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WADC Tech. Report 55-1

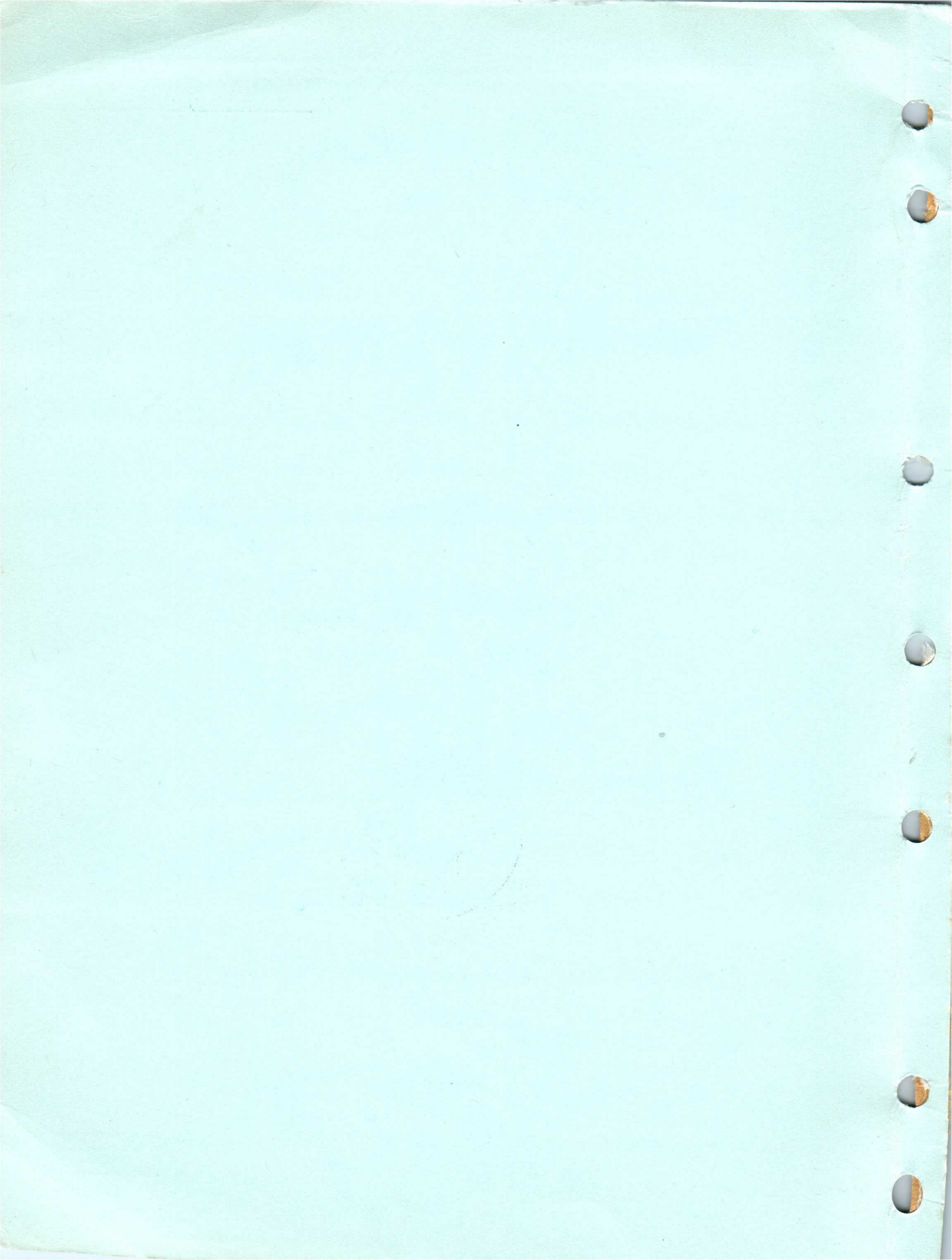
October 1957

ASTIA Document No. 142061

**MILITARY HANDBOOK**  
**ELECTRON TUBES, TECHNIQUES**  
**FOR APPLICATION OF IN**  
**MILITARY EQUIPMENT**



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# **MILITARY HANDBOOK**

## **ELECTRON TUBES, TECHNIQUES FOR APPLICATION OF IN MILITARY EQUIPMENT**



**UNITED STATES  
GOVERNMENT PRINTING OFFICE  
WASHINGTON, D. C.**

## FOREWORD

This handbook was prepared under joint Air Force — Navy sponsorship. The gathering of technical data, analysis and presentation of information was performed by Aeronautical Radio, Inc., under joint Services contract NObsr — 64508. Acknowledgement is made to the many persons and activities of the Military Services and the receiving tube manufacturing industry who provided assistance in obtaining technical data and furnishing constructive comments.

## ABSTRACT

This handbook is intended to provide guidance to design engineers in the application of electron tubes in military electronic equipment. The philosophy of conservative design and the necessity for awareness of tube-property variability are emphasized throughout the handbook. In Part I, tube properties and statistical concepts relating to them are discussed. Tube properties are classified by ratings, characteristics, and those properties that are detrimental to circuit design. Tube properties and statistical techniques are discussed in relation to circuit design in Part II. This portion of the book contains check lists of abnormal environmental conditions and important circuit design factors. Part III contains numerical and graphical information and special design data derived from MIL-E-1 specifications, for tube types appearing in MIL-STD-200. Manufacturer's life-test data on the tube-property behavior of these specific tube types are presented in Part IV.

## TECHNIQUES FOR THE APPLICATION OF ELECTRON TUBES IN MILITARY EQUIPMENTS

### INTRODUCTION

The objective of this handbook is to provide guidance to design engineers in the application of electron tubes in military electronic equipments.

