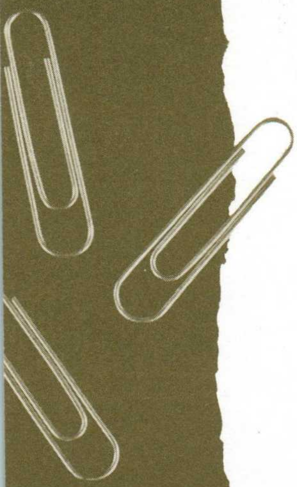
Item 49

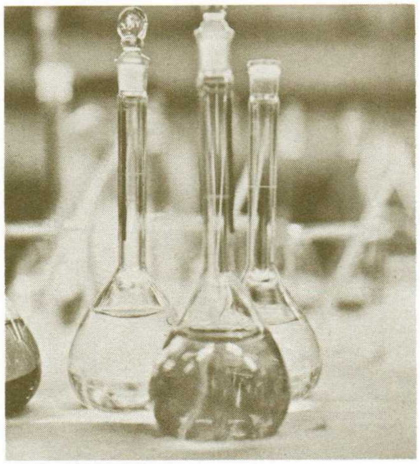
Receiving Valves Only

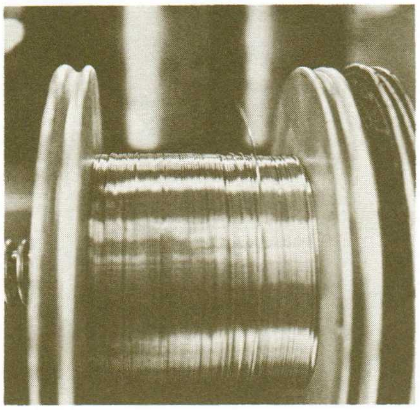
Electron Tube Application Notes

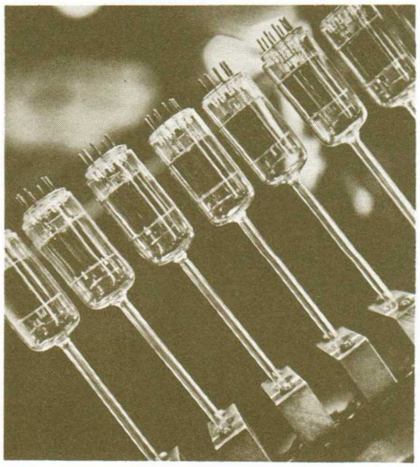
The Unmistakable Ring of Reliability...

SYLVANIA
ELECTRONIC TUBE DIVISION









Reliability Doesn't Just Happen!

The quality which makes Sylvania's Products more durable... More dependable... more in demand... is the result of four basic production concepts.

Design
Production
Product Control
Testing

Sylvania continually strives for product perfection in its design laboratories.

Sylvania automation is quietly eroding the element of human failure in tube making.

Since Sylvania produces nearly every component in its own plants, the company is able to maintain a firmer control—produce a superior product.

And—at Sylvania—vital tests are conducted at every strategic point of processing and manufacture—thus providing adequate controls to ensure the end result of tube reliability.

APPLICATION NOTES

Introduction

When a circuit designer sets out to develop or improve a piece of electronic equipment, he is almost invariably interested in making it reliable as well as meeting a prescribed performance level. Reliability, simply stated, is the ability of the particular apparatus to function satisfactorily for a prescribed period of time—which could be one flight of a missile, a certain number of hours for an industrial application, or the warranty period of an entertainment device. As a corollary, reliablity can also mean a minimum of production line hold-ups, where electronic equipment is manufactured in volume.

The degree of reliability achieved depends upon the practical considerations and techniques which most circuit designers learn in the course of practicing their profession.

Tube application technique has a direct bearing on equipment reliability. Although the technique is basically "common sense," it is not too well documented and is generally learned through experience.

It is the intent of this material to review some of the important "Do's" and "Don'ts" of tube applications, as they apply to the entertainment, and to a great extent, the industrial electronics fields. Although most of the information supplied is already common knowledge, it should serve as a reminder for the experienced engineer and a guide for the newest members of the profession.

SYLVANIA
ELECTRONIC TUBES
Receiving Tube Operations
Emporium, Pennsylvania

SYLVANIA
SUBSIDIARY OF
GENERAL TELEPHONE & ELECTRONICS

49-2-60-1

Application Notes

Prepared and Released by
TECHNICAL PUBLICATIONS SECTION
EMPORIUM, PENNSYLVANIA

SYLVANIA
ELECTRONIC TUBES
Receiving Tube Operations
Emporium, Pennsylvania

SYLVANIA
SUBSIDIARY OF
GENERAL TELEPHONE & ELECTRONICS

APPLICATION NOTES

TABLE OF CONTENTS

The Case for Good Tube Application

As the "active" elements of an electronic system, receiving tubes become the very heart of the system. The success or failure of a particular equipment design is therefore directly related to the successful application of tubes. This is true whether success is measured in terms of manufacturing ease, excellent survival rate in the field within the warranty period, or both.

Some curious anomalies exist within the electronics field that illustrate that the ultimate success or failure of an equipment design can be attributed, among other things, to the particular manner in which the designer applied the tubes. For instance:

(a) Large quantities of a given tube are manufactured at approximately the same time, on the same machinery, with all the tubes representing about the same "quality" level. Quite commonly, these tubes are distributed to two or more equipment manufacturers producing directly competitive versions of electronic equipment, such as TV sets. Some manufacturers experience a line rejection level of less than one percent (1%), while others—using tubes from this same group—experience line rejections many times higher in magnitude.

Why the vast difference, when all of the tubes are of essentially the same quality? In many cases, the difference can be attributed to the manner in which the equipment design utilizes the tubes. This might be operation outside rated limits; use of tube types not intended for the particular applications; or use in a marginal design that is incapable of utilizing the full production spread of the given tube types.

Quite obviously, a low line reject percentage is desirable to the equipment manufacturer in the interest of minimizing re-work programs, production slowdowns, and other assorted items which influence manufacturing costs. Furthermore, continuous problems at the manufacturing stage are forerunners of serious customer problems within the equipment warranty period.

(b) Sylvania Electric Products Inc. has been studying the set-survival of various TV receivers in an effort to gather information beneficial to both tube and set designers. This involved conducting many life tests on different makes and models of TV receivers.

Figure 1 compares the survival rates of two different TV receiver designs representing extremes observed during the study. (The receivers were operated at a line voltage of 130 volts which accelerates receiving tube failures by a factor of approximately 2.4 as compared to 117 volt operation.)

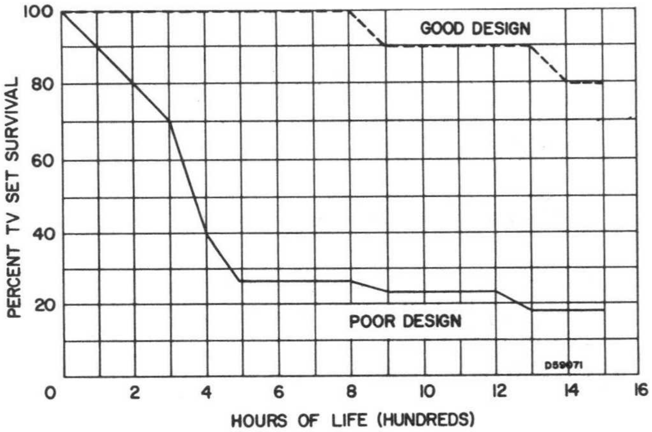


Figure 1—Computed Set Survival of TV sets manufactured.

