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AN ELECTROSTATIC ION BEAM SCANNING SYSTEM

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AN ELECTROSTATIC ION BEAM SCANNING SYSTEM

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ABSTRACT

An electrostatic scanning system has been designed and built to uniformly implant a 1 cm^2 sample with a charged particle beam. The full angular scan capability for a 2 MeV beam is 0.5 degrees at 6 kV p-p. The design of the system is extremely simple so it is very compact, easy to operate, and has shown very good reliability.

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1. Introduction

In ion implantation processes, it is often necessary to uniformly implant a large area sample with a positive ion beam having a cross-sectional area much smaller than that of the sample. Due to a typically Gaussian spatial profile of most ion beams, defocusing is an ineffective solution to the problem of nonuniform implants. Therefore a form of beam or sample scanning is desirable to evenly distribute the center of beam intensity to all points on the sample surface. Beam scanning allows for greater versatility in sample handling, and is the most practical choice for our application.

There are scanning systems commercially available from a few manufacturers, most of which use electrostatic deflection. However, there were drawbacks with the performance of these units. First, we desired an extremely low scanning frequency not available in commercial units. In addition, the maximum deflection plate voltage available would limit the size targets we could implant to unacceptably small areas for typical experimental configurations. The units available are also not inexpensive, the cheapest units being about \$3500.

We decided to design a unit that would fit our needs and be sufficiently versatile to accommodate most implantation applications. There are two different scanning techniques that will effectively displace a charged particle beam at a reasonable frequency. These are the electromagnetic and the electrostatic scanning systems. We chose the electrostatic system because it

is dependent upon beam energy and particle charge and independent of particle mass.

II. Design and Performance

It was desirable to build the system so that the scanning plates could be operated remotely, from the outside of an accelerator radiation vault, for example. This restriction gave rise to the two unit construction that we designed, consisting of a beam scan generator which delivers two low voltage triangular wave signals (25 V p-p) to a high voltage amplifier some distance away. Shielded cables connect the generator output to the amplifier input to eliminate noise pickup due to the distance the units are separated (≈ 60 ft.) and to the noisy environment in which they operate.

The maximum scanning condition we would need to meet was implanting a one centimeter square target with a 2 MeV singly charged ion beam. The angular displacement corresponding to these conditions can be determined from the equation:¹

$$\tan \theta = \left(\frac{L}{2d} \right) \left(\frac{V_o}{V_a} \right) \quad (1)$$

where L is the deflection plate length, d is the deflection plate separation, V_o is the deflection plate potential, and V_a is the acceleration potential. Since $\tan \theta$ is equal to the linear displacement, D , divided by the distance, λ , from the center of the scanning plates to the target area, the linear displacement is given by

$$D = \lambda \left(\frac{L}{2d} \right) \left(\frac{V_o}{V_a} \right) \quad (2)$$

Thus, the necessary deflection voltage for any condition is given by

$$V_0 = \frac{2dDV_a}{\lambda L} \quad (3)$$

A High Voltage Equipment Corporation deflection chamber was already installed in the beam line at a distance, λ , of 200 cm from the center of the deflection plates to the target area. The unit has a deflection plate length, L , of 23 cm and plate separation, d , of 3.8 cm. Using these values in Equation 3, V_0 is calculated to be approximately 6 kV p-p.

As discussed, our application dictated a two unit design. The beam scan generator (Fig. 1) produced two low voltage (25 V p-p) triangle wave signals of variable frequency. We will describe only the vertical channel since the operation of the horizontal channel is identical, except that the scan frequency is different. The composite of A1, R1, R2, R3, and C1 (Fig. 1) is a square wave generator, whose frequency is directly determined by the R1 and C1 components and indirectly by R2. The function of R2 is to set the threshold at which the A1 output changes polarity. If the output is positive (e_0^+), C1 charges through R1 towards e_0^+ and continues until e_{C1} exceeds the threshold, $e_0 R3/(R2 + R3)$ at which point e_0 changes polarity.

The square wave signal from A1 is D.C. isolated and coupled to the integrator A2 through C2. A gain control element, R4, sets the output to the desired level without clipping or any other unwanted distortion. The output of A2, e_0 , is related to the input, e_i , by the relation

$$e_0(t) \propto \frac{1}{R5C3} \int e_i(t) dt \quad (4)$$

Since e_i is a square wave, e_o is a triangle wave of the same frequency with an amplitude determined by R4, R5, and C3. Any portion of the A2 integrator output from 0-100% is available at the wiper of R7, a linear, precision 10 turn, 50 k Ω potentiometer, to the input of A3, the output driver. A3 is a unity gain buffer amplifier which is necessary to drive the large capacitive load of the great length of connecting cable to the beam scan amplifier.