Electronic equipments and systems have become so complex that the misapplication of a single part can nullify the effectiveness of a whole system. Misapplication of electron tubes is one important cause of system unreliability, and is a problem resulting in large part from a lack of information about the variability of tube properties. A consequence of this lack of information is that the significance of tube variability as an equipment design factor has frequently been overlooked, to the detriment of equipment operational reliability.

It is evident that reliability is influenced not only by the relationship between electron tubes and equipments, but also by environment, manner of application, and maintenance practices. This handbook is confined to a consideration of electronic equipment design as influenced by tube procurement specifications. Application information is given on the 56 receiving tube types listed in Military Standard, MIL-STD-200. Every effort has been made to present information simply, factually, and constructively.

Part I of the handbook is concerned with properties common to all electron tubes. Since many of these properties are random variables exhibiting definable probability distributions, basic statistical information is presented at the end of the discussion as an aid to the understanding of electron tube applications. Part II is concerned with the relationship between tube properties and circuit design, and provides techniques for using specifications information in circuit design. Part III presents a summary of applications information with reference to specific structural or functional categories of tubes. This material is followed by a discussion of the mechanical, electrical, and environmental-response characteristics of specific tube types, and by application notes which are uniquely applicable to specific tube types. Part IV outlines observed behavior of properties in specific tube types.

Data and advice presented in this handbook are not elsewhere available in consolidated form. However, the material is intended to serve only as a guide for the design engineer and should be used with discretion.

## GLOSSARY OF STATISTICAL SYMBOLS AND ABBREVIATIONS

(In Order of Appearance in Text)

