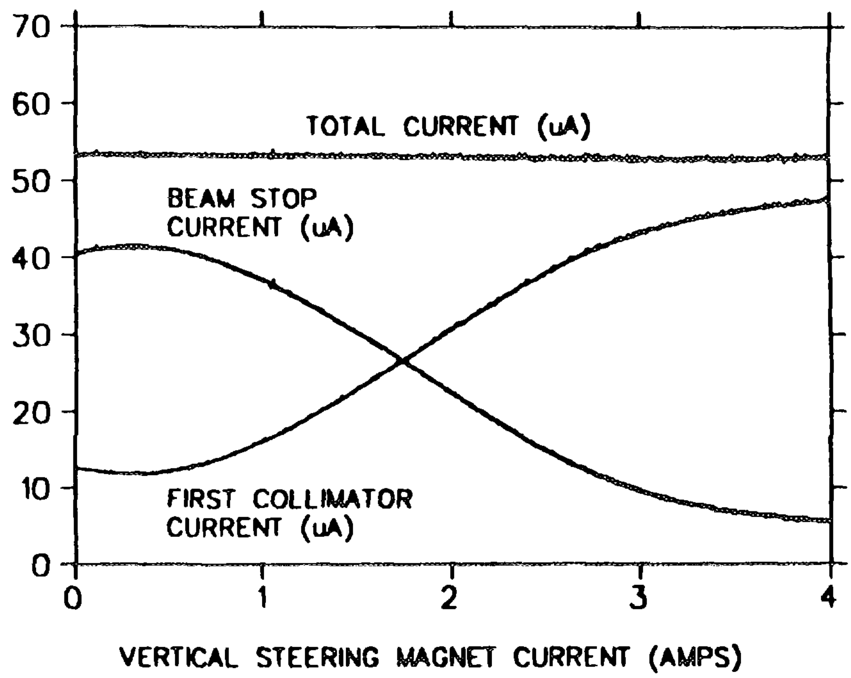

Figure 4. Beam steered across a collimator and a target.

ION SOURCE COLLIMATOR SIGNALS

A cusp H^- ion source was commissioned in Spring 1993. A current mirror unit was built for this project. It contains two high voltage power supplies providing bias for 4 measurement channels each. The bias is 400 V and up to 1 mA total can be drawn from each supply. Presently only 3 channels are in use. The unit has been in use for about 3 months and has performed well, except for the initial failure of a power supply module. Fig. 4 shows the signals from a collimator using a current mirror channel and from a downstream target that uses a conventional grounded input current amplifier. Beam that misses the collimator is collected by the target. As the ion beam is steered across the collimator and target the signals vary but their total remains constant.

REFERENCES

[1] W. R. Rawnsley, TRIUMF Design Note, TRI-DN-90-14 (1990)
[2] J. J. Ebers and J. L. Moll, Proc. IRE, vol. 42, p. 1761 (1954)