Switching Notes

Note 18

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Self-Biasing of Three-Electrode Switches

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ABSTRACT

A theoretical mechanism for the self-biasing of trigger electrodes in three-electrode switches is proposed. Experimental data consistent with the proposed mechanism are presented.

I. INTRODUCTION

The experimental work reported in this note was performed in order to determine the effect of trigger electrode biasing resistance on the self-fire voltage (V_{SB}) of three-electrode switches with sharp trigger electrodes. The study was stimulated by data obtained during testing of the 1 MV "Molecule" Marx generator shown schematically in Fig 1. The Marx switches (Fig 2) consisted of 0.5 inch brass balls for the main electrodes and a sharp, brass wedge trigger electrode. Total gap spacing was 0.243 inch, and the trigger electrode was positioned at the geometrical 1/3 position (theoretical V/3 position).

It was observed during testing that increasing the impedance of the switch biasing network significantly increased V_{SB} of the Marx. V_{SB} reached a maximum value when the biasing network was removed completely and the trigger chain allowed to float. It was postulated that this surprising effect was due to a self-biasing mechanism associated with corona produced at the sharp edge of the trigger electrode. Not to be confused with a self-shielding space charge effect, the postulated mechanism involves a change of trigger electrode potential due to corona charge transfer.

In theory, a perfect switch would have no static trigger corona at all. The trigger electrode would be positioned so that it perfectly matched an equipotential surface and caused no perburbation of the static fields. This theoretical switch would have no field enhancement and, therefore, no corona on the trigger electrode.

