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CHARACTERISTICS OF BEAM-X SWITCHES IN THE MEGACYCLE RANGE AND SUMMARY OF BASIC OPERATION

by

D. G. Czarnetzki

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D. G. Czarnetzki
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INTRODUCTION

A Beam-X switch circuit was designed to operate at a frequency of 1 mc/s, and to provide a nominal output into a small resistive load. Since constant currents of the order of 10 ma were desired, normally saturated NPN transistors were employed as common-emitter amplifiers at each of the ten outputs.

GENERAL DESCRIPTION

The Beam-X switch (Type BX-1000) developed by the Electronic Tube Division of the Burroughs Corporation, combines vacuum and magnetic technique in a decimal switching device which contains a four-electrode structure at each of ten positions. These ten arrays are located radially around a central cathode, each array consisting of:

(1) A spade element for beam-forming and locking;

(2) A target element providing constant-current outputs;

(3) A high-impedance switching grid;

(4) A shield grid for isolating grid input requirements from target output levels. This element, which results in greatly improved switching and output characteristics, clearly distinguishes the Beam-X switch from earlier switching tubes. In normal operation the shield grids are connected to the spade buss, and draw only negligible current.

The Beam-X switch in the basic circuit forms a ten-position device that may remain in one position indefinitely or switch at frequencies from dc to 3 mc/s--either sequentially or at random--for every change in negative voltage that is applied alternately to an even-odd paired grid input. The tube may be interconnected as a distributor of any number of positions and is capable of being preset to any position, resetting in less than a microsecond. These versatile tubes are also used to perform the functions of counting, multiplexing, dividing, gating, coding and decoding, sampling, timing, memory, and similar digital operations.

THEORY OF OPERATION

The contents of this section for the most part repeat existing literature, hence only the minimal elements of the theory of operation of Beam-X switches will be reviewed. These will serve to marshal just those facts and relations that make for simplification and ease from the standpoint of the design engineer. The elegant reports listed in the references should be consulted for a more thoroughgoing understanding of the "hidden mechanisms and inner workings" of switching tubes.

The Beam-X switch utilizes crossed electric and magnetic fields in its operation and is similar to the multiple anode magnetron. The standardized cross section of the Beam-X switch is shown in Figure 1, which illustrates the cut-off or cleared state. The tube has both stable and astable states. When the supply voltages are first applied, the tube will assume one of the stable states known as cut-off. In this state there is no current to any of the targets and grid driving pulses are ineffectual. The beam can be established in any of the positions by merely lowering the potential of the spade associated with that position. This operation is called "zero-setting," "resetting" or "beam setting." Figure 2A shows the beam in its formed state, and Figure 2B shows the corresponding static spade-target characteristic.

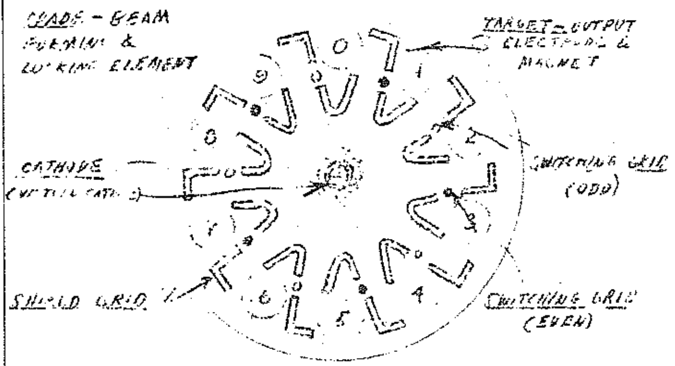
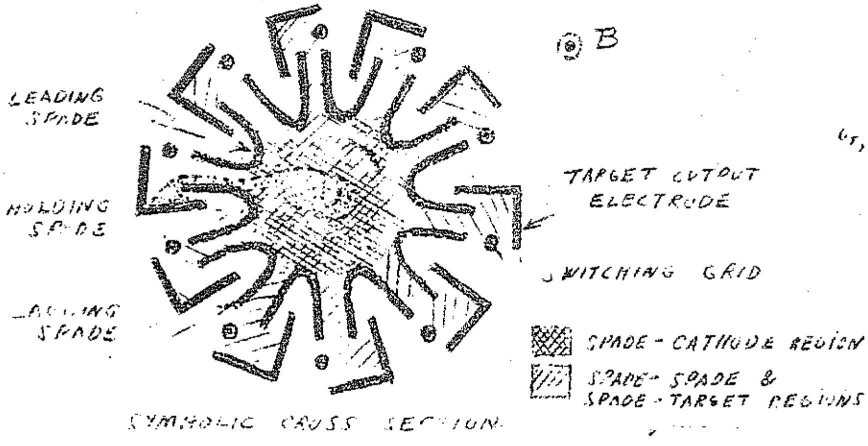


FIGURE 1



SYMBOLIC CROSS SECTION

FIGURE 2A

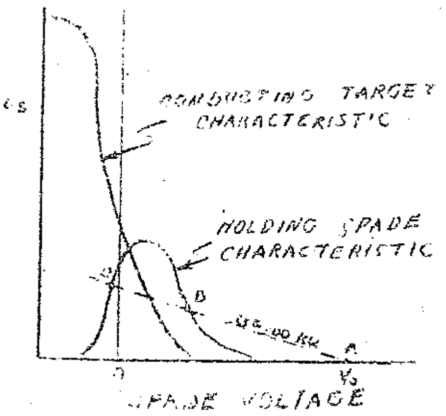


FIGURE 2B

Because of the beam-forming property of the crossed fields, the spade current voltage characteristic is such that as the voltage is lowered the current increases, comes to a peak, and then decreases. This nonlinear characteristic of the spade, similar to the anode in the split-anode magnetron, can result in either stable or astable states when proper impedances are added to the individual spades. Figure 2B shows a load line intersecting the static spade characteristic at points A, B, and C. Two of these, A and C, are stable operating points; point B, however, is a regenerative point and is unstable. At A all spades are at their operating potential V_s and no current is present; therefore, the tube is in the cut-off condition. If one spade, called the J spade, is lowered in potential, current will be initiated at an increasing rate to that spade. When at or near point B,[*] the spade current is sufficient to maintain the spade at this potential, but due to the negative and positive characteristic of the spade, the spade potential decreases until point C is reached. The process forms and locks the beam on the J spade. The holding spade requires only about 15% of the beam current to lock the spade at point C.[†] The remainder of the current is passed on to the associated target where it is available for a "pentode-like" constant-current output.[‡]

If the J spade is held at or near the cathode potential and the potential of the leading spade--the (J+1)th spade--is lowered from V_s, then a larger dynamic curve results for the leading spade characteristic during this switching interval

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[*] Refer to References (1) and (2) for a discussion of saddle points (equipotential line cross-over).

[†] The electron flow to a negative potential spade does not constitute a violation of the conservation of energy. Experimentation implies that an electronic oscillation exists along the beam. Hence, an electron leaving the cathode with low initial velocity may gain velocity, owing to this electronic oscillation, and be able to reach the negative potential spade.

[‡] The target current I_T is dependent on the spade-buss voltage V_s, spade-load resistance V_s, and the conducting-target voltage V_{TB}.

and becomes the static characteristic as the voltage of the J spade recovers through its RC time constant from point C to point A. This simulates the condition that exists during the switching interval which is of a nanosecond duration.[*] The resultant dynamic curve is due to the broader electric field obtained by two spades being near the cathode potential during switching.

Since the direction of the magnetic field controls the direction in which the electron paths shift when the potential of an adjacent spade is lowered, a change in potential of a lagging spade will therefore have little effect on the electron paths.

If load lines are drawn from point A tangent to the static and dynamic spade characteristic curves, there results a division of the region into three areas of operation. Now, if all the spades have the same value[†] of series load resistance R_s, then the tube circuit may be operated in any of the following four modes.