Note the vast difference between survival rates of the two receivers although both designs employ tubes of essentially the same quality and manufacturing period. The principal difference between the two receivers is in the manner in which the tubes were utilized. A complete report on this study, entitled "Progress in TV Receiver Reliability" is available, upon request, from your nearest Sylvania sales office.

From the foregoing discussion, it becomes evident that the equipment designer plays a major role in determining the successful production and field history of an equipment, and in all probability, his success will depend greatly upon the way in which he applies the required tubes.

Electrical Considerations

The receiving tube data provided for equipment designers normally falls into two basic categories; (1) Ratings—limiting values of operating conditions, and (2) Electrical Characteristics— specific properties of the individual tube type at selected operating conditions within specified ratings.

RATINGS

First, what is meant by tube ratings and why are they needed? Ratings define the limitations of a tube such as element voltages; element currents; bulb or ambient temperature and element dissipation. The numerical quantities presented as maximum ratings are the limiting operating values at which satisfactory tube life and performance is assured. It should be emphasized that values listed as ratings are meaningful *only* when applied according to the definition and procedure specified for a particular rating system. Until recently, two rating systems, namely the Design-Center System and the Absolute-Maximum System were used by the Receiving Tube Industry. Both of these systems had serious deficiencies, most of which stemmed from the illogical division of responsibility between the tube and equipment manufacturer. These deficiencies were accentuated by the ever-increasing diversification of receiving-tube applications. Thus, the Design-Maximum System was developed in an attempt to resolve some of the problems.

Comparison of Rating Systems

The Joint Electron Device Engineering Council (JEDEC) found it necessary to standardize the definitions of the two older rating systems to parallel the definition of the new Design-Maximum system. This provided a better understanding and a better means of comparing the three rating systems as applied to various electronic devices. The approved definitions are as follows:

Absolute-Maximum Rating System

Absolute-Maximum ratings are limiting values of operating and environmental conditions applicable to any electron device of a specified type as defined by its published data, and should not be exceeded under the worst probable conditions.

The device manufacturer chooses these values to provide acceptable serviceability of the device, taking no responsibility for equipment variations, environment variations, and the effects of changes in operating conditions due to variations in device characteristics.

The equipment manufacturer should design so that initially and throughout life no Absolute-Maximum value for the intended service is exceeded with *any* device under the worst probable operating conditions with respect to supply-voltage variation, equipment component variation, equipment control adjustment, load variation, signal variation, environmental conditions, *and variations in device characteristics.*

Design-Center Rating System

Design-Center ratings are limiting values of operating and environmental conditions applicable to a bogey electron device of a specified type as defined by its published data, and should not be exceeded under normal conditions.

The device manufacturer chooses these values to provide acceptable serviceability of the device in average applications, taking responsibility for normal changes in operating conditions due to rated supply voltage variation*, equipment component variation, equipment control adjustment, load variation, signal variation, environmental conditions, and variations in device characteristics.

The equipment manufacturer should design so that initially no Design-Center value for the intended service is exceeded with a bogey device in equipment operating at the stated normal supply voltage*.

**For an AC power source, 117 volts plus or minus 10% is accepted USA practice.*

Design-Maximum Rating System

Design-Maximum ratings are limiting values of operating and environmental conditions applicable to a bogey electron device of a specified type as defined by its published data, and should not be exceeded under the worst probable conditions.

The device manufacturer chooses these values to provide acceptable serviceability of the device, taking responsibility for the effects of changes in operating conditions due to variations in device characteristics.

The equipment manufacturer should design so that initially and throughout life no Design-Maximum value for the intended service is exceeded with a *bogey* device under the worst probable operating conditions with respect to supply voltage variation, equipment component variation, equipment control adjustment, load variation, signal variation, and environmental conditions.

Table I lists four elements whereby the rating systems can be judged and should give the reader a perspective which establishes the logical superior-

TABLE I
ELEMENTS OF TUBE RATING SYSTEMS

Element	*Absolute-Maximum*	*Design-Center*	*Design-Maximum*
1. Tube used for evaluation of ratings	Any	Bogey	Bogey
2. Equipment operating conditions under which tube ratings are evaluated	Worst probable	Normal	Worst probable
3. Responsibility for			
A) Variations in tube characteristics	Equipment Manufacturer	Tube Manufacturer	Tube Manufacturer
B) Variations in equipment and environmental conditions	Equipment Manufacturer	Tube Manufacturer	Equipment Manufacturer
4. Permissible excess of specified values of maximum ratings	None allowed	Exceeded under adverse operating conditions and with other than bogey tubes	Exceeded with other than bogey tubes

ity of the Design-Maximum System for presentation and application of most receiving tube ratings.

For instance, the Design-Maximum System retains the chief advantage of the Design-Center System; the use of a "bogey tube" for evaluation of ratings. This means that a normal, readily obtainable tube more representative of the industry product is used instead of one or more abnormal or possibly "limit" tubes for various characteristics which would have the greatest effect toward evaluation of Absolute-Maximum Ratings. To further clarify the "bogey tube" element, JEDEC offers the following definition:

Bogey Tube

> A bogey tube, in the exact sense, would be a tube of a specified type which has each and all of its characteristics equal to the published values. Such a tube is extremely difficult to find because of the large number of characteristics involved. For practical purposes of application, a bogey tube can be obtained by considering only those characteristics which are directly related to the class of service being evaluated.

The Design-Maximum System retains the chief advantage of the Absolute-Maximum System in that the values listed as maximum ratings are evaluated under the worst probable operating conditions so that serviceability attributes of the individual equipment may be established. These serviceability attributes are more easily appraised by the equipment manufacturer under the Design-Maximum System because, again, a "bogey tube" is used for evaluation and the tube manufacturer has made allowance in his rating for variations in tubes.

Under the Absolute-Maximum System, the equipment manufacturer is responsible for variations in tube characteristics. He must, therefore, consider the effects of any tubes he might receive that are within the suppliers' specification limits. Thus, he bears the entire burden of responsibility for both tube and equipment serviceability.

The converse is true for the Design-Center System, where the tube manufacturer is, theoretically, entirely responsible for equipment serviceability as far as tubes and operating conditions are concerned. Here the tube manufacturer is hampered in that his life tests and acceptance requirements must be based upon average applications of tubes in a given class of service operating within standardized allowable ranges of supply voltage. The equipment designer is also hampered in that he does not know the true limiting values of the ratings he can tolerate under high supply voltage conditions.

Thus it is seen that under the Design-Maximum System the responsibility is properly divided between the tube manufacturer and the equipment manufacturer, as each knows best the variations in his products, and environments that can be tolerated, for any given class of service.

The Design-Maximum System provides an ideal means of expressing heater or filament ratings. Depending on the intended service, permissible variations are specified on the data sheets for each individual tube type. For entertainment tubes operated from the AC line, heater voltage is listed as nominal 6.3 volts plus or minus 10% for types using transformer supply, and heater currents are listed as nominal plus or minus a smaller percentage for series heater string types depending upon what the normal heater string current variation might be when the line voltage is varied over the allowable range specified by JEDEC. For 600 ma series string heater tubes, the heater current is listed as nominal 600 ma plus or minus approximately 6 percent.