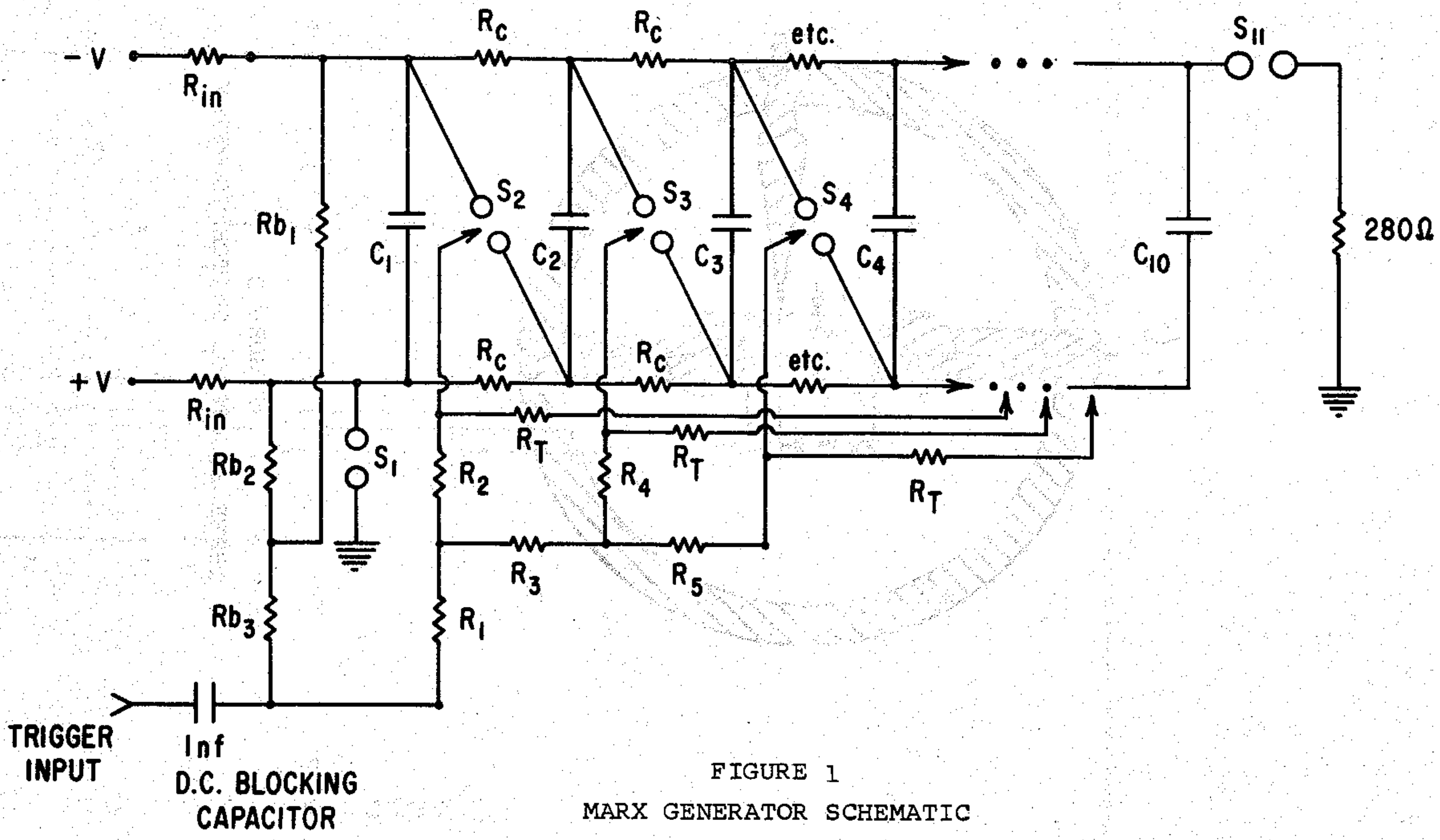

FIGURE 1
MARX GENERATOR SCHEMATIC

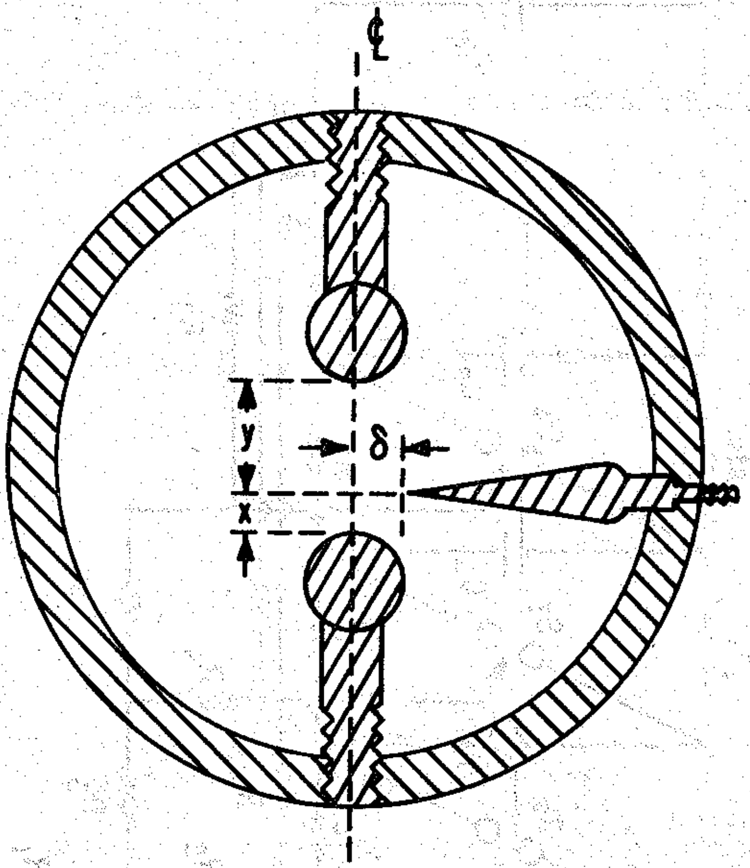

FIGURE 2
THREE-ELECTRODE SWITCH GEOMETRY

Such a condition can be closely approximated in a mid-plane configuration, since the trigger electrode can be thin and located exactly on the V/2 potential surface. A wedge electrode placed at mid-line fails to achieve perfect balance because of its finite thickness, even though it has some symmetry. If such an electrode is allowed to float it will alter the field distribution until it does fit an equipotential. In the process, however, redistribution charges can build up along the sharp edge and produce local gradients which exceed the corona threshold.

While the corona is occurring the trigger electrode will acquire a net charge and cause further field alteration until the edge drops below the corona threshold. At this point the electrode is perfectly balanced, and no further corona or field perturbation can occur.

A sharp wedge electrode located at the V/3 position as in Fig 2, due to lack of symmetry, should cause more severe field perturbation and consequently more corona than the mid-line electrode. Even so, if allowed to float it too will eventually reach equilibrium. The problems occur when the trigger electrode is clamped to some fixed potential. In the case of the mid-plane biased at V/2 there should be little problem. In the cases of the wedge trigger electrodes, the mid-line position should have some problems and the offset position even more due to its lack of symmetry. As the edge starts to corona the electrode tries to change potential, but the biasing network tries to keep the potential fixed. An equilibrium current will be established based on the amount of field perturbation and the ability of the biasing network (i.e., impedance) to clamp the trigger at a fixed potential.