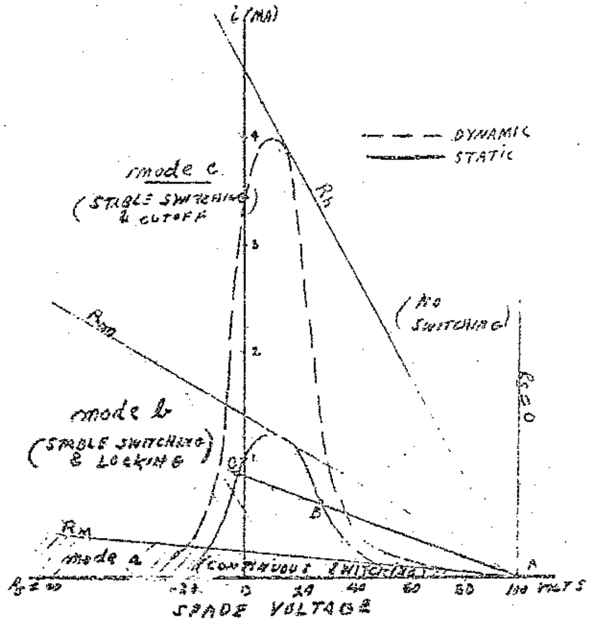

FIGURE 3

a. For $R_s > R_M$ and $R_s > R_m$, the tube oscillates.

b. For $R_m > R_s > R_m$, the tube has ten stable conducting states.

c. For $R_s < R_m$ and $R_s < R_M$, the tube is cut off.

d. For $R_M < R_s < R_m$, either cut-off or oscillation is possible.[‡]

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[*] This condition during which two spades are conducting takes place during an interval less than 0.3 μs. Hence, at operating frequencies below 100 kc, it may be assured that there is only one spade drawing current at any given moment.

[†] See Reference 1, Section III, for an analysis of the case where the space resistances are different in value.

[‡] Note that $R_M < R_m$.

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The proper mode for stable switching and locking is mode b, where ten stable and astable states are available for switching from one shade to another by applying a negative switching pulse alternately to each set of grids. Hence by lowering the switching grid voltage to a value where it changes the electric field significantly in the region between the spades, enough current will be diverted to the leading spade to switch and lock it on this position. However, once a beam is formed on a spade, there are other methods for advancing it as enumerated in the literature. Also, practical use may be made of the wide operating ranges of the other modes, i.e., beam forming and locking, beam switching and clearing, and continuous oscillation.*

Hence, the heart of the matter in designing a Beam-X switch circuit is to find the proper spade load resistor as a number of other parameters besides stable switching and locking will depend on this selection. A few of the more important relations involving R_s are

$$V_s \propto R_s$$

$$I_T \propto R_s, V_s$$

$$\nu M \propto \frac{1}{T_s}$$

$$T_s \propto R_s, \frac{1}{V_s}$$

where ν_M is the maximum switching rate, and T_s is the time required to switch the beam to the next position. Since, it was decided to operate in mode b, which has upper and lower bounds for K_S -

$$R_m < R_s < R_M$$

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* The beam will switch continuously at a frequency determined by the spade characteristics, load line, and associated spade capacitance. Refer to TM June 28, 1957 on "Investigation of the Characteristics of a Self-Oscillating MBS Tube Time Base."

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dependent on the spade current characteristics which in turn are functions of all operating parameters such as V_T, V_S, V_G, B, etc., some simplifying set of assumptions must be made. Let us assume for this purpose that:

1. The magnetic induction B is constant and uniform;
2. All spades, excluding the holding spade and with the possible exception of the leading spade, are maintained at V_s; and
3. The voltage of the target buss V_T and grid V_G are set equal to V_S. These voltages V_T, V_G do not affect the holding operation, but only the switching operation.

Therefore, the current of the J and J-1 spades are functions of V_J, V_{J-1}, and V_S. More specifically, the values of the limits of R_S depend on the tangential points of the load lines to the spade characteristic curves, which in turn depend upon the spade supply voltage.

The values for the upper and lower bounds are given in TM-54-68 as

$$R_m = \frac{V_s}{I_0}$$

where I_0 is the value of the holding spade current with the J spade at zero potential, and the value of the upper bound is given as

$$R_M = \frac{V_s}{2I_1}$$

where I_1 is the value of the leading spade current with the J spade at zero potential, the (J+1)th spade at 1/2 V_s, and V_T, V_G, and all other spades set at V_s. These values for the limits of R_S are admittedly conservative, since the currents (I_0, I_1) are slightly smaller and larger, respectively, than those obtained from the points on the load lines tangent to the spade current-voltage characteristics.

The values of R_m and R_M can be calculated from graphs of $I_0 - V_S$, and $I_1 - V_S$, which are measured experimentally. This graph is listed in the appendix as A.1 and shows the regions occupied by the four modes. This graph also shows the region for most reliable operation, granted other considerations not as yet stated, where the configuration space contains but two operation parameters (V_s, R_s). For the case where voltage fluctuations and resistance variations do not exceed a tolerance of 5%, a minimal relation is derived for R_s in terms of V_s. This relation was derived simply by locating the lower boundary curve and connecting the midpoints of the regions of 5% tolerance above this lower limit. This gives a relation for R_s and V_s that will ensure reliable operation over a given operating range.

Let us now relax some of the constraints and note the resultant effect on the bounds of R_S. First, it is to be noted that the leading spade characteristic was taken with the holding spade at cathode potential. However, in practice, the holding spade is slightly negative with respect to the cathode.* This may affect the leading spade characteristic and thereby change the upper bound of R_s. Insofar as the leakage current to the leading spade is reduced by this, the upper bound of R_s will be higher than the approximation arrived at previously.

Now, if we allow V_T and V_G to be different from V_s, due to output and switching requirements, the resultant electric field pattern will change the shape of the beam. Hence, the current distribution will also be changed. However, the holding spade, as was previously stated, is not affected to any appreciable extent so as to change the lower bound R_m, but the leakage portion of the leading spade characteristic is affected so as to change the upper bound R_M. Generally, the lower the potential of the target or grid, the larger the leakage current, and consequently the less the upper bound of R_S.

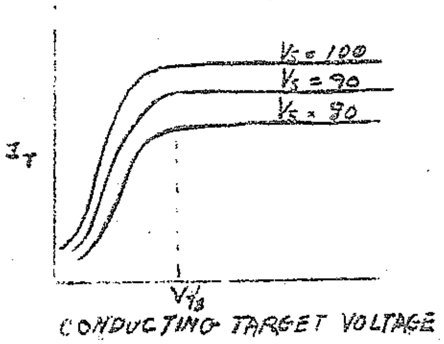

Figure 4A

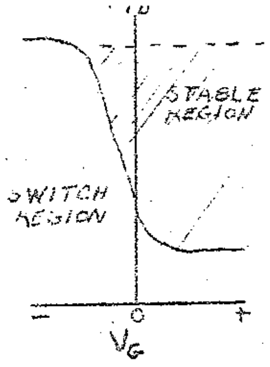

Figure 4B

As shown in Figure 4A, the output electrode has a constant current characteristic for $V_{TB} > V'_{TB}$, where the amplitude is primarily determined by the crossed fields in the spade-cathode region. It was found that

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* The amount depends on the value of R

the operation of the Beam-X switch was stable if $V'_{TB} \geq \frac{V_s}{2}$, within the operating range of V_s. It is also apparent that by operating closer to the knee of the curve, higher output currents may be obtained without exceeding the one-watt target dissipation rating. Below the knee of the target characteristic curve, where $V_{TB} \leq V'_{TB}$, the beam is drawn closer to the leading spade and the leakage current increases; thus decreasing the upper bound of RS. This leakage current was collected by both grid and leading spade in beam switching tubes, which tended towards instability at low target potentials; but in the Beam-X switch the addition of a new element--the shield grid--performs the function of collecting this leakage current and thereby permitting operation with target potentials as low as zero volts with only slight limitations in the operating range of the tube.