Nominal filament voltages are similarly listed for fly-back high voltage rectifiers, but a wider variation is usually stated to allow for variations of components and adjustments of the associated circuits as well as for variations of supply voltage. A range of 1.05 to 1.45 volts is permitted for most high voltage rectifiers which have 1.25 volts nominal filament voltage.

The ranges of supply voltages upon which ratings are based for various classes of service have been standardized by industry as listed in Table II.

TABLE II
ALLOWABLE RANGES OF SUPPLY VOLTAGE

AC Line Operated Equipment		
Low Line	*Nominal Line*	*High Line*
105 Volts	117 Volts	129 Volts
Automotive Equipment		
	Low Battery (Generator Not Charging)	*High Battery (Generator Charging)*
6-Volt System	5.0 Volts	8.0 Volts
12-Volt System	10.0 Volts	15.9 Volts
Dry Battery Equipment		
	Minimum	*Maximum*
"A" Battery (1.5 V cell)	1.1 Volts	1.6 Volts
"B" Battery	—	Rated Block Voltage +10%

Application of the Design-Maximum Rating System

To demonstrate how an equipment designer can apply the values listed as Design-Maximum Ratings to determine the serviceability of his equipment, consider the example of the horizontal deflection system of a TV set. Here, interdependent variables make serviceability evaluation very difficult because the operating conditions of the damper and the high voltage rectifier depend on the operation of the horizontal deflection tube which in turn is driven by the horizontal oscillator. The suggested procedure is as follows:

1. Bogey tubes are selected by the designer and placed in the stages being evaluated.
2. The line voltage is adjusted to the usual maximum of 129 volts because generally all element voltages, currents, dissipations and bulb temperatures are highest at this point.
3. Then the designer determines the effects of variations in such components as the cathode resistor, screen dropping resistor, series plate resistor, deflection yoke and flyback transformer; and he must exercise good judgment based on the numerous variables in the system and other tubes as to the worst probable combinations of these items. At the same time, he must consider the probability of maladjustment of such controls as drive, horizontal hold, brightness, width and linearity as they may affect the operating conditions of the tubes. The various items listed as ratings are thus measured under the worst probable operating conditions that the designer feels are commensurate with the intended service.
4. The supply voltage is dropped to the usual minimum value of 105 volts. Here, only measurements of heater voltages and filament voltage of the high voltage rectifier are considered. Again, for the high voltage rectifier tube, control adjustment and other tube and component variations must be judged to determine the most probable value of low filament voltage.
5. The equipment designer compares his measurements with the values listed as ratings in the registered data. If any one item exceeds the rating, serviceability of the equipment may be unsatisfactory and it is his responsibility to affect the necessary corrections. Good judgment must be exercised concerning the reliability requirements of the equipment in its intended market and price range, but it is only common sense that tubes operated near or above maximum ratings cannot be expected to provide as good service as tubes operated well below maximum ratings.

The Design-Maximum Rating System is now being used for many tubes in TV applications where serviceability is difficult to evaluate. In automotive applications where ranges of supply voltage have been standardized, the new system provides, for the first time, an ideal means of applying meaningful values to tube ratings.

Since all three systems are still currently in use, the designer must pay attention to the rating system employed for the particular tube type being used to preclude exceeding a tube rating under a "limit" operating condition.

What happens when a designer yields to the temptation of exceeding a maximum rating? Actually, much depends upon which specific rating is exceeded. Should a peak inverse voltage rating be exceeded, a high incidence of arc-over problems on the production floor could be the result. On the other hand, other ratings are not of such a finite and immediately catastrophic nature. For instance, if the plate dissipation rating is exceeded, there would not necessarily be any immediate repercussions on the production line—but in field service, there would probably be a high incidence of complaints due to short life, caused by the evolution of gas from the tube parts or other similar phenomena.

Table III describes what transpires within a tube when ratings are exceeded. Actually, this results in one of two things, (a) either the full production spread of tubes cannot be utilized on the production lines without a high percentage of production rejects, or (b) a high failure rate will occur in field service, within the warranty period.

It can be seen that ratings specified by single value limits cannot usually be considered as absolute barriers on one side of which satisfactory operation can continue indefinitely, while on the other side almost immediate degradation will occur. The equipment design engineer must realize that the expected period of satisfactory operation decreases in a continuous manner as the rating is approached. Exceeding the rating accelerates this decline. Therefore, the more conservative the use of the tube with respect to these ratings, the greater will be the life expectancy of the tube.

The foregoing is substantiated by the data compilation completed by ARINC Research Corporation and shown graphically in curves 1, 2, 3 and 4. This data is a direct result of a recent study of a particular system in which the failure rate of electron tubes was less than 44.3 per million hours. Although the ARINC study was based upon equipment employing Military tubes, the data is representative of commercial equipment employing entertainment tubes. To better describe the influence of operating conditions during this study, the tube operating conditions were divided into the eight classes defined in Table IV. By selecting a relative scale normalized about Class 6 to represent the vertical axis, a curve relating tube operating conditions to expected, relative tube failure rates was plotted as shown in Figure 1. It should be noted that opera-

TABLE III

APPROACHING THIS RATING

MAY CAUSE	RESULTING IN	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			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
	Increased "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	Emission (Shifts Bias More Positive) Increased Effects of Control Grid			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			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

Courtesy of Wright Air Development Center

TABLE IV
CLASSIFICATION OF OPERATING CONDITIONS FOR TUBES

CLASS	OPERATING CONDITIONS
1	All voltages (except heater voltage) and all currents at less than 50 percent, and power dissipation of all elements at less than 25 percent, of rated values.
2	All voltages (except heater voltage) and all currents at less than 75 percent, and power dissipation of all elements at less than 50 percent, of rated values.
3	All voltages (except heater voltage) and all currents at less than 90 percent, and power dissipation of all elements at less than 75 percent, of rated values.
4	All voltages (except heater voltage) and all currents at less than 90 percent, and power dissipation of all elements at less than 90 percent, of rated values.
5	All voltages (except heater voltage) and all currents at less than 90 percent, and power dissipation of all elements at less than 100 percent, of rated values.
6	All voltages (except heater voltage) and all currents at less than 100 percent, and power dissipation of all elements at less than 100 percent, of rated values.
7	All voltages (except heater voltage) and all currents at less than 110 percent, and power dissipation of all elements at less than 100 percent, of rated values.
8	All voltages (except heater voltage) and all currents at less than 110 percent, and power dissipation of all elements at less than 125 percent, of rated values.

NOTE: Use absolute maximum ratings from MIL-E-1B when available.

tion at 10% above maximum rated conditions (Class 8) will essentially double the relative tube failure rate; whereas, operation at 10% below maximum rated conditions (Class 4) will cut the relative tube failure rate approximately in half.

Figure 2 portrays the functional relationship between the relative failure rates of electron tubes and the ratio of applied heater voltage to rated heater voltage. It will be noted that the curve indicates rated life with the heater operated at its center rated value; and, that severe deterioration occurs with operation above rated heater voltage. Conversely, the curve indicates improvement in tube life when the heaters are operated at less than rated heater voltage. However, extreme caution should be exercised when attempting to operate tubes in the latter manner. (Recent ARINC studies have been conducted at lower than rated heater voltage with the majority of circuit application showing improved reliability and thereby providing the data for this curve.) Before attempting to use this technique, it must first be determined if the tube characteristics resulting at reduced heater voltage are compatible with satisfactory circuit performance.