- $f(X)$  = Probability density function. The various values of  $f(X)$  give the relative frequencies of occurrence corresponding to the particular values of  $X$ .
- $\sigma$  = Population standard deviation.
- $\sigma^2$  = Population variance.
- $X$  = A variable, usually the independent variable; the number of times an observed event occurs in the binomial distribution; length of life of a product in reliability theory.
- $X_i$  = The  $i^{\text{th}}$  observation of the variable  $X$ .
- $A$  = Parameter of the logarithmico-normal distribution.
- $M$  = Population mean value.
- $A$  = Parameter of the uniform distribution.
- $B$  = Parameter of the uniform distribution.
- $p$  = Probability of an event occurring on any trial.
- $m_j$  = The  $j^{\text{th}}$  order moment of the variable  $X$  about an arbitrary origin.
- $Z$  = Some arbitrary origin about which the moments of the variable  $X$  may be computed.
- $\bar{X}$  = Sample arithmetic mean of  $X$ ; an estimate of the population mean.
- $s^2$  = The sample variance; an estimate of the population variance.
- $s = \sqrt{s^2}$  = The sample standard deviation; an estimate of the population standard deviation.
- $n$  = Number of cases; size of sample.
- $\beta_1$  = A measure of relative skewness; The value of  $P_1 = 0$  for a normal curve.
- $\beta_2$  = A measure of relative kurtosis (peakedness); the value of  $B_2 = 3$  for a normal curve.
- $F$  = The sample variance ratio; the ratio of two independent estimates of the same population variance.
- $n_1$  = Degrees of freedom associated with greater mean square of F-ratio.
- $n_2$  = Degrees of freedom associated with smaller mean square of F-ratio.
- $W$  = A weighting factor.
- $X_{ij}$  = The variate found in the  $i^{\text{th}}$  row and  $j^{\text{th}}$  column of a two-way table of classification.
- $f_0(X)$  = Probability density function of the null hypothesis.

$f_1(X)$  = Probability density function of the alternative hypothesis.

$k$  = A predetermined constant for acceptance of the null hypothesis; number of a product which fail in time  $t$  in reliability theory.

$s_x = \frac{s}{n}$  = Standard error of a sample mean.

$\alpha$  = Probability of rejection; level of significance; risk of an error of the first kind.

$1 - \alpha$  = Probability of acceptance; confidence coefficient.

$t$  = The deviation of a variable from its mean divided by an estimate of the population standard deviation based on the sample standard deviation; a distribution.

$t_\alpha$  = The  $\alpha$  percent point of a  $t$  distribution.

$k_\alpha$  = The  $\alpha$  percent point of the normal probability distribution.

$Pr$  = The probability that.

$SS$  = Sum of squares.

$DF$  = Degrees of freedom.

$MS$  = Mean square =  $SS/DF$ .

$L_1$  = Lower tolerance limit.

$L_2$  = Upper tolerance limit.

$l$  = Tolerance factor.

$K$  = Scale factor.

$Y$  = A variable, usually the dependent variable.

$Y_i$  = The  $i^{\text{th}}$  observation of the variable  $Y$ .

$A$  = Constant in the population regression equation.

$B$  = Population regression coefficient.

$a$  = Estimate of  $A$ ; a constant in the sample regression equation.

$b$  = Estimate of  $B$ ; a sample regression coefficient.

$\Sigma$  = The summation of.

$\bar{Y}$  = Arithmetic mean of  $Y$ .

$e$  = Residual; error; discrepance term.

$s_e$  = Standard error of estimate.

$\rho$  = Population correlation coefficient.

- $r$  = Sample correlation coefficient; an estimate of  $\rho$ .
- $r^2$  = Coefficient of determination; a measure of the closeness of the relationship between two variables.
- $X'$  = A particular value of  $X$ .
- $\hat{Y}$  = Sample estimate of the mean value of  $Y$  obtained from the estimated line of regression.
- $\hat{Y}'$  = Confidence limits for the mean of the  $Y$  values for a particular value of  $X$ .
- $\hat{Y}''$  = Confidence limits for an individual  $Y$  value.
- $\hat{Y}'''$  = Tolerance limits for  $Y$  for a given value of  $X$ .
- $SS_y$  = Sum of squares of all  $Y_i$  values about  $Y$ .
- $SS_0$  = Sum of squares of the deviations of the  $\bar{Y}_i$  values about the regression line.
- $P = 1 - \alpha$  = Value of confidence coefficient.
- $y = \text{Log } \bar{Y}$ .
- $x = \text{Log } \bar{X}$ .
- $\hat{y}$  = Sample estimate of the mean value of  $y$  obtained from the estimated regression line.
- $s_y$  = Sample standard deviation of  $Y$ .
- LAL = Lower limit for  $X$ .
- UAL = Upper limit for  $X$ .
- Log = Common logarithm.
- $T$  = Time measured from some beginning point.
- $R(T) = \text{Pr}(X > T)$  = Reliability function; the probability that the length of life of a product will be greater than time "T."
- $\hat{R}(T) = \frac{n - k}{n}$  = Estimate of  $R(T)$ .
- $R(t) = P(X > t)$  Reliability function obtained by an approach other than that used for  $R(T)$ .
- $\hat{R}(t)$  = Estimate of  $R(t)$ .
- $i$  = The  $i^{\text{th}}$  ordered failure.
- $t_i$  = Time to the  $i^{\text{th}}$  failure.
- $\hat{R}(t_i)$  = Estimate of  $R(t)$  at the time of the  $i^{\text{th}}$  failure.
- $n_i$  = Number of survivors beginning the interval which precedes the  $i^{\text{th}}$  failure.