The influence of a negative switching pulse on the dynamic characteristic curve is shown in Figure 5 by the family of dotted additions to the curve. A negative potential on the grid in the holding position will alter the equipotential line configuration in the spade-spade region, and thereby allow those electrons with higher energy to reach the leading spade. The resultant lowering of the leading spade potential produces further changes in the equipotential lines, and the process is repeated until the leading spade potential is lowered to point B of Figure 5 and the beam switches to this position. The dynamic characteristic curve, however, exists only during the switching interval and becomes the static characteristic as the voltage of the spade from which the beam has switched recovers through its RC time constant from point C to point A. Refer to Figure 3. A larger negative switching pulse results in more

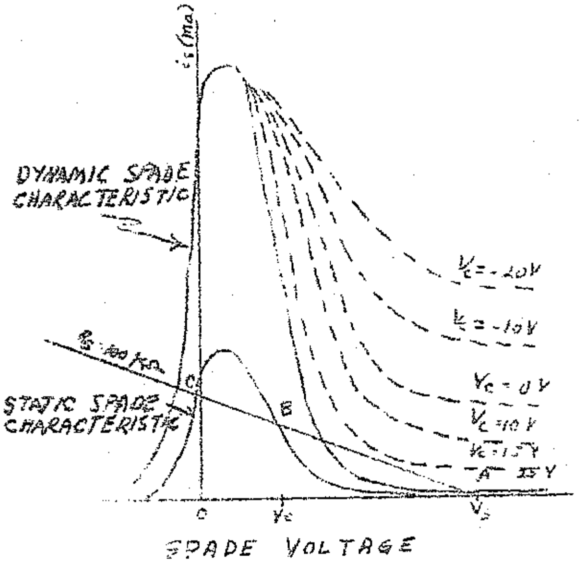

Figure 5

current being collected by the leading spade and a faster switching transition, which gives in turn a higher maximum switching frequency. A large negative switching pulse causes excessive leakage currents with a resultant lowering of the upper limit of R_S.

Since a constant and uniform field is required for proper operation of the Beam-X switch, the last constraint need not be removed. However, if the tubes are not mounted at least one inch from magnetic material or spaced at least two inches from center to center, then the magnetic field may have components from sources other than the internal magnets of the tube. If the magnetic field is subject to change in any manner, it will have an effect on R_M. In order to see just what effect the magnetic induction B has on the upper limit of RS, consider the following:

$$B' = k_3 B$$

$$R'_S = k_3^{-1} R_S$$

$$V'_S = k_3^2 V_s$$

where the prime quantities denote the values after scaling, and the magnetic induction scaling factor is represented by k_3. Hence, the effect of changing B on the operating parameters V_S and R_S is to shift the region of stable operation with the tolerances of the operating parameters remaining the same.

Thus far it appears that a conservative estimate may be made for the lower bound of R_S, whereas an estimation of the upper bound appears to have doubtful significance. However, it is necessary that we have a good method for estimating R_M, since the stability of a switching circuit (or its reliability)* depends directly on the location

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* If it is considered that the reliability of switching circuits consists of two components, which are

(1) stability - variations of operating conditions (other than input signal) do not disturb stability of operating state, and

(2) consistency - one to one correspondence between operating state switching and input triggering signals.

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of the operating point within the bounds of the operating parameters. The upper limit may, as pointed out in the footnote on page 4, drop below the lower limit due to a large leakage current resulting from a low value of grid voltage. Since the curve of R_M and R_m as a function of V_s cannot intersect due to their negative curvature for $R_M < R_m$, there can be no region of stable operation in the R_s, V_s plane.

For the purpose of materializing an estimation of R_M, let us consider the minimum resolving time and maximum operating speed of the tube. Figure 6 illustrates the high frequency circuit formed by the lead wire inductance and the interelectrode capacitance between the spades. For high switching rates the RC time constant associated with the spades, which is formed by the spade load resistance, interelectrode capacity of spades, and external wiring capacity, will determine to what extent the characteristic curves of the Beam-X switch are affected. Hence, the spade load resistors should be located adjacent to the Beam-X rocket in order to minimize external spade capacity and thereby reduce the switching time (t_s) of the beam from spade to spade. If this and the proper design conditions are observed, switching rates up to 3 mc/s may be attained.*

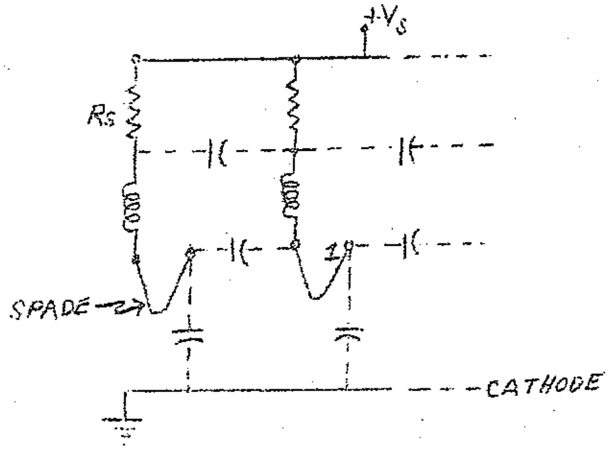

Figure 6A

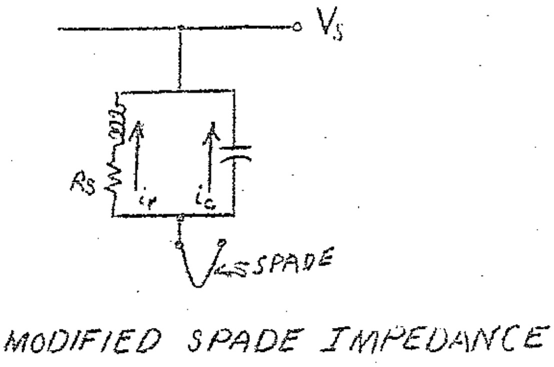

Figure 6B

Since the value of the RC time constant is to be a minimum it may seem, by analogy with wide-band video amplifiers, that t_s may be decreased to a considerable

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* Refer to page 9 of Reference 3

extent by inductive compensation in the spade load impedance. However, if we examine the spade load impedance as shown in Figure 6B, where C represents the total spade-capacitance to ground and to all other electrodes and L the compensating inductance, it is found, when solving the differential equation for the case of critical damping[†] with $L_c = \frac{R^2C}{4}$, that

$$f = 1 - (x + 1)\, e^{-2x} \quad .$$

Also, the relation for the case when $L = 0$

$$f = 1 - e^{-x}$$

where $x = \frac{t}{RC}$, and f is the fraction of final response. Let us assume that the critical point to which the leading spade must be lowered is approximately[‡] $0.4\ V_s$. Then, if t'_s is the switching time for critical damping, we have

$$t'_s = 0.80\ t_s \quad .$$

Moreover, if the switching interval without inductive compensation is approximately 0.3 µs, then the maximum repetition frequency for the case of critical damping is

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[†] See Reference (4) for a discussion on the oscillatory approach to the final response, which may well result in instability, when L is greater than L_c. However, for completeness and an estimation of the absolute limit of frequency, the following are included for L_∞ $(L = \infty)$

$$t''_s \text{ (absolute minimum)} = 0.66\ t_s$$

and therefore

$$F_{ABS\ MAX} = 4.5 \text{ mc}$$

[‡] Refer to Reference (4) for a discussion of the switching mechanism in relation to the critical point. This critical point is related to the saddle point potential. Now, if V_J is the holding spade potential and V_{J+1} is the leading spade potential, then the saddle point potential V_{SAD} is given as follows:(2)

(1) for $V_j = V_s$; $V_{SAD} = V_s$
(2) for $V_j = 0$; $V_{SAD} = 0.40\ V_s$
(3) for $V_{j+1} = V_s$; $V_{SAD} = 0.40\ V_s$
(4) for $V_{j+1} = 0$; $V_{SAD} = 0.33\ V_s$

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3.7 mc/s. It seems then, for all practical purposes, that the best way for an improvement in the switching time is to reduce the external spade lead capacitance to the limit instead of resorting to inductive compensation.

Also, it is readily seen that if T is the time for (n - 1) successive pulses in an n-state operation of the tube, then T should be at least

$$T \geq (n - 1)\ t_s$$

where t_s, the switching time, gives the minimum resolving time for the tube to be ready to switch to the next position. In addition, T should be of sufficient duration in order for the spade to discharge --

$$T \geq 5R_sC$$

We see, then, that for uniform switching in n-state operation that

$$\frac{1}{t_s} \lessgtr \frac{(n - 1)}{5R_sC}$$

and the maximum repetition frequency is equal to the smaller of the two factors.