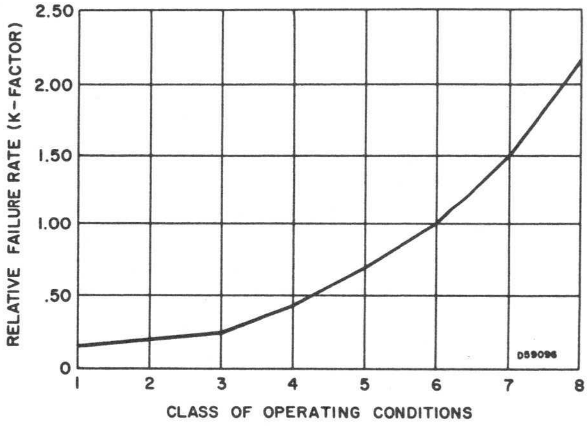


Figure 1—Functional relationship between the failure rates of electron tubes and tube operating conditions. (Courtesy of ARINC Research Corp.)

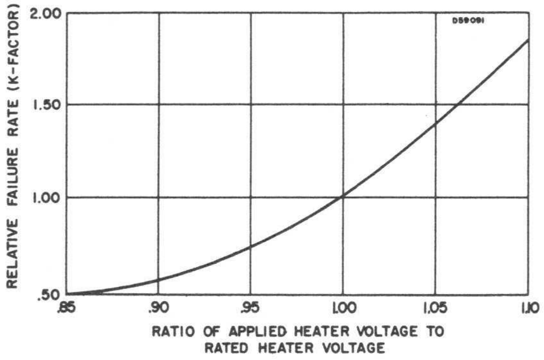


Figure 2—Functional relationship between the relative failure rates of electron tubes and the ratio of applied heater voltage to rated heater voltage. (Courtesy of ARINC Research Corp.)

Extreme care should be taken when a tube is to be used in a circuit demanding high peak cathode currents since the lower heater voltage and resulting lower cathode temperature will reduce the peak current capabilities of the tube. It should be recognized that in the event heater voltage is reduced in a circuit where a slight deterioration in tube characteristics may impair circuit reliability, the curve would take the form of a U with optimum reliability at rated heater voltage.

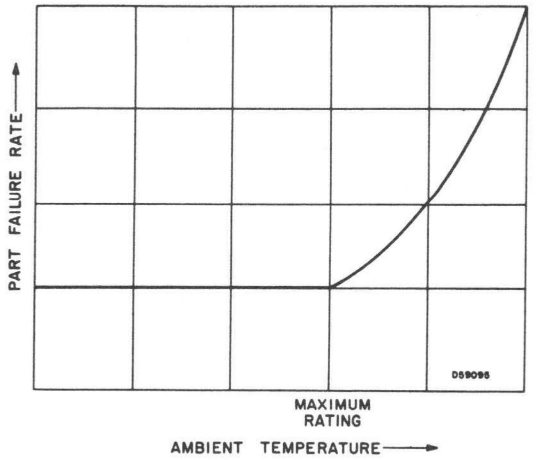


Figure 3—Relationship between part failure rates and ambient temperature. (Courtesy of ARINC Research Corp.)

Operation in excess of the specified ambient temperature (or bulb temperature) is another factor contributing to high tube failure rates. Figure 3 illustrates that tube failure rates remain constant up to a maximum rated temperature, beyond which they increase in an exponential manner. It can be shown that at excessive temperatures a single mode of failure becomes prominent, while at reduced temperatures, the modes of failure are randomly distributed and presumably are fairly independent of temperature.

Figure 4 shows the relative failure rates of component parts when operated above the recommended ambient temperature. Note that the relative failure rate for electron tubes is much lower than all other circuit components shown.

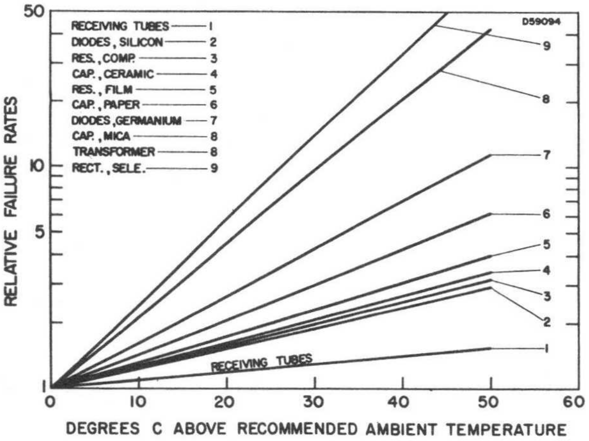


Figure 4—Relative failure rates of component parts when operated at various degrees above recommended ambient temperatures. (Courtesy of ARINC Research Corp.)

Some tube ratings are inter-dependent with others. In such cases, rather than simply establish a maximum condition for each one of these ratings, a chart is provided to describe this relationship, and show how one rating must be reduced as another one is increased. Typical examples of such rating charts are:

(a) *Rectifier tubes*—relationship between DC output current and AC supply voltage. DC output current versus rectification efficiency; and minimum effective plate supply resistance as a function of AC plate supply voltage.

(b) *Pentodes*—screen voltage versus screen dissipation.

Rating charts define boundary conditions for satisfactory tube performance while providing a wider latitude in the choice of operating conditions.

In the dynamic electronics industry, with its very resourceful and imaginative equipment designers, new and different applications for receiving tubes are constantly appearing. When there is a rather radical departure from conventional application, the designer may not find ratings in existence that define the boundaries of interest to him. Rather than merely take a best guess, he should consult with tube manufacturers on the maximum capabilities and probable problems to be encountered with his new development. Appropriate ratings can be developed, or if no existing tube is adequate for this service, one can be developed, rated, and controlled in production for the particular application.

ELECTRICAL CHARACTERISTICS

The electrical characteristics of a vacuum receiving tube are the electrical properties of the tube which relate to its performance in application. For sake of convenience, they can be broken down into two groupings:

Controlled Characteristics—the electrical properties of receiving tubes which are essential for proper design and operation in the intended application. They are the properties stated in the EIA releases and manufacturer's literature for each tube type.

Uncontrolled Characteristics—Every vacuum tube has many different electrical characteristics other than those stated in the published data. These uncontrolled characteristics are generally not of importance to proper circuit function in the intended applications.

STANDARDIZATION OF CHARACTERISTICS

Much of the progress that has led to today's highly refined receiving tubes, and consequently, electronic equipment, is attributed to standardization.

Most equipment, whether television, radar, radio, or guided missile is composed of certain "building blocks" which are combined to provide the desired end result. These "building blocks" are the basic tube applications such as AF and RF amplifiers, mixers, oscillators, rectifiers and etc. There is a certain set of tube characteristics of importance for each basic application, differing in part or in entirety from the characteristics of importance to other basic applications. "Universal" tubes, which supposedly perform in a multitude of basic applications, may appeal to the imagination, but have very serious drawbacks. They will, of necessity, reflect many compromises in design because of conflicting requirements of the various applications that they are expected to serve. They will be expensive because of the numerous manufacturing controls which the tube producer must observe. In the end, the equipment manufacturer pays for extra controls of no concern in an individual application. Further, the user does not obtain optimum tube performance.