The beam scan amplifier receives the 2 low voltage triangle wave signals from the beam scan generator, splits each channel into an inverted and noninverted signal, amplifies each signal, and delivers the high voltage triangle waveforms to the appropriate deflection plates.

As can be seen in Figure 3, the horizontal and vertical channels of the beam scan amplifier are also identical thus only the operation of the vertical channel will be described. The output of the generator is coupled through C1 to the grid of V1 and the inverting input of A1 (Fig. 2). A1 is used as a balancing system to ensure that the amplitude of the input to V2 is equal to the amplitude of the input to V1. This is accomplished through gain control element R3. A1 also serves the purpose of a phase splitter, since e_o is 180° out of phase with e_i or $e_o = -Ae_i$. As the output of V1 goes negative, the output of V2 goes positive and the effective peak scanning voltage is doubled. V1 and V2 are high gain (≈ 250) high voltage amplifiers with DC isolated, zero centered outputs (zero centering can be ensured with a high resistance ground return: $R > 100 \text{ M}\Omega$). The bias

level (V1) is determined by the series combination of R15 and R19. Copper shielding and coaxial cables are used extensively to prevent crosstalk between the four high voltage triangle wave output signals

The signal generator unit was built entirely from readily available standard value components with both channels mounted in one 2 1/2" standard rack mount chassis. The simple operation and small component count are responsible for the compactness of the unit. The ultimate frequency limiting factor is the frequency response of the op amps which is much higher than the necessary scanning frequency. Therefore the horizontal channel gives a usable 25 V p-p output from 0.5 Hz to 250 Hz and the vertical channel from 100 Hz to 3 kHz. Operating below the lower frequencies affects the linearity of the triangle waves, while extending the upper ranges reduces the output amplitude below acceptable levels. Once the scan frequencies and gain are set the output potentiometers can be continuously varied to set the proper scanning voltage for a given beam energy to whatever displacement is desired.

The entire high voltage amplifier unit is enclosed in a chassis on an 8" standard rack mount panel, the size being limited by the dimensions of the Del power supply. The amplifier is capable of producing a 6 kV p-p signal to each deflector plate with a DC offset of not greater than 20 VDC with the plates floating and no beam passing between the plates. In the presence of a beam the plates develop a self charge. To counteract this phenomenon we added 500 M Ω ground return resistors to each plate.

This has no noticeable effect on the output amplitude. The absolute maximum power consumption of the unit is 12.5 W.

The frequency response of the amplifier is from < 1 Hz to 2.5 kHz. However, the overall response is limited by the total capacitance of the connecting cables from the output of the amplifier to the deflection plates, so it is desirable to make these cables as short as possible. We used 5 foot lengths of RG59 B/U coaxial cable. With these cable lengths roll off occurs at approximately 370 Hz. We operate the vertical channels at 160 Hz with 90% output and 2 Hz with 100% output for the horizontal channels. This provides 80 vertical scans for each horizontal trace which evenly covers the target area.

III. Conclusions

We examined the problems associated with even implantation of samples with charged particle beams and decided on an electrostatic scanning system. We designed the system such that it requires readily available standard value components. Because of this simple design, the unit is very compact and easy to operate. The frequency response and maximum deflection angle of the system are such that it will exceed any scanning requirements we can reasonably expect. It has also proven to be very reliable in laboratory usage.

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REFERENCES

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2. John D. Lenk, Manual for Integrated Circuit Users (Reel 1 Publishing Co., Inc., Reston, Virginia, 1973).

NOTES:

1. A1-A6 μ A741 OP AMPS
2. ALL RESISTORS IN Ω 'S 1/2W
3. PS1 ANALOG DEVICES NUMBER 902

BEAM SCAN GENERATOR

Figure 1. Beam scan generator - schematic diagram.

NOTES:

1. V1-V4 VICTOREEN 7235 TRIODE
2. A1-A2 μ A741 OP AMP
3. C5-C6 0.1 μ F 5 KVDC
4. PS1 DEL ELECTRONICS 7.5-10-1
5. PS2 ANALOG DEVICES 902

BEAM SCAN AMPLIFIER

Figure 2. Beam scan amplifier - schematic diagram.

FIG. 3
 PLATE VOLTAGE vs. BEAM DEFLECTION
 FOR ION BEAMS OF DIFFERENT ENERGIES

Figure 3. Plate voltage vs linear beam deflection at length of 200 cm for varying ion beam energies.

FIG. 4

CABLE ATTENUATION vs. FREQUENCY
5 FT. LENGTHS OF RG 59 B/U COAXIAL CABLE

Figure 4. Attenuation due to connecting cables vs frequency for 5 ft. lengths of RG59 B/U coaxial cable.