Usually the reciprocal of the switching time is the larger of the two factors. Hence, for 10-state operation with 200 KΩ for the spade load resistor and 9 pf for the total spade capacity, the maximum operating frequency is

$$\nu = \frac{n - 1}{5R_sC} \simeq \quad \text{mc/s.}$$

Since R_s is dependent on V_s, a relation for the lower bound in the R_s - V_s plane with V_s bounded by

$$35 \text{ volts} < V_s < 100 \text{ volts}$$

is as follows

$$R_s = 1.24\ V_s^{-1.13} \times 10^4\ K\Omega$$

Therefore, we can now state the range for R_s, but with a zero tolerance, as

$$70\ K\Omega < R_s < 200\ K\Omega$$

A few of the relations involving R_s and V_s were given previously on page 5. One of the relations showed a proportionality between I_T and V_S. It has been found that the switching tube, when a beam has been formed, behaves like a non-linear circuit element with spade and target currents higher than first power functions of the spade potential V_s.

$$I_S = KV_s^{a}$$

$$I_T = CV_s^{b}$$

Therefore, if the spade potential is maintained at a particular value the total current I_K through the tube will remain at a constant value (assuming the exponents a, b are constant). Dr. Fan (in TM 54-68) derived some relations showing the dependency of I_K and I_T on V_S and B. These relations, which were borne out in TM 55-90 for MB3 tube types, are similar to the Langmuir-Childs or three-halves power law. However, since we are not interested in either voltage or geometric scaling, the relations will be modified to conform to the Beam-X tube with a constant magnetic field.

$$I_K = KV_s^{3/2} \cdot F(V_s) \text{ ma}$$

$$I_T = CV_s^{2} \text{ ma}$$

where $f(V_s)$ is some function of V_s and the constants K, C are in the order of 1×10^{-2} (for $F(V_s)$ = constant), and 1×10^{-3} (for $B \simeq 450$ gauss), respectively.

The final point to cover in this section is the requirement on input pulses; that is, amplitude and duration must be defined for the grid switching pulse. This can best be seen from a consideration of Figure 7,* where two characteristic curves

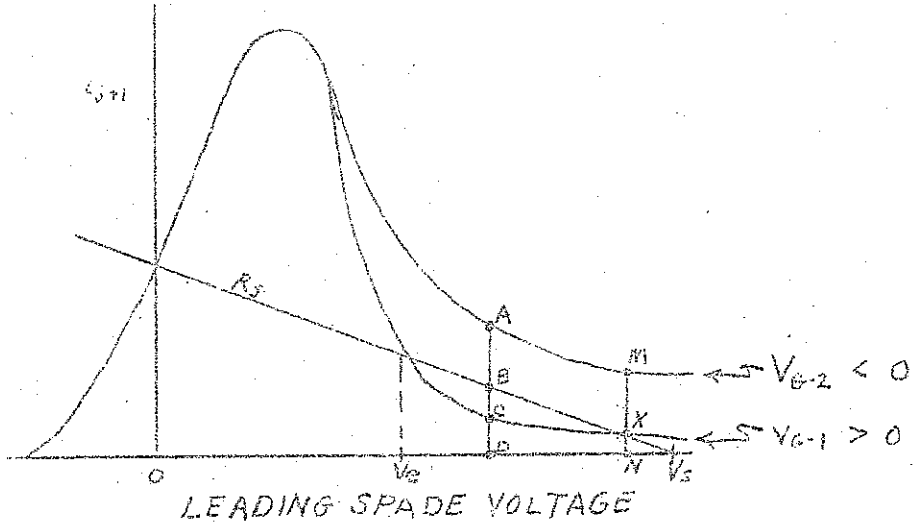

Figure 7

are shown as a plot of the leading spade current versus the leading spade voltage for two different values of V_G. If at $t = t_o$ the grid of the holding spade is made instantaneously negative, characteristic curve V_{G-1} becomes characteristic curve V_{G-2}. A current equal in magnitude to the distance MX is initiated to the leading spade. As shown in Figure 6B, this current divides into two components i_r, i_c.

The current i_c through C causes the spade to become more negative with time. The total current available from the space charge cloud is equal to AD at a general point defined by $V_e < V_{j+1} < V_s$. The following shows the significance of the distances --

AD - total current to spade i_s
AB - represents i_c
BD - represents i_r

and $i_s = i_c + i_r$. If the grid pulse is terminated at this point the current in the capacitor becomes BC with opposite sign. Hence, since $i = C\frac{dv}{dt}$, the potential of the leading spade reverses and moves in a positive direction towards V_s. This means that the grid pulse has been of insufficient duration to complete the switching process. The duration of the switching pulse must be of sufficient length to allow v_{j+1} to fall below V_e. Also, it is apparent that the grid pulse amplitude must be such so as to raise the leading spade characteristic sufficiently to avoid any intersection with the spade load line. This is shown by the intercept AB, which is the current charging C (the total spade capacity). Thus the switching operation starts comparatively slowly until we get to the point of the characteristic where the curve rises quite rapidly ($V_e \simeq 0.4\ V_s$).

Hence if the tube just starts to oscillate when the grid voltage is lowered by some amount, say V_i (where $V_i = V_g - V_c$), the duration t_i (dependent on V_G and spade time constant) of the input pulse is longer than the time required by the

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leading spade to lower its potential to V_e after the input pulse is first applied, then the product*

$$V_i t_i \leq V_i t_s$$

should be somewhat less than

$$V_i t_s = 25\ (0.3)\ \text{volt-second} = 7.5\ \text{volt-second}$$

where the value of V_i was taken from a standard grid voltage vs. target voltage characteristics graph of the Beam-X switch. Also, the value of the area of the input pulse for 1 mc continuous switching was found to be

$$V_i t_i = (15)(.5)\ \text{volt-second} = 7.5\ \text{volt-second}$$

and the minimum value is most likely

$$V_i t_i \geq (15)(.3)\ \text{volt-second} \simeq 5.0\ \text{volt-second}$$

CONCLUSION

The normal operation of the Beam-X switch may best be studied through its basic circuit (or typical test circuit).(3)(6)(7) Various combinations of supply voltages were used over a frequency range of 200 c/s to 2 mc/s. The spade buss can be operated at any voltage from 15 to 100 volts by employing spade load resistors of appropriate values. Since the spade buss voltage V_S determines the magnitude of the target current output I_T, this output current can range from 300 microamperes to 10 milliamperes. However, the conducting target power P_T must not exceed the maximum target dissipation rating of one watt:

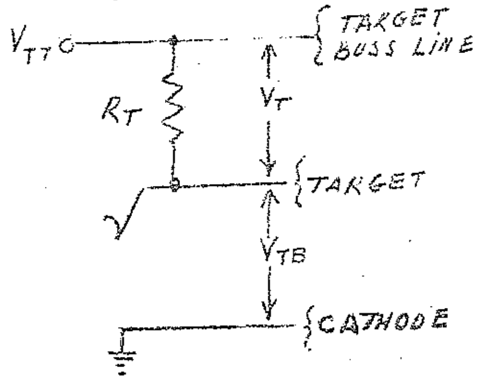

Figure 8

$$P_T = V_{TB} I_T < 1\ \text{watt}$$

where

$$V_{TB} = V_{TT} - V_T = V_{TT} - I_T R_T$$

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* Since the Beam-X tube has a high impedance input and draws only negligible current during switching, the input driving source need only supply the power to charge

Hence, constant current outputs can be obtained in conjunction with voltage swings in excess of 200 volts.* Moreover, we have seen that the voltage V_{TT} and resistance R_T should be properly selected to satisfy design parameter affecting the conducting target voltage switching input requirements and maximum wattage considerations.

The next phase investigated was the operation of the Beam-X switch at a maximum frequency of 1 mc/s. The circuit was designed to provide a constant-current output voltage level of 11.5 volts. NPN transistors were employed as common emitter amplifiers at each of the ten outputs. The test circuit is shown in Figure 9. The precautions and limits to be observed are:

(1) $V_{TB} = (V_{TT} - I_T R_T) > E_S/2$

or $V_{TT} \geq V_S$ (for more reliable operation)

(2) $V_{TT} < 300$ volts

$V_S < 100$ volts

$V_{SG} < 300$ volts

(3) $P_T = (V_{TB} I_T) < 1$ watt

For the case for 1 mc switching, the target supply V_{TT} was maintained at 11.5 volts more positive than V_S for a forward bias of -11.5 volts and a reverse bias of -0.5 volts between emitter and base, giving an output voltage V_0 of 12 volts. The shield grids were connected to the spade buss as in normal operation, and the spade load resistance R_S was 100KΩ. Graph A1.1 shows the data obtained under these conditions. The shaded area banded by upper and lower limits has a mean curve given by

$$I_T = 7.0\ (V_S)^{2.6} \times 10^{-5}\ \text{ma.}$$

Moreover, the potential on the shield grids was varied and the resultant effect is

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* A negative transient may appear on adjacent spades during switching (due to coupling through interelectrode capacity) for target swings in excess of 100 volts. This can be remedied by padding the targets with about 5 pf or more.