Under the current method of standardization, each tube type is optimized in design and controlled during manufacture for a limited number of basic applications, as indicated in the manufacturer's data and the EIA release. Many benefits accrue from this approach including:

In Engineering—highest tube performance at the lowest cost, consistent with the needs of the particular application.

In Manufacture—line rejections are minimized.

In the Field —failures and in-warranty returns are minimized.

As a corollary, all tube manufacturers, who supply a given tube type, control it in production in much the same way. This provides multiple sources for the type and insures that the product of each will function properly in the equipment. This has major business advantage at the manufacturing stage, and further insures easy access to replacements in the field.

Tubes for basically different types of service occasionally look identical in bulb and mount configuration, and perhaps even in static electrical parameters upon superficial examination. One example is the close resemblance between the vertical deflection amplifiers and audio power output tubes encountered in TV sets. Nevertheless, differences do exist. The vertical deflection amplifier is controlled in production for linearity, amount of scan, and microphonism; whereas the power output tube is controlled for power output and distortion—the basic tube characteristics for the two services not being *necessarily* interrelated. There may be price differentials based upon the relative difficulty encountered during manufacture of the two tube types.

The user who ignores the conventions of tube standardization will, in all probability, experience high line rejects, unsatisfactory field history, or perhaps find that the necessary tubes are no longer available.

Occasionally, radical new products, or even new basic applications within an existing product, are anticipated. When this occurs, it is advantageous to have a tube type established for the particular service. This avoids the problems connected with using a non-standard type, and permits realization of the benefits of employing a component that is specifically designed and controlled for the new application. *For further discussion on this subject, reference should be made to the Sylvania Engineering Information Service article "THE UNRELIABLE UNIVERSAL COMPONENT", Vol. 3, No. 2, July 1956.*

Detriments

Tube detriments are inherent tube properties which must be considered in circuit design on the basis of their adverse effects upon circuit operation. Certain of these detriments are apparent with new tubes, while others develop with the passage of life. These detriments, or undesirable properties, must be recognized as potential contributors to equipment failure.

In order to reduce the probability of equipment malfunction due to these detrimental properties, the equipment design engineer can:

(a) Select a tube type which is adequately controlled for the intended service.
(b) Avoid operating the tube under conditions which aggravate the effect or accelerate its development.
(c) Design the circuit to tolerate the presence of the detrimental properties both initially and after extended operation.

Some of the major detrimental properties of electron tubes, their nature and effects upon circuit operation, and methods of minimizing such effects, are:

GRID CURRENTS

Control grid current arises from four basic sources within the tube:

(a) Contact Potential—initial electron velocity from the cathode.
(b) Gas Currents—caused by positive ions striking the grid. These ions are created by collision of electrons with extraneous gas molecules in the tube.
(c) Inter-element Leakage.
(d) Spurious emission from the control grid itself and elements other than the cathode.

Figure I shows a comparison of the four sources of control grid current. It can be seen that, depending upon the particular tube type and operating conditions, the net grid current can vary extensively.

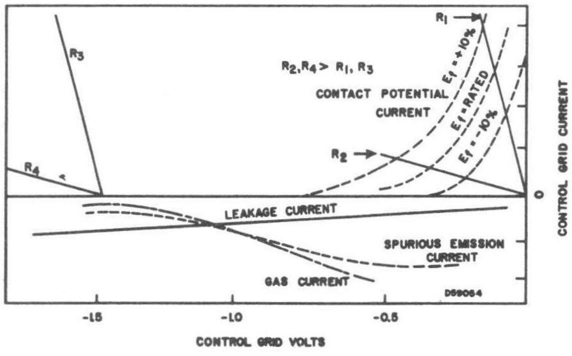


Figure 1—Comparison of the four sources of control grid current.

Contact Potential—The "contact potential" of a vacuum tube is arbitrarily designated as the negative grid potential required to establish a current of 0.1 microampere. The particular current stems largely from the initial velocity of electrons emitted from the cathode. The contact potential point describes a specific retarding electrical field required to restrain the electrons which have sufficient kinetic energy to move from the cathode to the grid.

Contact potential also includes voltages generated by the thermal difference between dissimilar metals in the grid and cathode structures. Since among other things, contact potential is a function of initial electron velocity; it will also be a function of the heater voltage. Figure I shows how the contact potential point changes with variations in heater potential. In addition, there will be differences from tube to tube, particularly among tubes of different manufacture, unless the tube type in question is controlled for contact potential.

To the circuit designer, the effect of initial velocity electron current is two-fold in the grid potential range between zero and approximately -1.3 volts. It represents a finite dynamic grid impedance, and also, a direct current source of high internal resistance. Within the contact potential region, the effect may; appear as the loading of tuned input circuits; be the cause of distortion at low frequencies in audio amplifiers; cause variations in AGC or AVC bias; and in cases where the grid resistance is high, cause major variations in the bias level from tube to tube. In normal application, the effects of initial velocity grid current are avoided by the use of sufficient bias between the grid and cathode to remove the grid operating potentials from this region. About 1.3 volts bias will usually suffice, although excessive heater voltage will greatly increase the magnitude of the current, and some tubes may actually require more bias in particular applications. If a tube is to be operated in the contact potential region, low grid circuit resistance will help to minimize the effects of initial velocity grid current.

Referring to Figure I, two resistance load lines are drawn from zero bias into the grid current curves. One represents a low grid resistance; the other a high grid resistance. It is evident that wide variations in heater potential will have less effect upon shifts in the actual bias point with low grid resistance.

Note that quantitatively, the bias values will be less for the low grid resistance, and hence, grid bias can be brought closer to zero potential.

The two values of grid circuit resistance shown in Figure I illustrates that the application of negative bias essentially eliminates any consideration of contact potential currents.

Normally, contact potential is not a controlled tube specification. However, "hybrid-auto" tube types are an exception. Because of the low plate potential, the grid must be operated very close to zero bias to obtain adequate performance. This necessitates operation within the contact potential region—hence, this phenomena must be very carefully controlled. Tubes designed for higher voltage operation should not be operated in the contact potential region since they are not controlled for this service. One exception to this is the low plate current tubes commonly used in conjunction with high values of plate load resistance in low level RC-coupled applications.

The use of higher voltage tubes can introduce extremely wide variations in initial performance; performance over a wide range of supply potentials; and performance changes with life.

Gas Currents—In the manufacture of vacuum tubes, the tube elements are heated to high temperatures while the tube is being pumped to the lowest vacuum obtainable. The tubes are heated to drive out occluded gases which exist within the glass, metals, and mica parts. After the tube is exhausted and sealed, the getter is flashed. The purpose of the getter is to absorb any additional molecules of occluded gas which may be driven from the parts during normal tube life.

The vacuum tube user normally assumes that a perfect vacuum exists in tubes. This, of course, is not quite so since there are frequently some gas molecules still within the tube envelope, and others being released from the parts during operation. Although the getter eventually absorbs these molecules, they do exist temporarily within the bulb. When electrons collide with these gas molecules, positive ions are formed which are attracted to the control grid—normally the most negative tube element. As one might expect, the greater the cathode current, the greater the probability of collisions, and hence, the greater the gas current. Further, the number of occluded gas molecules which are freed at any time are a function of the temperatures of the various tube elements. A tube which is operated at or beyond its maximum rated dissipation, or in a particularly warm location within the equipment, will probably be a greater source of difficulty than one which is more conservatively operated.

