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TECHNICAL REPORT RN-76-1

MATERIAL AND TEST REQUIREMENTS FOR FIELD EFFECT EMITTER ARRAYS

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1 July 1975

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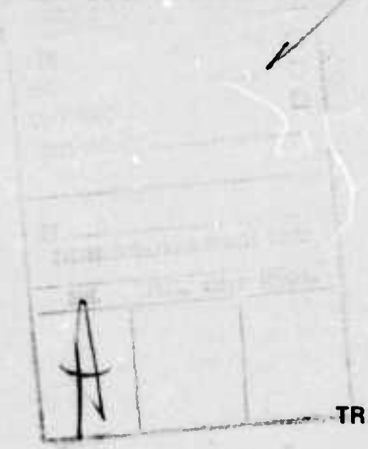

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REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: RN-76-1 (14)	2. GOVT ACCESSION NO. / 3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): (6) MATERIAL AND TEST REQUIREMENTS FOR FIELD EFFECT EMITTER ARRAYS.	5. TYPE OF REPORT & PERIOD COVERED: (9) Technical Report.
	6. PERFORMING ORG. REPORT NUMBER: RN-76-1
7. AUTHOR(s): (10) Joe Shelton	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Commander, US Army Missile Command, Attn: AMSMI-RN, Redstone Arsenal, Alabama 35809	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: N/A
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: (11) 1 July 1975 (12)
	13. NUMBER OF PAGES: 8 (11p.)
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Field-effect electron emitters
Tungsten fibers
Electric field lines

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents a discussion of the material and test requirements necessary for field effect emitter arrays.

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A review of the use of conventionally formed tungsten fibers for field-effect electron emitters indicates that there is room for progress [1]. Problems encountered in using tungsten fibers include erratic operation, short life, and extreme vacuum requirements. Although disappointing, these results should be expected from the materials and the experimental techniques used. To achieve substantial emission from multiple points, the material must be uniform and the experiment must be designed to minimize edge effects.

Recent advances in fabrication techniques for field-effect electron emitters have resulted in an improved material for use as a field-effect emitter. This material is melt grown at high temperatures and contains more than one million emitting points in each square centimeter with each point having a radius of less than one micron [2]. This material has been tested for thousands of hours at current levels of 100 milliamperes per square centimeter, and final current densities of several amperes per square centimeter are expected based on presently achieved experimental data and theoretical limitations. A number of unique applications have been postulated for the material in various fields* [3].

To achieve maximum current densities from arrays of field-effect emitters, it is not only necessary to have a material with the proper characteristics, but the experiment must be properly designed. Consideration of the equations for arrays of emitting points not only shows the requirements for the array, but the experiment itself.

The basic equation for single point field emitters has been developed and verified by experimental data [4]. In its basic form, which can be quickly derived by considering concentric spheres, it can be written as:

$$F = K \frac{V}{r} \quad , \tag{1}$$

where

F = field strength

K = constant

*Shelton, J., et al, "Field Effect Electron Emitter," Patent 3,745,402, July 1973.

Shelton, J., "Field Effect Electron Gun Having at Least a Million Emitting Fibers Per Square Centimeter," Patent 3,783,325, January 1974.

Cason, C. M., et al, "Laser System Incorporating a Field Effect Electron Emitter," Patent 3,798,570, March 1974.

v = potential

r = radius of emitter.

A more general equation for field emitters that is valid for single and multiple point emitters can also be derived from the concentric sphere model. This equation is written as:

$$F = K \frac{\sqrt{Ac}\ v}{\sqrt{Ae}\ a} \quad , \tag{2}$$

where

Ac = area of collector

Ae = area of emitter

v = potential

a = distance between collector and emitter.

For single point emitters, Equation (2) reduces to Equation (1).

If Ac is assumed to be the collector area associated with the emitter area directly under this area, then Equation (2) can be written as:

$$F = K \frac{v}{a} \frac{l}{d} \quad , \tag{3}$$

where l is the spacing between emitting points and d is the diameter of the emitting point.