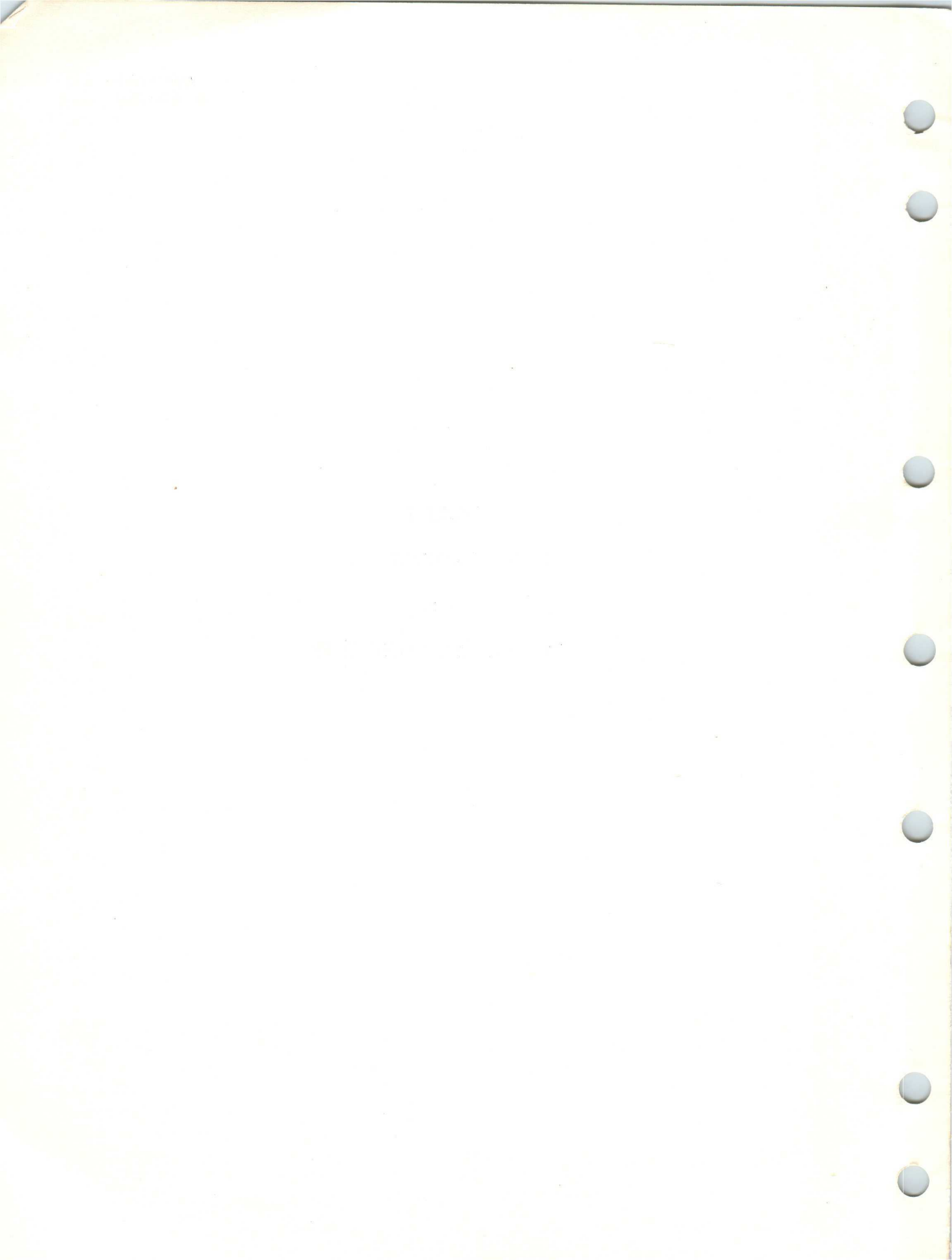
$r_i$  = Number of failures occurring at the time of the  $i^{\text{th}}$  failure.