Maximum values of grid circuit resistance for self and fixed bias operation are found in the published ratings for practically all vacuum tubes. Gas current is the limiting factor which determines these maximum values of grid circuit resistance. If the grid circuit resistance is too high, the gas current flowing through it produces a positive bias, which in turn, permits more plate current to flow. An increase in plate current raises element dissipations, which increases the release of occluded gas, causing more gas current to flow. This cycle, once it is established, produces a run-away condition which eventually destroys the tube. In the case of self bias, increased plate current will increase the cathode bias too, and hence, partially counteract the bias change at the grid. Thus, for self biased operation, the maximum permissible value of grid circuit resistance is normally higher than that for fixed bias operation.

Inter-Element Leakage—While critical in terms of its effects upon grid current, this phenomenon is not peculiar to the grid. *Reference should be made to the section entitled Inter-Element Leakage for discussion of this item.*

Spurious Emission Currents—Most vacuum tube elements are capable of some sort of emission current during operation.

The major concern is with currents originating at the control grid as primary or secondary emission to some more positive element. In this case, a positive shift in bias occurs, the amount being dependent upon the value of the grid circuit resistance. This effect, like that produced by gas current, is capable of compounding itself into a condition where the tube can be destroyed, if the grid circuit resistance is too high. In applications where the control grid is not maintained as the most negative tube element, the grid may act as an anode and receive emission currents from other elements, causing a negative shift in bias. This effect is most common where AC supplies are employed for the plate and screen elements.

Spurious emission currents vary widely in magnitude from tube to tube and with operating conditions. Reduced operating temperatures and/or dissipations and low values of grid resistance will help reduce these effects.

HEATER-CATHODE LEAKAGE

Figure 2 illustrates a typical, indirectly heated, receiving tube heater-cathode assembly. Simply described, the assembly is a pure tungsten heater wire which is insulated from the cathode sleeve by means of an aluminum oxide coating. The tungsten wire, when properly operated at temperatures approximating 1150° to 1350°C, heats a nickel-cathode sleeve to a temperature range of approximately 735° to 850°C.

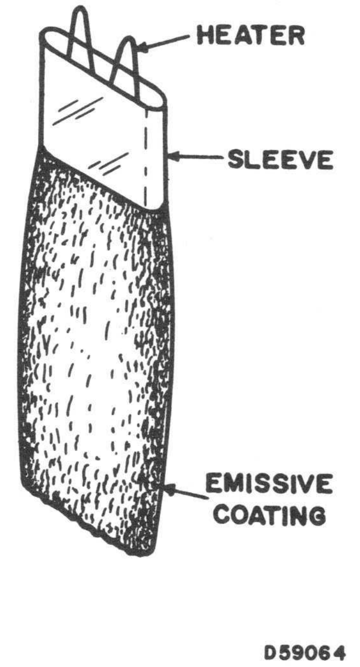


Figure 2—A typical indirectly heated, receiving tube heater-cathode assembly.

In description and appearance, the heater-cathode assembly seems simple—but in reality, is quite complex from a chemical and electrical viewpoint. It gives rise to important tube detriments, as well as being a predominant factor in determining electrical characteristics. This discussion will be confined to tube detriments and their effects upon specific circuit design problems.

The principal detriment is heater-cathode leakage current. Other inter-related problems include heater-cathode breakdown, and improper heater warm-up time in series string circuits.

Electrons find their way between the heater and cathode, in both directions, by at least three known methods:

(1) The first is a straight resistive component.

(2) Bare heater wire, exposed as a result of cracks or fissures in the aluminum oxide coating, can emit primary electrons if the heater is negative with respect to cathode. In the same manner, electron emission can take place from the cathode to the heater if any emitting material is present on the inner-surface of the cathode sleeve. This type of leakage would take place when the heater is positive with respect to cathode.

(3) The third type of leakage is of a controversial nature, with many theories as to its source. For the purposes of this discussion, it is sufficient to say that it is caused by some sort of ion migration with the heater and cathode being electrodes and the aluminum oxide being the "ionizable" medium.

The heater-cathode leakage current phenomena which affects circuit performance is a combination of the three aforementioned sources of such leak-

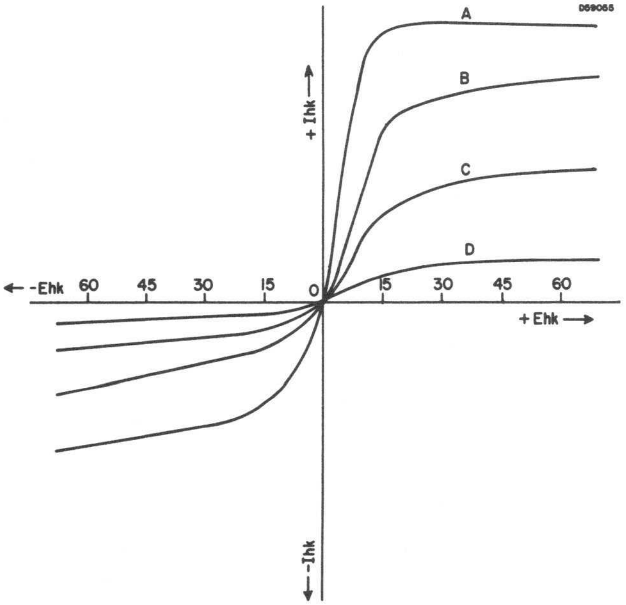


Figure 3—Assorted curves of heater-cathode leakage current versus heater-cathode potential. Curve A shows the effects of saturation and biasing.

age. The actual shape of a curve of heater-cathode potential versus heater-cathode leakage is very much dependent upon the magnitude of each of the three components and the manner in which they are combined. Figure 3 shows a variety of different patterns which can be assumed by the heater-cathode leakage phenomena. It should be noted that in the case of a high level leakage current, this phenomena tends to saturate with about 10 to 15 volts DC bias between heater and cathode, and may or may not be symetrical with respect to voltage polarity.

There are two generally accepted methods for measuring heater-cathode leakage. Figure 4 shows the conventional DC method. This measurement technique is generally of sufficient validity to be related to most circuit functions. However, in the case of low level audio amplifiers, a more discriminating type of test may be needed.

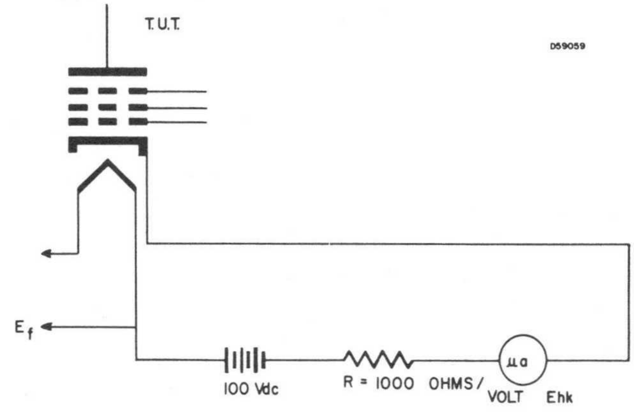


Figure 4—Basic Heater-cathode leakage test circuit.