Consideration of Equation (3) in conjunction with the sharp variations in current density with small changes in electric field leads to the following conclusions concerning the material:

1) The emitting points must be uniformly spaced.

2) All emitting points must have essentially the same height and diameter.

3) The diameter must be very small to operate at reasonable potentials.

Consideration of Equation (3) also shows that the equipment with which field effect emission measurements are made must be properly designed. The equation shows that severe edge effects will be encountered if the collector is larger than the emitting array, and that the edge effects will be more severe as the spacing is increased. This is

due to the larger collector area seen by the outer most emitting points and, hence, the larger field at these points. This effect can easily result in a field sufficient to damage the outer points before the field at the inner points reaches a value capable of producing emission.

Figure 1 illustrates the condition encountered when the collector is larger than the emitting array. Because of the very close spacing of the emitting points (a few microns), even very small extensions of the collector beyond the emitter array will result in a sharp increase in the electric field and thus a very sharp increase in current from the outer emitting points.

Techniques such as the use of guard rings can possibly be used to reduce edge effects, but this approach may be complicated by the small spacing between emitting points. One simple solution that can be used is to reduce the collector size such that it is smaller than the emitting array as illustrated in Figure 2. This will result in a sharp decrease in the field at the points not directly below the collector and should result in little current flow from these points. This will allow the field to be increased such that all emitting points contribute to the observed current and not just a narrow ring directly below the edge of the collector.

The seriousness of edge effects and an indication of the validity of Equation (3) can be shown with an electrolytic tank as shown in Figures 3 and 4. The tank was constructed such that the anode size and the number of equally spaced emitting points used could be easily changed over a large range. Figure 3 shows the configuration used to simulate the condition of an emitting array smaller than the collector by using various numbers of emitting points. Figure 4 shows the configuration used to simulate the condition of an emitting array larger than the collector where all emitting points were used. Line AA' is the line in front of the emitting array along which potential measurements were made for each configuration. Line AA' and the current flow through the tank were selected for ease in data collecting.

Figure 5 shows a plot of the potential to ground versus horizontal position along AA' for the configuration shown in Figure 3. Curve A shows the variations for a three-point array with points located at positions 4, 5, and 6. Curve B shows the variations for a five-point array with points located at 3, 4, 5, 6, and 7. As expected, the curves show a rapid increase in potential beginning at the outer point which indicates an increased electric field at the outer points.

Figure 6 shows a plot of the potential to ground versus horizontal position for the configuration shown in Figure 4 for two positions of line AA' with curve A showing the potential closer to the emitter points. These curves show that the potential drops very quickly for points on the array not located under the anode. In this case, the anode extends

from horizontal position 3.5 to position 6.5. At positions 2 and 8, the potential has dropped considerably indicating a greatly reduced electric field at these points as expected from considering Equation (3).

The preceding equations and curves show that not only must the field emitter material be of high quality, but that the potential of the field emitter cannot be realized using experimental techniques borrowed from thermionic emitters. Each experiment and device design will be new in that extreme care must be used to insure that the electric field is uniform across the entire array of emitting points.

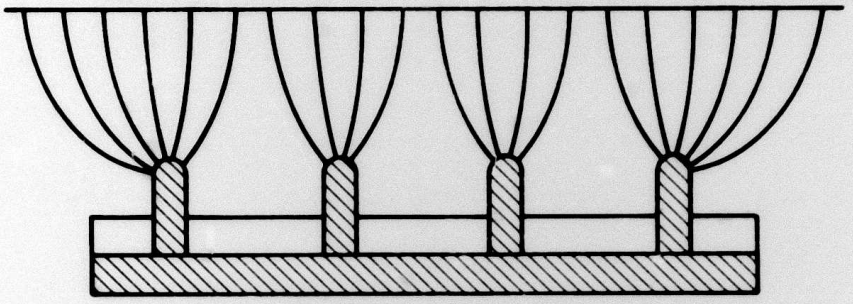

Figure 1. Electric field lines for configuration with anode larger than emitter array.