$\pi$  = The product of.

V = Variance.

$W_i$  = Number of withdrawals (censored observations) during the  $i^{\text{th}}$  time interval.

**PART I**  
**TUBE PROPERTIES**  
**AND**  
**STATISTICAL CONCEPTS**



## 1. TUBE PROPERTIES

The electronic equipment designer may best evaluate the ability of a specific tube type to satisfy a given circuit requirement by considering the following five types of tube properties.

- (1) *Ratings*: the set of limiting values defining each operating condition within which the tube type can be expected to yield a nominal period of satisfactory service.
- (2) *Controlled Characteristics*: tube properties essential to the operation of the circuit, and having a distinct range of values defined for a given tube type by specifications.
- (3) *Uncontrolled Characteristics*: tube properties essential to the operation of the circuit, but existing within an indeterminate range, owing to lack of specification control.
- (4) *Controlled Detriments*: inherent tube properties which must be considered in circuit design because of their detrimental effects upon circuit operation. These properties have no specified range of values; they are restricted by a single specified limit on their magnitude or frequency of occurrence.
- (5) *Uncontrolled Detriments*: inherent tube properties which are detrimental to circuit operation and which are not subject to specification control.

Table I indicates the extent to which tube ratings, characteristics, and detrimental properties are controlled by specifications.

### 1.1 Tube Ratings as Limitating Values

Three rating systems are currently in

use for defining conditions of operation within which a tube type can be expected to yield a nominal period of satisfactory service. These are the design-center system, the absolute-maximum system, and the design-maximum system. Although military specifications usually employ the absolute-maximum system, the designer must occasionally use a tube type for which no set of absolute ratings is available and must therefore be able to work easily with any of the three systems.

#### *The Design-Center System*

The design-center system was developed to control the use of tubes in relatively simple circuits. Because of the complex and critical nature of many present-day circuits, this system is no longer adequate and is not used in military specifications. The design-center maximum ratings allow for a 10-percent increase over rated values to accommodate limited variations in operating conditions. This increase is not always sufficient for modern equipments operated under stringent conditions. An additional inadequacy in the design-center rating system is that no allowance is made for variations in tube characteristics. Tube abuse may result inadvertently if the calculated operating conditions are near a rating value. For proper use of the design-center system, design ratings must be specified sufficiently below the design-center maximum values to allow for variations in tube characteristics.

#### *The Absolute-Maximum System*

In the absolute-maximum system, the rated values of a tube must not be exceeded under any specified condition of supply-voltage variation, change in ambient temperature, manufacturing variation in tube or other component, equipment control adjustment, or any combination of these specified condi-

RATINGS	CHARACTERISTICS	DETRIMENTAL PROPERTIES
<b>FREQUENTLY CONTROLLED IN SPECIFICATIONS</b>		
Heater Voltage Anode Voltage (d-c) Screen Grid Voltage (d-c) Heater-Cathode Voltage Anode Dissipation Screen Grid Dissipation Output Current (Rectifiers) Output Voltage (Rectifiers) Peak Current (Rectifiers) Peak Inverse Voltage (Rectifiers) High Impact Shock	Transconductance Plate Current Screen Grid Current Heater Current Inter-Electrode Capacitance Amplification Factor Power Output Emission Conversion Conductance	Control Grid Current at Rated $E_f$ Heater-Cathode Leakage Microphonics Noise Shorts and Continuity Vibration Output
<b>OCCASIONALLY CONTROLLED IN SPECIFICATIONS</b>		
Anode Voltage—Peak Forward Anode Voltage—Peak Inverse Control Grid Voltage Control Grid Resistance Average Cathode Current Bulb Temperature	Dynamic Plate Resistance Bias For Plate Current Cutoff	Electrode Insulation Grid Current at Elevated $E_f$ Change of Characteristics with Life Change of Characteristics with $E_f$
<b>RARELY CONTROLLED IN SPECIFICATIONS</b>		
Pressure—Temperature Derating Peak-Pulse-Cathode Current	Zero-Bias Plate Current Zero Bias Screen Current Plate Current at Multiple Bias Points Screen Current at Multiple Bias Points	Initial-Velocity Electron Current (Contact Potential) Electron Coupling Effects Plate Emission Screen Emission