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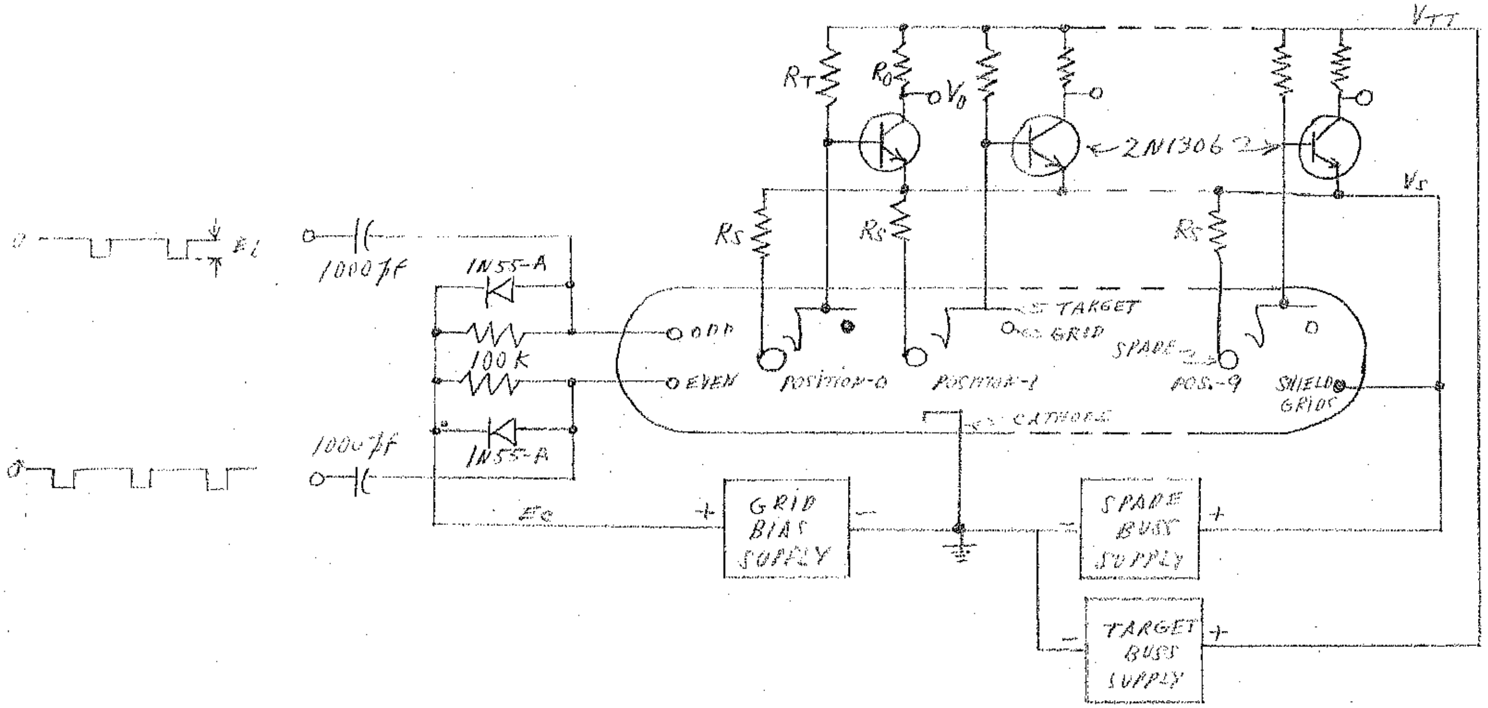
FIGURE 9

TEST CIRCUIT



NOTE: THE 3 SUPPLYS MAY BE REDUCED TO ONE BY:

(1) PROVIDING A BLEEDER NETWORK BETWEEN V_{TT} AND THE CATHODE OF THE BEAM-X TUBE AND THEREBY ELIMINATING THE GRID BIAS SUPPLY,

(2) INSERTING A BATTERY $(B^+ = \Delta V)$ BETWEEN THE SPADE AND TARGET BUSSES SUCH THAT $V_S = V_{TT} - \Delta V$, AND ELIMINATING THE NEED OF A SEPARATE SPADE BUSS SUPPLY.

NO INSTABILITY RESULTS IF THE STANDARD PRECAUTIONS ARE OBSERVED. REFER TO REFERENCES (3) AND (6).

shown on the graph. Also included on the graph are two representative slopes which indicate a trend with slope greater than 2.0.[*]

Graph A1.2 plots I_T as a function of V_S and R_S. Here it is seen that a consideration of the parameter R_S introduces but little change in I_T.

$$I_T = 7.0 \left(\frac{R_S}{100}\right)^{0.12} V_S^{2.6} \times 10^{-5} \text{ ma}$$

where K_S is in KΩ. The normal operating region is contained between the curves for $R_S = 0.0$ and $R_S = 0.1$ MΩ. The general trend or slope is approximately 2.5.

If we consider the spade voltage and spade load resistance characteristics of the tube circuit, then Graph A1.3 results. This graph gives the upper and lower limits[†] of stable spade-buss operating voltage as a function of spade load resistance. The upper boundary curve is a function of grid bias and marks the upper limit of stable operation at frequencies below 1 kc/s. At continuous high frequencies the upper boundary curve shifts to the right in the direction shown. However, at switching rates of 1 mc/s, the upper boundary has shifted considerably to the right so that the region of stable operation is as shown by the hatched region of Graph A1.3. If a tolerance of 10% in both R_S and V_S is allowed, then the relation for R_S in terms of V_S is

$$R_S = 1.7\, V_S^{-1.2} \times 10^4 \text{ K}\Omega$$

when V_S is 100 volts. Hence, the following limits may be stated for V_S and R_S =

$$50 \text{ volts} < V_S < 100 \text{ volts}$$

$$85 \text{ K}\Omega < R_S < 299 \text{ K}\Omega$$

where

---

[*] For purposes of comparison, the relation $\left(I_T = CV_S^{\,2}\right)$ derived formally gives 2.0 as the value of the slope.

[†] The lower limit is a conservative one, as an operating point was found for a spade potential of 60 volts, $R_S = 100$ KΩ, and with an $I_T = 2.34$ ma at a 1 mc/s switching rate.

$$R_S = \frac{1.7 \times 10^4}{{V_S}^{1.2}}$$

The limits of the target current can be found from

$$I_T = 1.3\, {V_S}^{5/2} \times 10^{-4} \text{ ma}$$

which was derived by combining the relations given above. The limits for I_T are

$$2.1 \text{ ma} < I_T < 11 \text{ ma} \quad .$$

However, since

$$I_T V_{TB} = (V_{TT} - I_T R_T) < 1 \text{ watt}$$

the minimum value that R_T may have for $V_{TT} = (V_S + 11.5)$ is

$$R_T > 2.1 \text{ K}\Omega .$$

Also, since

$$V_{TB} = (V_{TT} - I_T R_T) \geq V_S / 2$$

and R_T has a minmax value of 5.4 KΩ for a spade potential of 100 volts (a maximum value of 17 KΩ at $V_S = 50$ volts). However, it is not essential that the target remain above the knee of its characteristic curve as the shield grid provides independence of target characteristics. Of course, other limits than those given above for R_T will be the result if, for $\Delta V = (V_{TT} - V_S)$, ΔV is some other value than 11.5 volts.

The value of R_T was varied from 2.4 KΩ to 5.6 KΩ without incident; that is, the target output current remained constant. Hence, if it is desirable to obtain a certain voltage swing as the output of a Beam-X switch, then the value of the target load resistance is given by

$$R_T = \frac{V_{TT} - V_{TB}}{I_T} = \frac{V_T}{I_T}$$

The largest voltage swing is found to be

$$V_T < \left(\frac{V_S}{2} + \Delta V \right) \simeq 60 \text{ volts}$$

for $\Delta V = 11.5$ volts (for an $V_{TT} = 300$ volts the maximum voltage swing is 200 volts.)