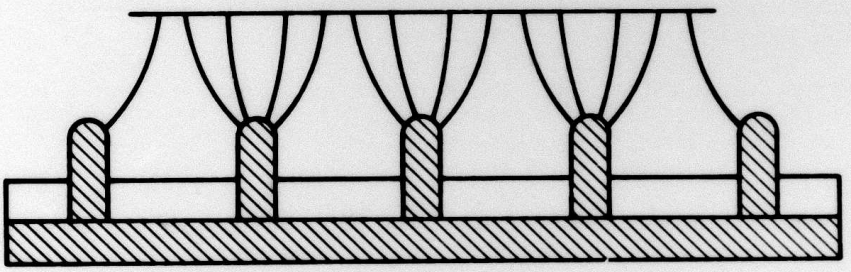

Figure 2. Electric field lines for configuration with anode smaller than emitter array.

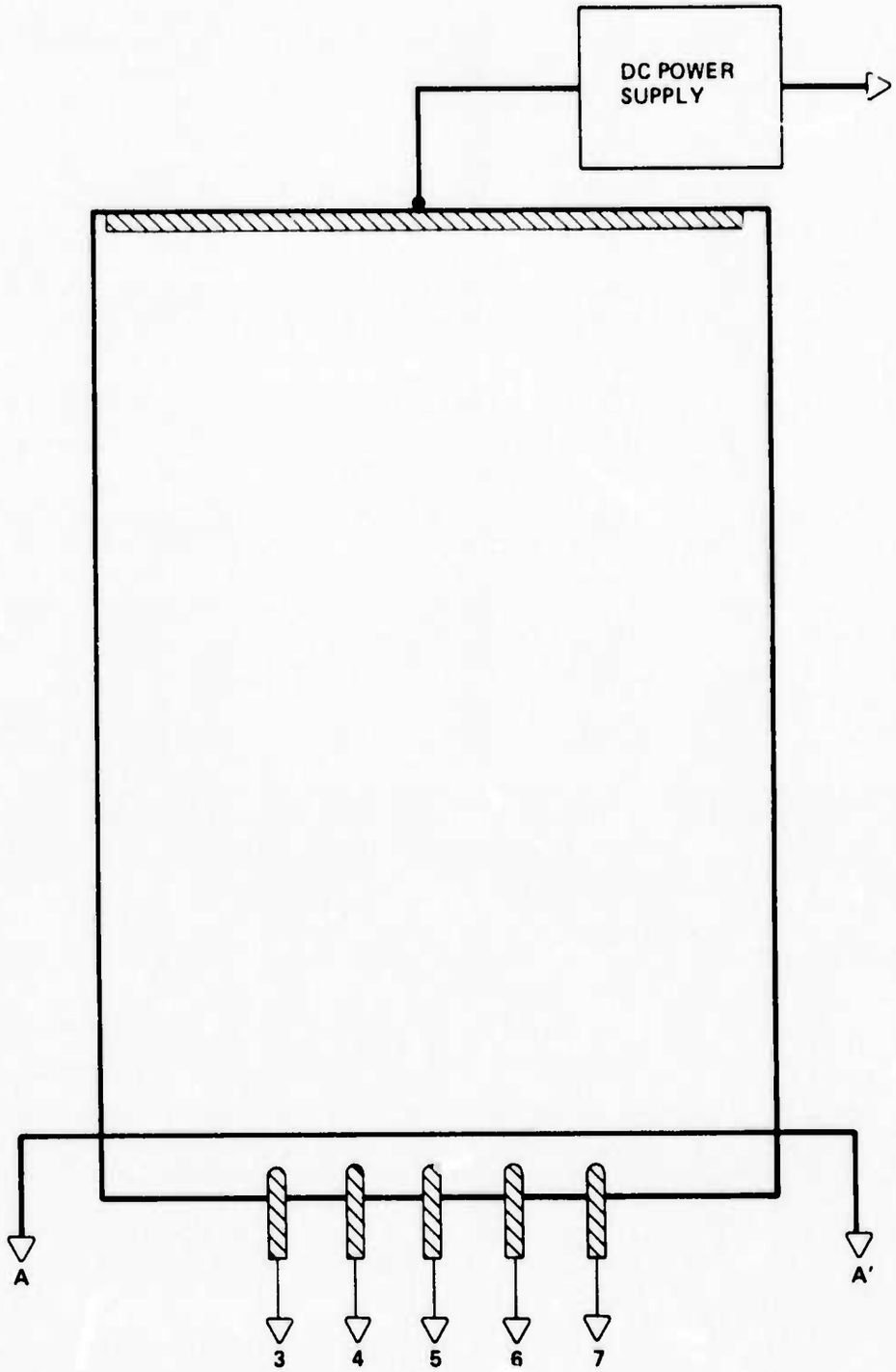

Figure 3. Electrolytic tank configuration with anode larger than emitting array.