Table 1. Degree of Specifications Control of Specific Tube Ratings. Characteristics, and Detrimental Properties.

tions. The equipment designer is responsible for determining design values such that the absolute maximum value of any rating will not be exceeded under any combination of anticipated variations in the operating conditions. This rating philosophy requires that the designer take into account the normal variation in tube characteristics and allow for the severest possible condition of signal voltage.

#### *The Design-Maximum System*

Under the design-maximum system, the ratings are based upon the behavior of the average tube. In setting these ratings, the tube manufacturer takes the responsibility for manufacturing variation by life-testing at or near the rating value. It is the responsibility of the designer using this system to see that the rating is not exceeded under any possible combination of voltage-supply variation, control misadjustment, or signal-voltage level.

Although ratings are specified by single-valued limits, these limits are not absolute barriers on one side of which satisfactory operation will continue indefinitely and on the other side of which almost immediate degradation of performance will occur. The equipment designer must realize that the expected period of satisfactory performance decreases gradually as the rating is approached and exceeded, and that the life expectancy of the tube is greater if the tube is used conservatively with respect to its ratings. The numerical value specified is usually the value which assures acceptable performance under specified life-test conditions and is not necessarily closely related to field usage. Table 2 summarizes the types (and causes) of tube failure which may result from use of tubes at values approaching common tube ratings.

#### **1.2 Characteristics Essential to Circuit Operation.**

Essential characteristics of an electron tube are those properties that support the performance of the tube in the application in which it is employed.

In many cases, the tube properties which are essential to specific circuit performance characteristics are known. For example, the gain of a pentode amplifier circuit is closely related to transconductance ( $S_m$ ); the gain of a triode amplifier circuit, on the other hand, is related both to transconductance and to the tube amplification factor ( $\mu$ ). In some applications, inter-electrode capacitances can be regarded as essential characteristics, whereas in other applications (for example, low-frequency circuits) these properties are of no consequence.

The optimum situation obtains when the essential characteristics are known, when their variability is adequately defined by the applicable specification, and when a high degree of correlation exists between the variability of the essential characteristics and the variability of performance characteristics of the circuit.

Certain methods used for specification control of variability in essential characteristics are discussed at the end of Part I. Techniques for determining the correlation between essential tube characteristics and circuit performance characteristics are discussed in Part II.

#### **1.3 Properties Detrimental to Circuit Operation.**

Detriments are inherent tube properties whose deleterious effect on circuit operation must be taken into consideration in circuit design. These properties have no specified range of values, but are restricted by a single specification limit upon their magnitude or frequency of occurrence. Certain detriments manifest themselves upon initial installation of the tube; others become evident only through equipment malfunction with the passage of time.