Hum—Figure 5 shows that hum, generated from heater-cathode leakage in low level audio amplifiers may not be related to DC heater-cathode leakage measurements because of nonlinear aspects. Output A would be the result, assuming that resistive heater-cathode leakage is linear. On the other hand, output B is actually experienced in many applications. Figure 6 shows a basic test circuit for measuring "dynamic" heater-cathode leakage. Hum can be introduced into low level audio amplifiers as follows: (a) dynamic heater-cathode leakage in the tube (b) magnetic hum induced within the tube (c) magnetic hum induced into the signal circuits external to the tube (d) circulating chassis currents in the equipment (e) leakages across the sockets (f) inadequate filtering of power supplies (g) capacitive coupling, either within the tube or external to it.

It is thus evident that circuit design can contribute as much to good or poor hum performance as the tube itself. Hum can be minimized by good electrostatic shielding of all signal leads, good filtering of power supply, use of good quality sockets and proper placement of the tube and components for low level stages to preclude hum pickup from magnetic devices including transformers, motors and chokes. The methods used for grounding, and the actual locations of the various grounds will also be major factors, as will the use of non-magnetic materials for the chassis.

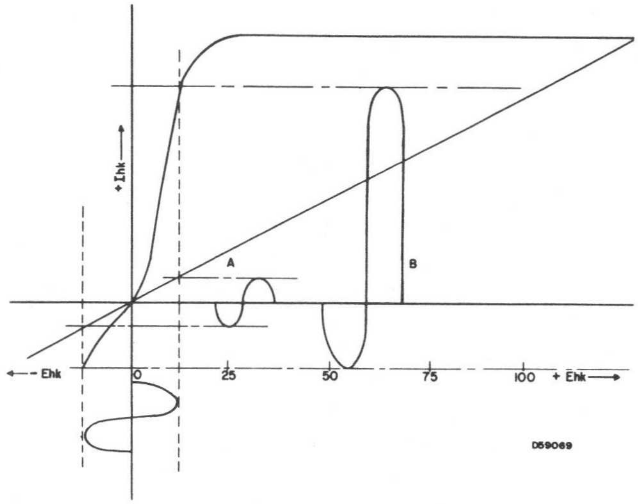


Figure 5—The linear and non-linear aspects of hum generated by heater-cathode leakage.

Hum from all the above mentioned sources is not directly additive, but is a function of the phase and wave shape of each of the various components of the hum output. (It should be noted that heater-cathode leakage seldom induces a sinusoidal hum output.) Thus it becomes quite understandable that tubes with high heater-cathode leakage can occasionally be regarded as good in some circuit designs since hum of the proper magnitude and phase from this source will actually buck out hum introduced through poor circuit design. On the other hand, a tube with low level hum will not effectively do this, and can very readily be mistakenly labeled "bad".

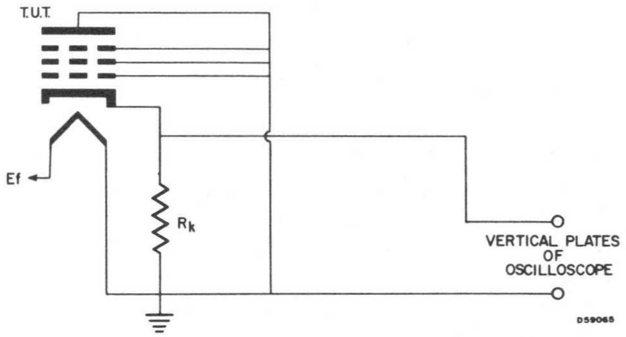


Figure 6—Basic "dynamic" heater-cathode leakage test circuit.

The Dynamic Hum Test chassis is designed and constructed so that complete magnetic shielding is obtained for the tube and circuit. Hum output is essentially zero with a tube in the socket but heater power off. Thus, there is a fair degree of assurance that the property being measured is true hum, attributable to heater-cathode leakage. (How this will relate to hum output in a specific piece of equipment is very much dependent upon the thoroughness of the designer.) One criteria of good circuit design would be the amount of hum output with the particular tube in the socket, but with heater power off.

The circuit designer can minimize the effects of heater-cathode leakage in many ways: (1) The most obvious measure is to select a tube type with the lowest heater-cathode leakage obtainable, and if at all possible, one which is controlled for dynamic heater-cathode leakage. In this respect, it is worth noting that tubes with high wattage heaters tend to have more heater-cathode leakage than tubes with low wattage heaters. This also applies in the case of low voltage counterparts. (2) Using the lowest practical value of cathode resistance will reduce hum voltage, (Rk x Ihk), induced in signal circuits. (3) Thorough by-passing of the cathode resistor for the power supply frequency will essentially reduce the cathode impedance to the point where injected hum from this source is inconsequential. (4) The method used for powering the heater will play a major part in determining the final hum level. One side of the heater (6.3 volt types) is normally grounded, while the cathode is usually biased above ground potential.

A reduction in hum may be realized if the heater transformer can be grounded at the center tap. In the case of a heater transformer that has one side grounded, the side above ground will swing (assuming 2 V bias) from −10.9 to +6.9 volts with respect to cathode. With the center tap grounded, the voltage excursions between cathode and heater are only from −6.5 to +2.5 volts. The 180° phase difference in the currents in the two halves of the heater further reduces hum with the latter arrangement due to cancellation. Figure 3 shows that saturation frequently occurs above a certain value of heater-cathode potential. If it is possible to operate the tube with a DC bias of approximately 30 volts between the heater and cathode, advantage can be taken of this effect as a means of reducing hum. The bias can be applied in either direction as shown by Figure 3, curve A. Variations in AC potential about the operating point will not introduce a corresponding current change, since the current is saturated throughout this region.

In series heater strings, the location of tubes within the string can be very critical with respect to hum. The tube which is closest to the grounded end of the string will have only a small AC potential generated between the heater and cathode, whereas a tube at the high voltage end of the heater string will have a very large AC potential between these two elements. The hum critical tube should, quite obviously, be placed as close to the grounded end of the string as possible.

Heater-Cathode Breakdown—This occurs when the voltage between the heater and cathode is sufficient to destroy the insulating properties of the heater coating. For maximum insulation, it is desirable to have the heater coating as thick as possible. However, there are very distinct limits in this respect. If the coating is too thick, the warm-up time of the tube will be prolonged—an important consideration for series string operation. Further, the thermal expansion of the heater coating is not identical to that of the heater wire and could fracture with repeated heater cycling. Within the limits which a tube designer must stay, it is not unusual to have voltage gradients of 50,000 volts per inch with only 100 volts applied between heater and cathode. Thus, voltages which do not appear excessive can in reality place the heater-cathode assembly under very severe stresses.

Exceeding the maximum heater-cathode voltage ratings can cause quick and decisive tube failure. Care in circuit design to hold heater-cathode potentials to the lowest values possible consistent with the application will contribute to obtaining maximum equipment reliability. For example, in Sylvania's TV Reliability Studies discussed previously, it was found that two of the most critical applications in television sets are the damper and cascode RF stages. A major cause of failure in both of these cases was heater-cathode breakdown. The best set survival rates were obtained when the tubes were conservatively operated in this respect.