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Thus far we have been considering the target output levels in isolation of the common emitter output circuit. Normally, it is desirable to limit the target current to values below about 6 ma. If higher currents are desired, then current amplifiers would be employed at each of the outputs in order to obtain these high constant current outputs. An output resistance R_0 of 1 KΩ (admittedly a bit low for the NPN's used in the output circuit provided an output V_0 of 12 volts and 12 ma. Moreover, the target current dropped to its minimum value of 2.34 ma with a corresponding voltage level of 11 volts. Graph A1.4 shows the effect that the NPN in the output circuit has on the target.

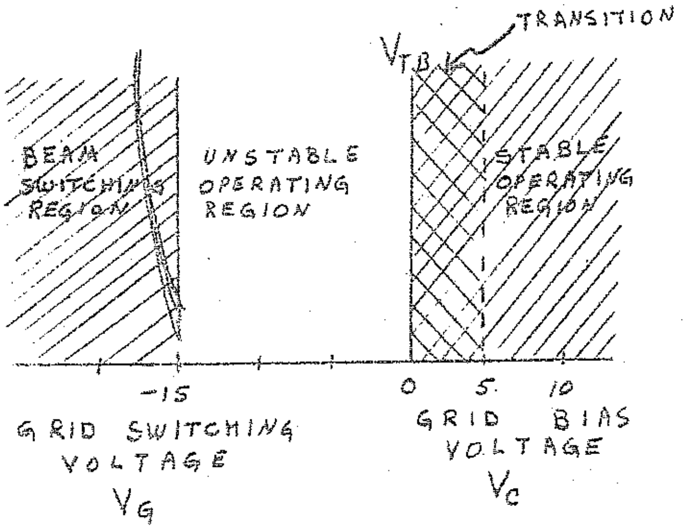

Figure 10

A minimum grid-bias voltage V_c between 0 and 5 volts was needed which resulted in a minimum grid input switching pulse of 20 volts. The necessary grid switching voltage V_G for 1 mc/s switching was found to be 20 volts. These grid voltages are related by

$$V_i = V_G - V_C \qquad (V_c < 100 \text{ volts})$$

where the grid driving voltage V_i is the algebraic difference of the grid switching potential V_g and the grid bias voltage V_c. Since V_g is normally negative with reference to V_c, the driving voltage V_i will have a negative value. Generally, the limits for V_i may be stated as

$$20 < V_i < 85$$

A rule of thumb is that the amplitude of V_i should be approximately equal to the spade buss voltage when operating at extremely high frequency* and/or providing large target outputs.

The total interelectrode capacitance of the spade circuit was measured for two tubes and found to be

$$7.5 < C_s \text{ (pf)} < 9.5 \quad .$$

Hence, an average value of 8.5 pf may be used in the following in order to determine R_M:

$$R_M = \frac{9}{5 \nu C} \simeq 200 \text{ K}\Omega$$

for 1 mc/s switching.

The spade switching rise time t_r was measured and found to be 1µs. (Refer to Graph A2.1 which shows the spade voltage/time relationship). However, as the capacitance of probe was 11.5 pf, the spade switching time and hence the minimum resolving time t_s for the tube to be ready for the next input pulse

$$t_s = \frac{C_S}{C_T} (t_r) = \frac{7.5}{19} (1) \underline{\quad} 0.4 \text{ µs}$$

Therefore, the maximum operating frequency would be 2.5 mc (when $t_s > \frac{5}{9} R_S C_S$).

It has therefore been found feasible to employ Beam-X switches in computer circuits because of their inherent reliability, economical power requirements, adaptability to the current and voltage levels of transistor operation, and megacycle switching rates. Moreover, the Beam-X switch is versatile (number of states can be changed), the output current is constant and can be used to trigger another tube

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* This is due to the fact that if the period of the counting frequency approaches the value of the target RC time constant, then the potential of the target will not drop to the quiescent value of V_{TB} before the arrival of the next pulse. This is equivalent to a higher V_{TB} and hence a greater value for the driving pulse amplitude V_i.

(direct cascading is possible)*, outputs are separate (not limited to decimal counting), and the resolving time is of the order of 0.3 µs. Hence, the unique properties of the Beam-X switch can be used to full advantage in any form of data conversion.

EX AEQUO ET BONO

It can be truly said that there would have been no theory section, or even a report for that matter, if it were not for the published papers of the authors listed as references. Since these papers are classics in themselves, I can only justify the outright plagiarism of phrases, sentences, and whole paragraphs (without quotation marks) by stating the desire of this author to bring most of the work long since accomplished together in one report with as little distortion as possible.

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* Refer to articles by:

John Bethke, "New Applications for Beam Switching Tube," Electronics, Vol. 29, No. 4, April 1956.

Roger Wolfe, "A New Transfer-Storage Counter," 1957 IRE Wescon Convention Record, Vol. 1, Part 5.

REFERENCES

1. S. P. Fan, "Magnetron Beam Switching Tube--Its Operation and Circuit Design Criteria," TM 54-68, Burroughs Corporation, July 1954.

2. S. H. Chow, "Mechanisms of the Beam Switching Tube," TM 55-68, Burroughs Corporation, June 1955.

3. Burroughs Beam-X Switch -- Technical Brochure BX535, Electronic Tube Division.

4. Hilary Moss, "The Switching Mechanism in the Magnetron Beam Switching Tube," TM 55-38, Burroughs Corporation, April 1955.

5. L. R. Landrey, "Experimental Investigations of the Scaling Laws Pertaining to the MBS Tube," TM 55-90, Burroughs Corporation, September 1955.

6. A. Somlyody, "The Basic Beam Switching Tube Circuit," TM 10/27/58, Burroughs Corporation.

7. Engineering Data Report on Beam-X Switch -- Bulletin No. 1000, Electronic Tube Division, Burroughs Corporation, August 1960.

8. Data Sheet on Beam-X Decade Counter Modules (Types DC-111A and DC-111B) -- Bulletin No. 1002, Burroughs Corporation, Electronic Tube Division, August 1960.

9. Hilary Moss, "Equivalent Circuits of the MBS," TM 54-61, Burroughs Corporation, June 1954.

10. Hilary Moss, "The Magnetron Beam Switching Tube as a General Tool in Electronic Circuitry," TM 54-62, Burroughs Corporation, August 1954.

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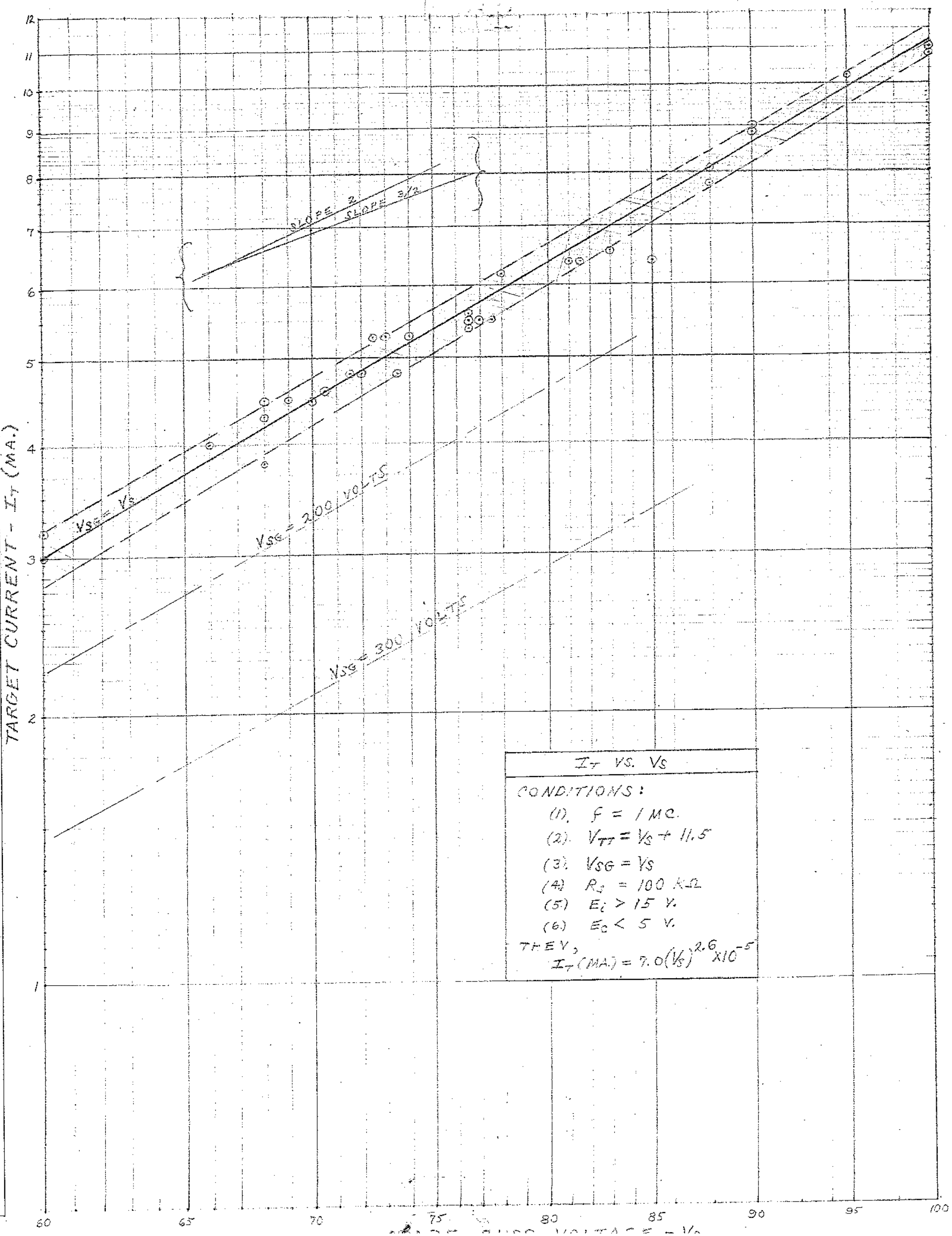
A1.1