<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="text-align: center;"> <p><b>APPROACHING THIS RATING</b></p> </div> <div style="text-align: center;"> <p><b>MAY CAUSE</b></p> </div> <div style="text-align: center;"> <p><b>RESULTING IN</b></p> </div> </div>		Max. Anode or Screen Voltage	Max. Peak Forward Anode Voltage	Max. Positive Control Grid Voltage	Max. Negative Control Grid Voltage	Max. Heater Voltage	Min. Heater Voltage	Max. Control Grid Return Resistance	Max. Anode or Screen Dissipation	Max. Heater-Cathode Voltage	Max. Cathode Current	Min. Cathode Current	Max. Output Current for Rectifiers	Max. Output Voltage for Rectifiers	Max. Inverse Voltage for Rectifiers	Max. Bulb Temperature
		Increased Operating Temperature of Tube Elements	Accelerated Evolution of Gas (Positive Shifts in Bias and Progressive Loss of Emission)			X		X		X		X		X		
Thermal Expansion of Tube Parts (Shorts and Temporary Change of Characteristics)						X		X							X	
Accelerated Formation of Leakage Paths						X										
Cracks in the Glass Envelope						X		X				X			X	
Changed "Contact Potential"						X										
Shortened Heater Life						X										
Increased Potential Gradient	Voltage Breakdown of Insulation		X	X					X				X	X		
	Increased Rate of Heater-Cathode Shorts					X			X							
Increased Temperature of Elements and/or Potential Gradient	Increased Effects of Control Grid Emission (Shifts Bias More Positive)			X		X	X	X							X	
	Increased Effects of Anode Emission (Arc-Back in Rectifiers or Positive Bias Shift in Amplifiers)		X			X	X	X				X	X	X	X	
	Increased Heater-Cathode Leakage					X			X							
	Accelerated Formation of Cathode-Interface Resistance				X	X					X					
	Accelerated Electrolysis Effects (Glass Leakage Current and Possible Loss of Vacuum)	X	X			X		X				X	X	X	X	
Accelerated Change in Characteristics With Time		X			X	X		X		X	X	X			X	
Increased Initial Variation in Characteristics from Tube to Tube				X		X	X			X	X					
Inadvertently Exceeding Other Ratings		X	X	X	X	X		X	X	X		X	X	X	X	

Table 2. Specific Tube Defects Resulting from Operation Under Conditions Closely Approaching Common Tube Ratings.

To obtain maximum utilization of the Essential Characteristics, it is necessary that detriments be recognized as potential contributors to equipment failure. In general, if the equipment designer has properly assessed the nature or mode of equipment malfunction resulting from detrimental properties, he has three means of preventing such malfunction:

- (1) By selecting a tube type for which the specification quantitatively defines the undesired property.
- (2) By avoiding operation of the tube under conditions which will aggravate the effect of the detriment or accelerate its development.
- (3) By designing the circuit so that the presence of the undesired property is tolerated both initially and after extended operation.

The following material describes briefly the source and nature of some generally undesired but often unrecognized properties of present-day electron tubes, the variables involved and their effects upon circuit operation, various methods of reducing the effects of the undesired properties, and certain applicable methods of testing for and simulating the presence of these properties.

### 1.3.1 *Initial-Velocity Grid Current*

Figure 1 shows a typical relationship between control-grid current and potential resulting from the initial velocity of electrons emitted from the cathode. Tube manufacturers often refer to the value of grid potential producing a current of 0.1 microampere as the "contact potential"\* of the tube.

The diagonal lines showing grid current versus grid voltage may be considered plots of the number of electrons emitted per unit

\* "Contact potential" must be clearly distinguished from "contact difference of potential" of dissimilar materials.

time (grid current) with sufficient kinetic energy to move to the grid against a given retarding electrical field. (The retarding field must be considered as the actual potential between the surface of the cathode and the surface of the control grid. This potential includes any separately introduced sources of bias voltage as well as the "contact difference-of-potential" of dissimilar materials in the grid-cathode circuit loop.) The resulting current is consequently a function of grid-cathode potential and cathode temperature, as well as of cathode composition and area.

Cathode area is reasonably constant in tubes of the same type. Cathode temperature is usually dependent upon the operating voltage of the heater. Hence, variations of initial-velocity electron current in a given tube type will occur primarily with changes in heater voltage. However, such variations will also occur from tube and, in particular, from manufacturer to manufacturer.

The circuit designer must consider the fact that initial-velocity grid current in the grid-potential range between 0 and approximately -1.3 volts is manifested in two phenomena which have different effects in different applications. On the one hand, initial-velocity grid current represents a finite dynamic grid impedance with magnitude dependent upon grid potential. The effect of this impedance may appear as loading in tuned input circuits or as extreme distortion at low frequencies in audio amplifiers. On the other hand, initial-velocity grid current represents a direct-current source having high internal resistance, with the negative pole on the grid and the positive pole on the cathode. Where the major portion of grid-return resistance is common to several grids, this direct-current source may cause variations of AVC bias, since the tube having the highest value of initial-velocity grid current will determine the residual bias under no-signal conditions and thereby the