It is postulated that the equilibrium corona current is some function of the field perturbation and the biasing network impedance:

$$(I_c)_{eq.} = g(f_p, Z_B) \tag{1}$$

and,

$$\frac{\partial g}{\partial f_p} \geqslant 0 \tag{2}$$

$$\frac{\partial g}{\partial Z_B} \leqslant 0 \tag{3}$$

where, I_c = corona current

f_p = a field perturbation factor which is a function of electrode geometry

f_p (mid-plane) < f_p (mid-line wedge) < f_p (offset wedge)

But because the corona current is feeding irradiation into the gap its effect is to reduce V_{SB}. The same phenomenon occurs when a charged spark gap is irradiated with external UV. In general, the greater the UV intensity the lower the voltage at which the gap will spark.

If V_{SB_o} is the theoretical maximum self-fire voltage for the marx switch with no irradiation or trigger electrode perturbation then,

$$\left[V_{SB_o} - V_{SB}\right] = f\left[(I_c)_{eq.}\right] = f\left[g(f_p, Z_B)\right] \tag{4}$$

and,

$$\frac{\partial f}{\partial f_p} \geqslant 0 \tag{5}$$

$$\frac{\partial f}{\partial Z_B} \leqslant 0 \tag{6}$$

II. PROCEDURE

The Marx switch was tested in the circuit configuration of Fig 3. All voltage readings were taken directly from the power supply panel meter which was checked periodically with an electrostatic voltmeter. Accuracy was within the panel meter reading precision of ± 1 kV.

Self-fire measurements were made for combinations of three main gap settings, two trigger electrode positions, and three gas pressures. Bottled air which had been passed through a drying cartridge was used for all measurements. For each combination of switch parameters, at least twenty voltage readings were taken and the results averaged. All measurements were corrected for the voltage drop across the 2 meg input resistor.

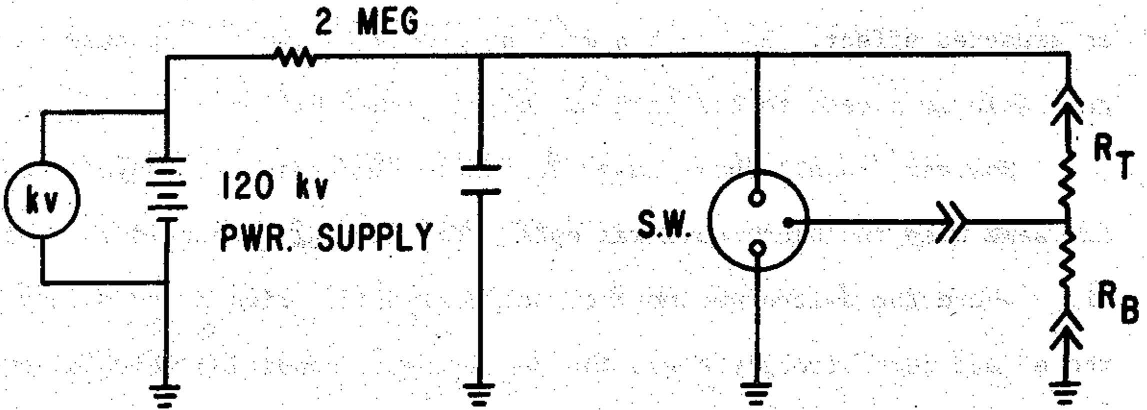

FIGURE 3. TEST CIRCUIT

III. RESULTS

The graphs in this section show the effect of biasing impedance on V_{SB}. All switch dimensions are referenced with respect to Fig 2 and bias parameters with respect to Fig 3. It should be noted that when the biasing impedance is listed as "open", the external biasing network was disconnected. The actual biasing was then determined by the surface resistance of the switch housing. Error bars shown on the graphs include both V_{SB} scatter and measurement uncertainties.

Data for three main gap settings are presented, all with a total gap spacing of 0.243 inches but with different trigger electrode positions. Fig 4 was obtained with the trigger set at the V/3 position, or a long gap to short gap ratio of 2:1. In Fig 5 the ratio was 1.3:1, and in Fig 6 it was 3.2:1. In all cases, when the biasing ratio did not match the gap ratio, the result was a reduction of V_{SB} -- certainly an expected effect. In Fig 5 a maximum occurs at 200/200 because the gap ratio is closer to 1:1 than any of the other biasing ratios.