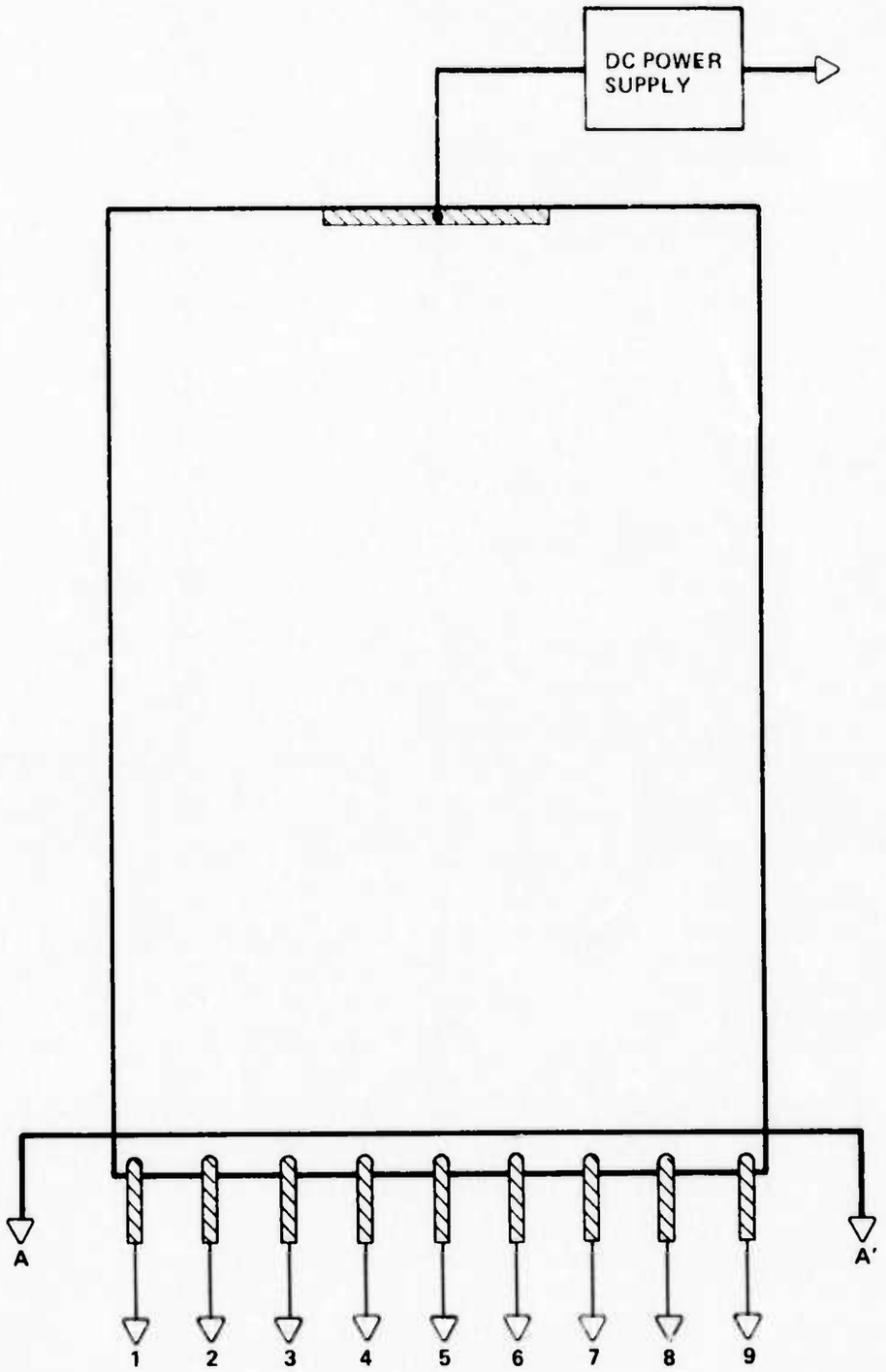

Figure 4. Electrolytic tank configuration with anode smaller than emitting point array.

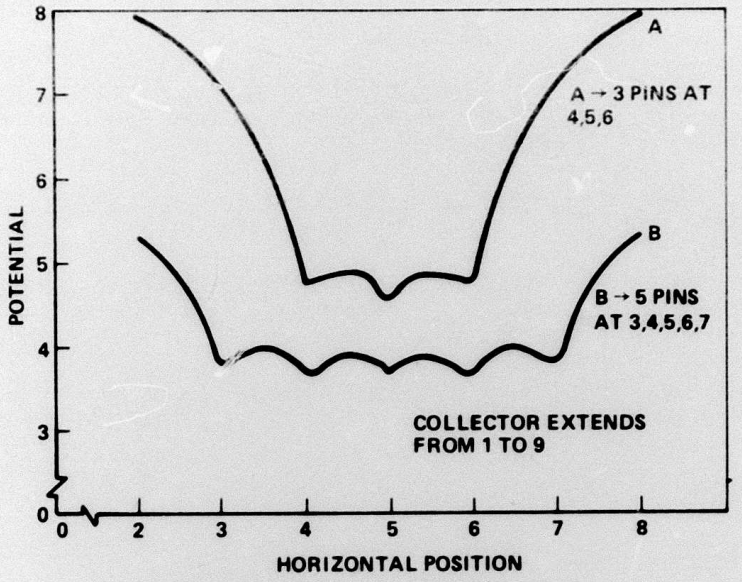

Figure 5. Potential versus horizontal position