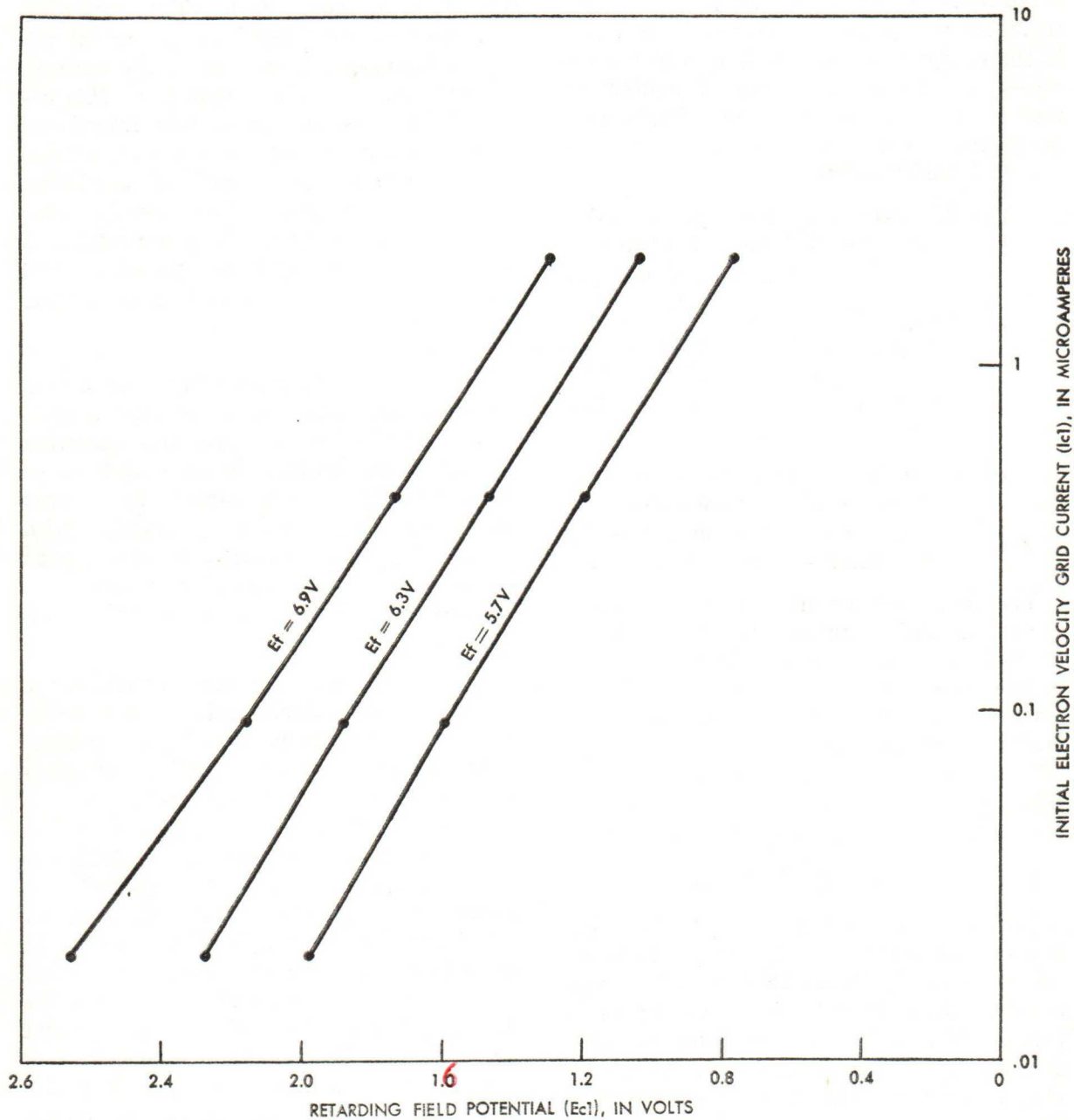


Figure 1. Typical Initial Electron Velocity Grid Current of a Receiving Pentode as a Function of Heater Voltage and Grid Potential. Screen and Plate tied to Cathode.