However, in all three cases V_{SB} either increased or stayed about the same when the bias chain was open. The weakest effect is shown in Fig 4 where the switch was most closely balanced. Figs 5 and 6 show the effect more strongly since the only biasing condition which allowed them to properly balance was the open circuit. Also, in most cases V_{SB} was slightly higher for $\delta = 0.09$ inches than for $\delta = 0.00$ inch. This effect is consistent with a decrease in field perturbation as the trigger electrode is withdrawn into a region of lower field strength.

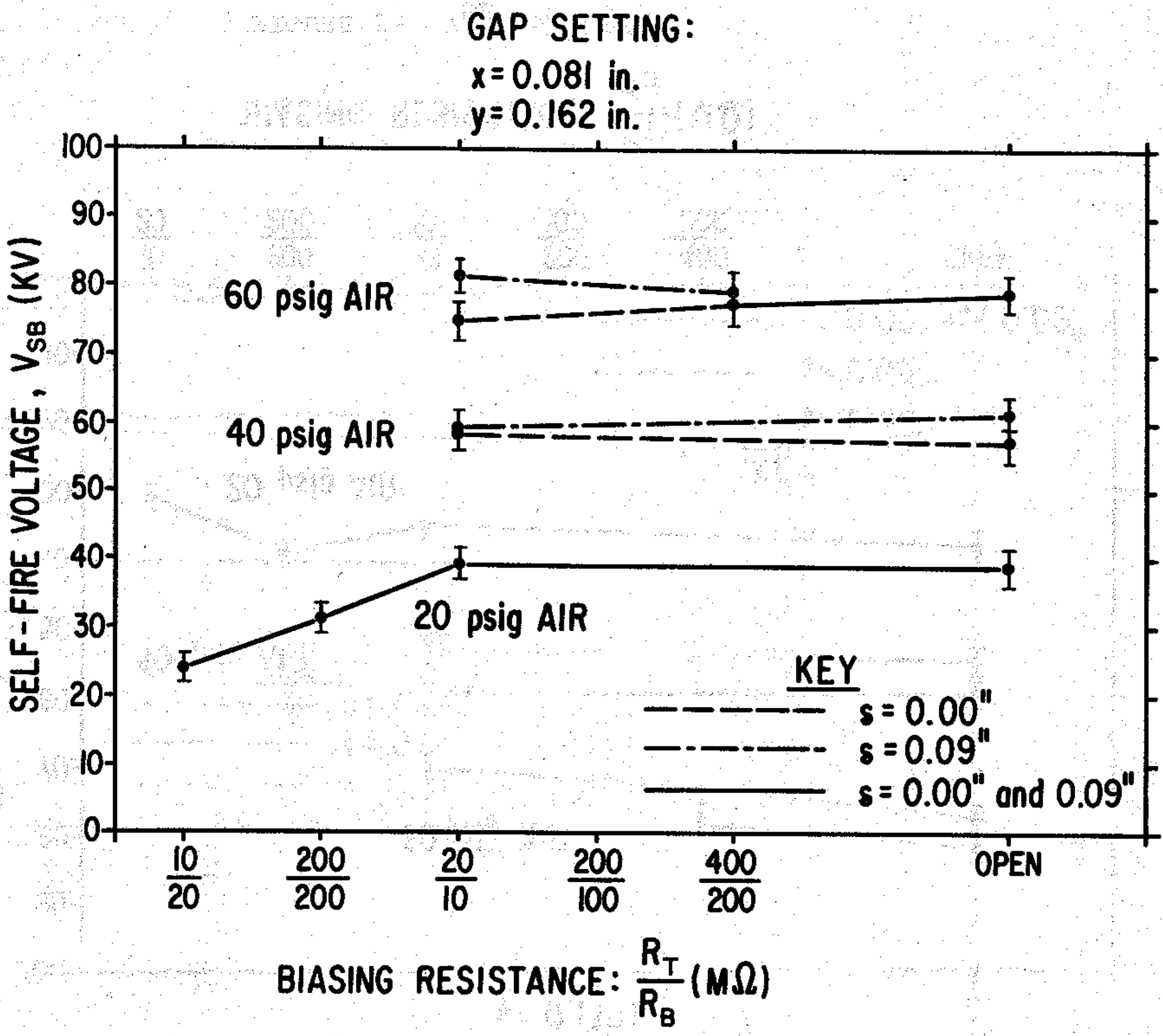

FIGURE 4. V_{SB} vs BIAS

GAP RATIO: 2:1

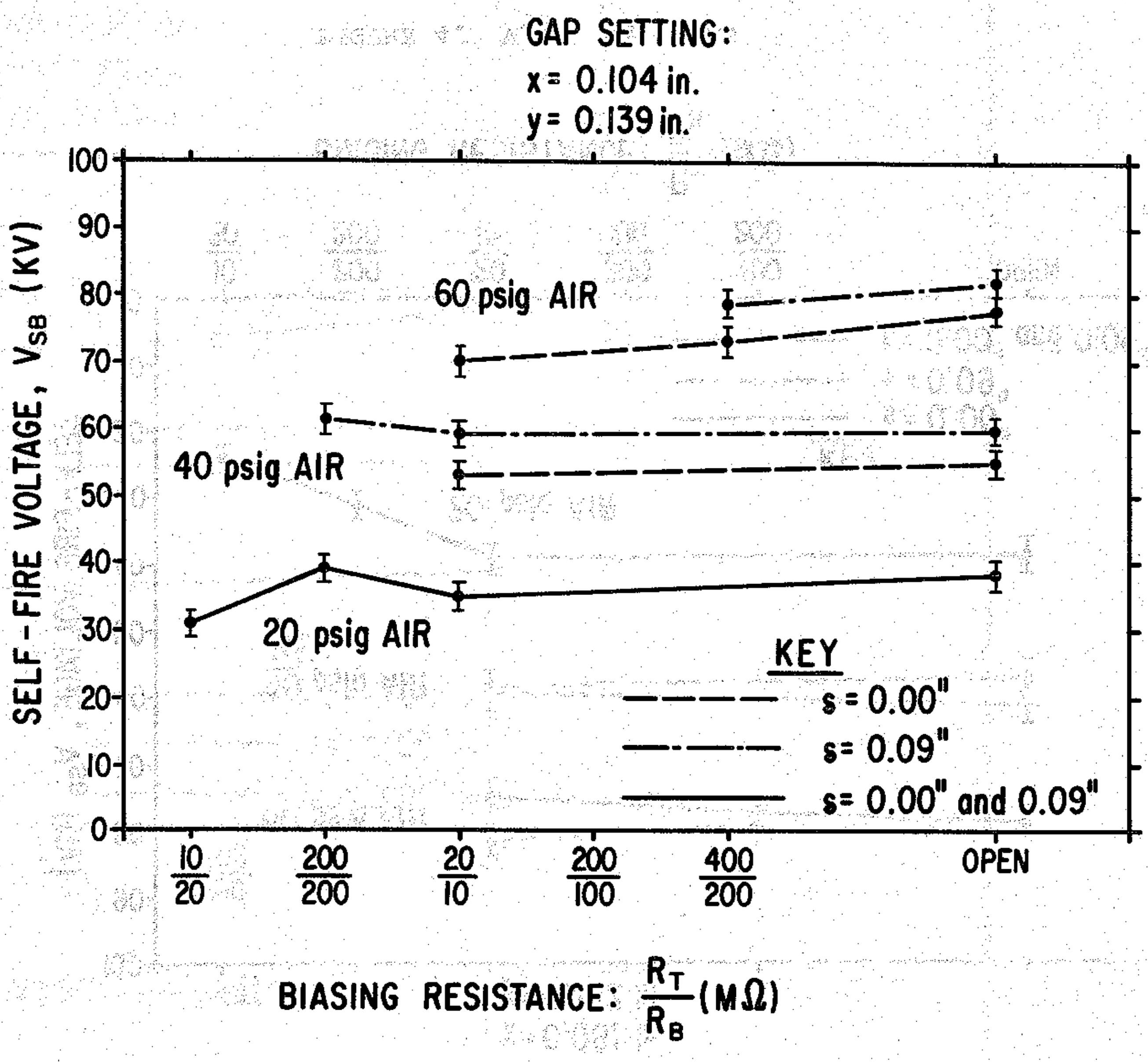

FIGURE 5. V_{SB} vs BIAS

GAP RATIO: 1.3:1

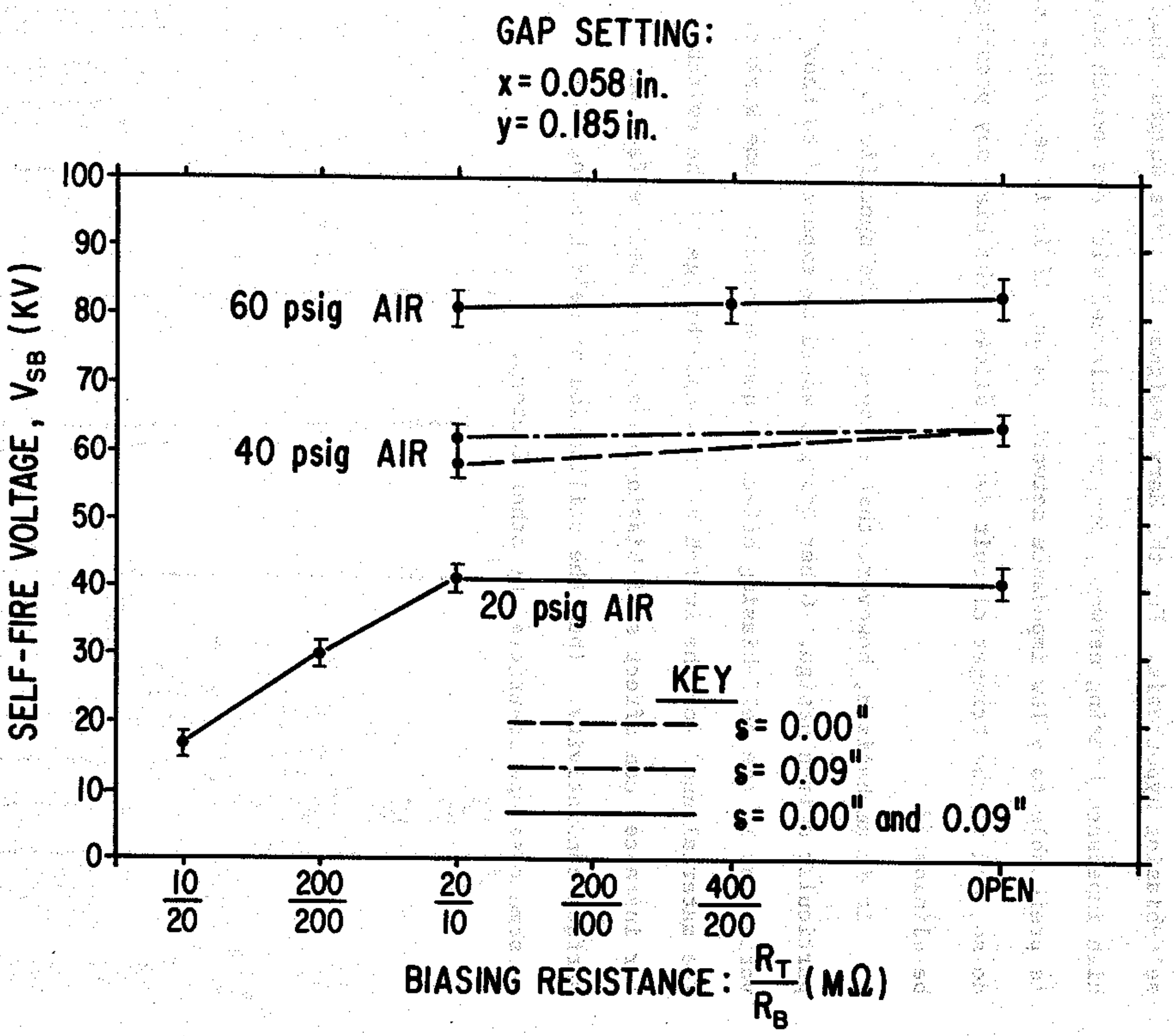

FIGURE 6. V_{SB} vs BIAS

GAP RATIO: 3.2:1

IV. CONCLUSIONS

Within experimental limits, the results of this study follow the relationships of equations 4, 5 and 6, thereby lending support to the self-biasing hypothesis. For the Marx designer the data suggest that a high impedance biasing network, properly balanced with the switch settings, is preferable to a low impedance network. Also, if it is desirable to do so, and if the trigger circuit design allows, the bias may possibly be eliminated.

It is emphasized, however, that these data are specific to a particular switch design. Other designs would be expected to show variations in the self-biasing effect -- some stronger, some weaker. The material used for the switch housing and the age of the switch, for instance, can affect self-biasing because of their effect on surface conductivity. Thus the utilization of self-biasing, may in some case, be restricted by other factors.