for anode larger than emitting array.

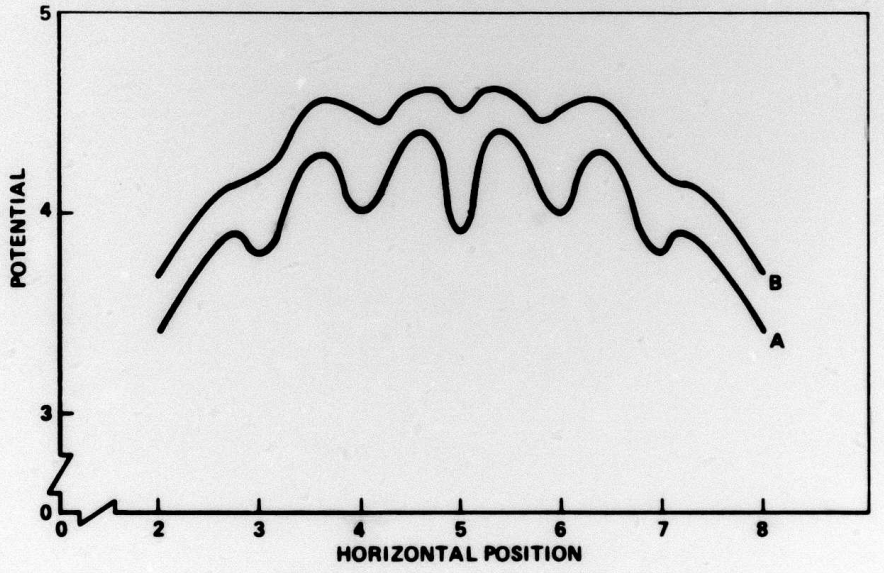

Figure 6. Potential versus horizontal position for anode smaller than emitting array.

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