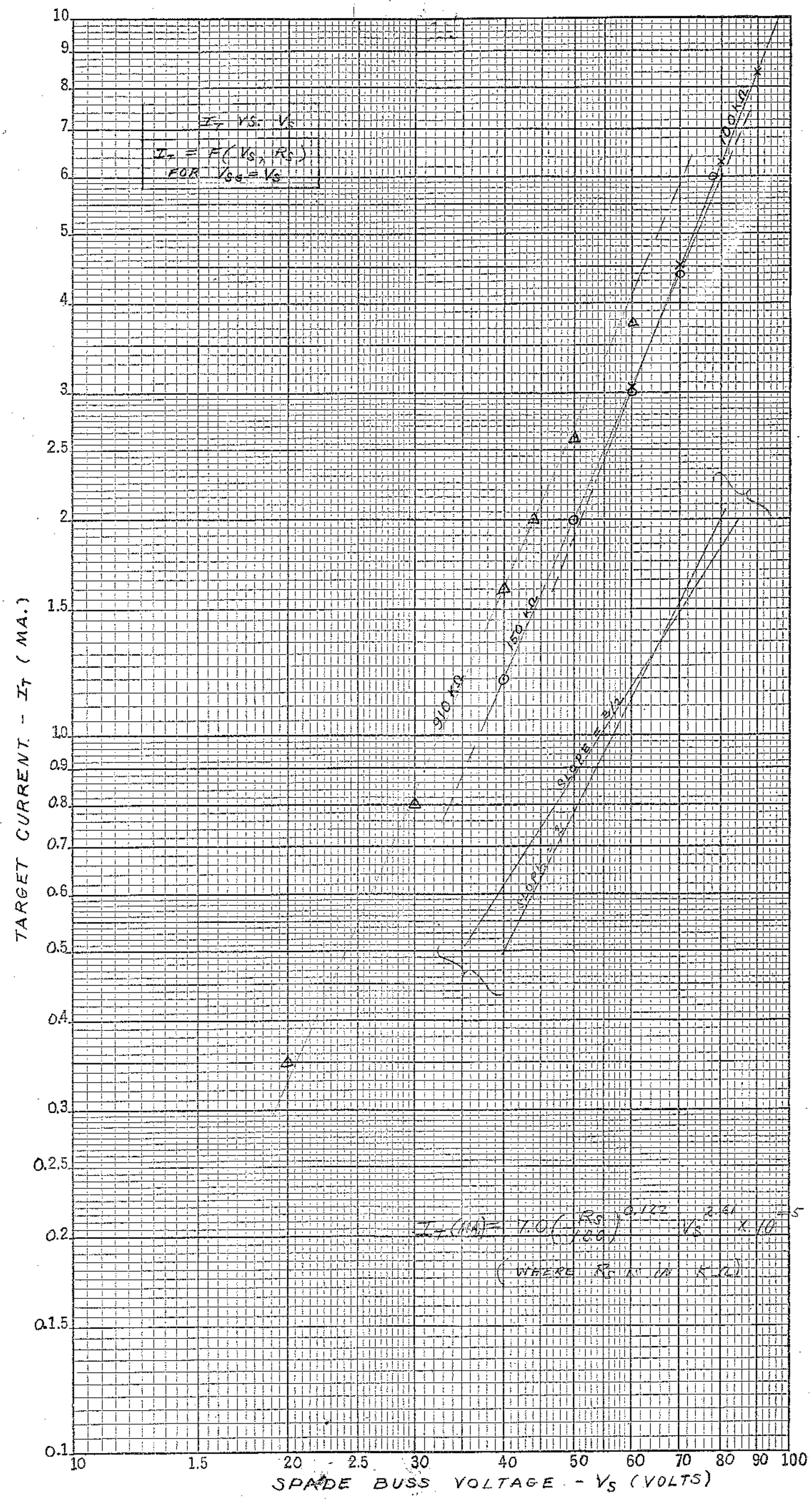
I_T VS. V_S

CONDITIONS:

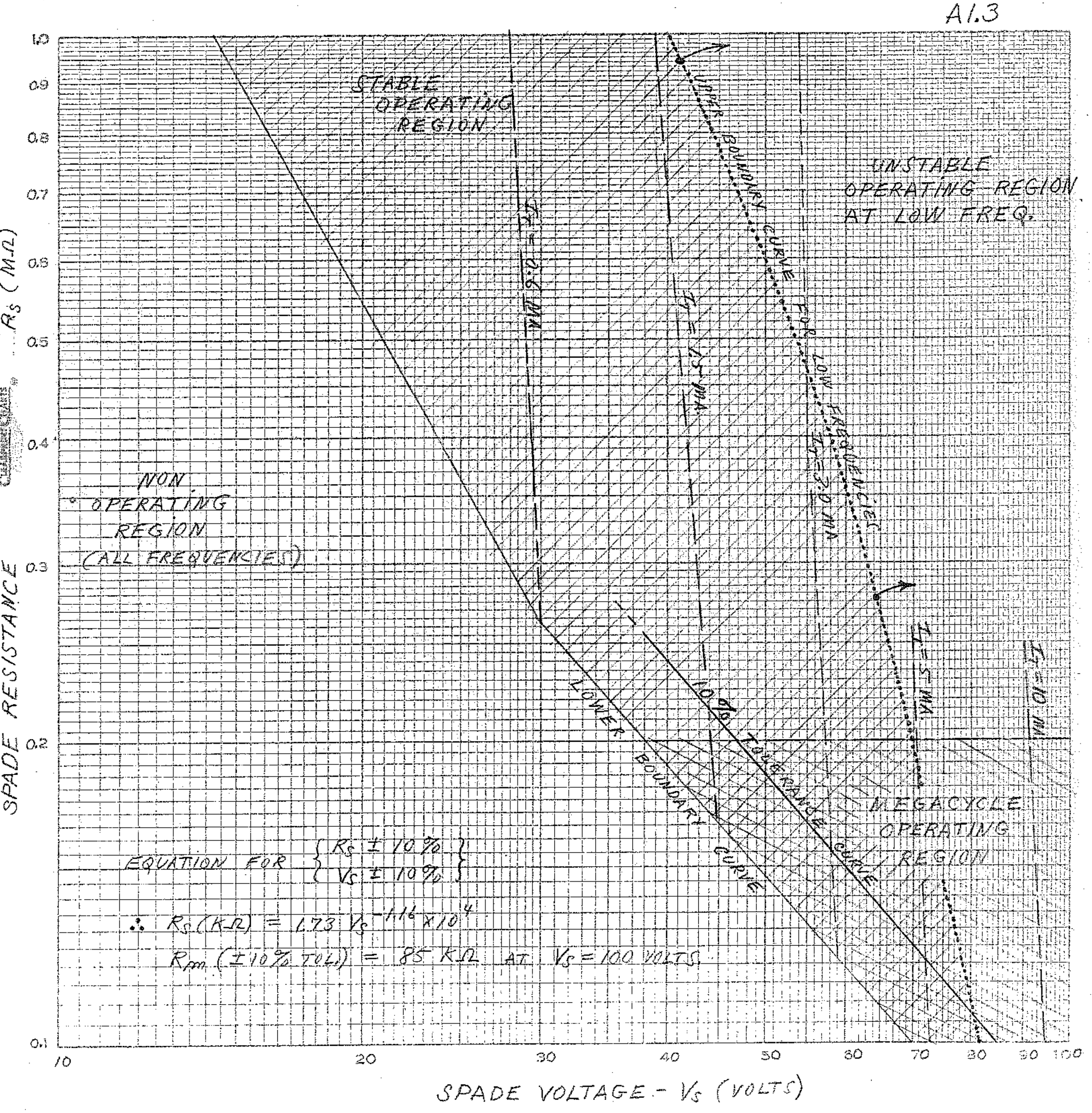
(1). $f = 1$ MC.
(2). $V_{TT} = V_S + 11.5$
(3). $V_{SG} = V_S$
(4). $R_3 = 100\ K\Omega$
(5). $E_i > 15$ V.
(6). $E_O < 5$ V.

THEN,

$I_T(MA.) = 7.0(V_S)^{2.6} \times 10^{-5}$


I_T VS. V_S
$I_T = F(V_S, R_S)$
FOR $V_{SG} = V_S$
100 KΩ
150 KΩ
910 KΩ
SLOPE = 3/2
SLOPE = 2
I_T (MA) = $7.0\left(\frac{R_S}{100}\right)^{0.122} V_S^{2.61} \times 10^{-5}$
(WHERE R_S IS IN KΩ)
TARGET CURRENT - I_T (MA.)
SPADE BUSS VOLTAGE - V_S (VOLTS)
10
9
8
7
6
5
4
3
2.5
2
1.5
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.25
0.2
0.15
0.1
10
15
20
25
30
40
50
60
70
80
90
100

A1.3



EQUATION FOR $\left\{ \begin{matrix} R_S \pm 10\% \\ V_S \pm 10\% \end{matrix} \right\}$

$\therefore R_S(K\Omega) = 1.73\, V_S^{-1.16} \times 10^4$

$R_m (\pm 10\%\ TOL.) = 85\ K\Omega$ AT $V_S = 100$ VOLTS

AREA WITHIN DASHED LINES DESIGNATES NORMAL OPERATING REGION.

- ◇—◇ $R_T = 2.4\ K\Omega$
- △—△ $R_T = 3.9\ K\Omega$
- ⊙—⊙ $R_T = 4.7\ K\Omega$
- ⊡—⊡ $R_T = 5.6\ K\Omega$

R_T IS GIVEN BY THE RECIPROCAL OF THE SLOPE.

INTERSECTION OF EXTENSION OF R_T CURVE AND THE HORIZONTAL AXIS GIVE THE VALUE OF V_{TT} AS READ ON THE V_{TB} SCALE.

METHOD:

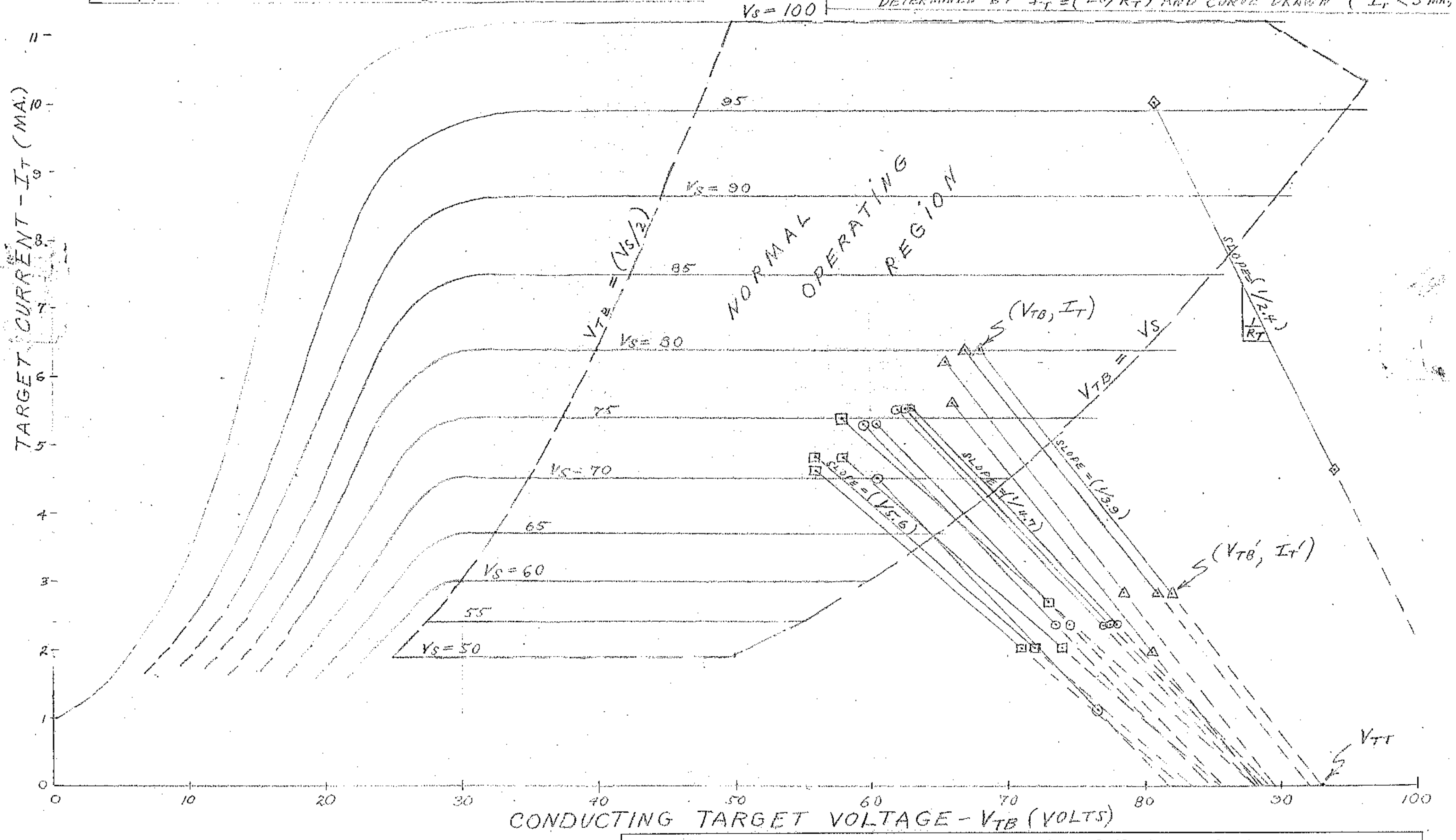
(1) GIVEN : AVAILABLE SUPPY VOLTAGE – V_{TT}
REQUIRED OUTPUT V_0 ($V_0 = I_0 R_0$)

(2) DETERMINE R_S FROM GRAPH A1.3 OR FROM $R_S = 1.73 V_S^{-1.16} \times 10$
WHERE $V_S = V_{TT} - \Delta V = V_{TT} - V_0$.

(3) PICK A POINT IN THE NORMAL OPERATING REGION ON THE V_S CURVE. CONNECT THIS POINT WITH V_{TT} POINT AS READ ON V_{TB} SCALE.

(4) R_T IS GIVEN BY THE SLOPE OF THE LINE DRAWN IN STEP 3

(5) NEW OPERATING POINT WITH TRANSITORIZED OUTPUT IS DETERMINED BY $I_T' = (E_0/R_T)$ AND CURVE DRAWN ($I_T' < 3$ MA



A2.1

SPADE-SPADE & SPADE-TARGET PHASE RELATIONS