INTER-ELEMENT LEAKAGE

The electrical insulation between elements in electron tubes is usually provided by mica, and sometimes glass or ceramic spacers. Mica, which is by far the most common, may develop finite values of resistance as a result of thin deposits of conductive materials collecting on its extremely smooth surface. This source of leakage is minimized in the manufacture of tubes by: cutting slots through the mica to interrupt the leakage paths; roughening; coating the surface; and by selecting only the best grades of mica. There will, however, still be a certain definite amount of leakage present. Further, during manufacture and particularly during operation, the mica or other insulating materials may become lightly coated with conductive material via "sublimation", i.e., metallic materials evaporated from the cathode sleeve condence on the relatively cool surfaces, such as mica to form leakage paths. The formation of such paths during operation is generally a function of the cathode temperature.

The external surface of the tube envelope and base represents another source of leakage under humid or relatively dirty environmental conditions.

The formation of inter-electrode leakage is accelerated by high heater potential and high bulb temperature—generally attributable to a high ambient operating temperature combined with high internal dissipations. The resistance of these paths usually decreases as the applied voltage between elements and tube operating temperatures increases. By proper control of these conditions, the design engineer can reduce the effects of leakage upon circuit operation. Further, leakage resistances generally form voltage divider networks with circuit resistances. If the latter components have exceedingly high values, i.e., in the same order of magnitude as the inter-electrode leakages, the bias may be shifted enough to cause malfunction of the circuit or a "runaway" condition.

CROSS COUPLING

One section of multi-section tubes can affect the performance of the other section in several ways:

(1) The development of inter-element leakages introduces finite resistance paths between sections.

(2) Electron coupling caused by electrons actually flowing from the cathode of one section to one or more elements of the other section.

(3) Capacitive coupling, which becomes serious at higher frequencies.

First and foremost, the circuit designer can minimize cross coupling by selecting tube types which are adequately designed and controlled to insure satisfactory operation in the intended application. Another alternative is to design the circuit to tolerate small cross currents. In this respect, some areas of concern are:

(a) Where one tube section handles a large and the other a small signal current. For example, if a triode pentode is used for first IF amplifier and sync amplifier respectively, trouble could be anticipated since the large sync voltages might conceivably be coupled to and modulate the low level IF signals in the pentode section.

(b) Where cross coupling can cause spurious radiation. An example is a combined local oscillator and RF amplifier. The large oscillator signal could couple to the RF stage and be radiated from the antenna.

(c) Where feedback from one section can cause the other to oscillate; and

(d) Where it becomes impossible to turn the volume completely off in equipment employing combined detector-audio amplifiers.

INOPERATIVES (CONTINUITY OR SHORTS)

These particular tube detriments upon superficial examination seem to be obvious defects which should never occur, but in reality represent one of the most complex and misunderstood problems facing both tube manufacturer and tube user today. Some of the factors involved are:

(a) The detection device used to test for inoperatives.

(b) The mechanical excitation (if any) used to stimulate potential inoperatives.

(c) The tube itself, the various tube properties that cause inoperatives (either real or falsely indicated) and the non-repetitive nature of such inoperatives.

Continuity, or an open circuit, is a tube defect arising from an open tab which breaks the connection between an external pin and an internal tube element. This particular type of failure can be quite satisfactorily detected using the bridge circuit shown in Figure 7.

The resistance of the tube under test, which appears in one leg of the bridge, is balanced by the resistor R_1 in the other leg. With a regulated poten-

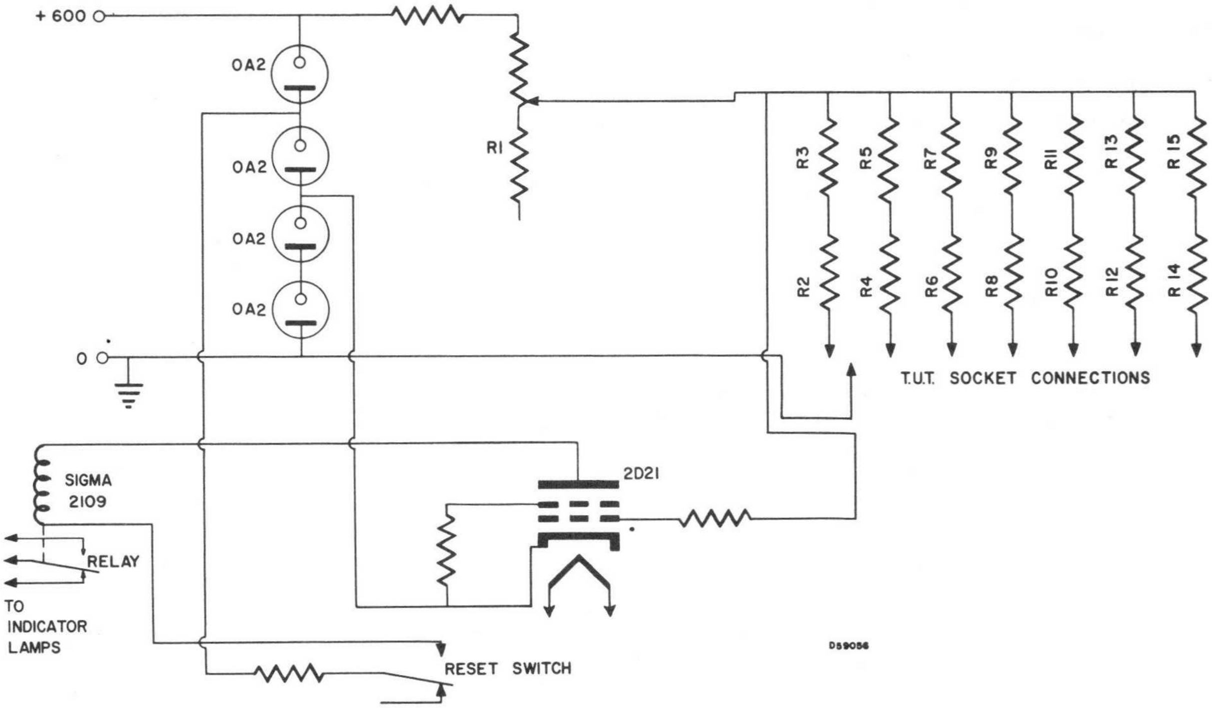


Figure 7—Basic DC Continuity test circuit.

tial of +300 volts on the thyratron cathode, a tube exhibiting continuity would reflect approximately 5 volts hold-off bias which would prevent the thyratron from firing. However, should the tube under test have an open element, the grid voltage would rise to +300 volts or better causing the thyraton to fire. Since tube manufacturers can and do take every precaution to eliminate such tubes from their production, the occurence of "opens" in the equipment manufacturer's plant is relatively uncommon.

There is one source of false indications common to most test equipments. When tubes are subsequently inserted and tapped, the connection between the tube-pin and socket-pin-clip can become intermittent. When a number of "opens" are evidenced during testing, the pin-clips should be tightened and a group of "rejects" retested to determine if the condition still exists.

Permanent and intermittent shorts, which represent an extremely complex problem, arise from two basic sources within the tube.

(a) True mechanical shorts—caused by tube parts or connections that make physical contact either permanently or intermittently when the tubes are mechanically excited. These are legitimate tube defects which are normally eliminated by the tube manufacturer before the tubes are shipped.

(b) Intermittent or flicker shorts—caused by interelement leakage and spurious emission, are the principal source of most of the present problems and misunderstandings on the subject. They vary with test conditions, mechanical excitation, and the test circuit used, its sensitivity, and the types of extraneous tube properties that affect it.

Some of the common sources of disagreement are:

(a) ELECTRICAL

Interelement leakages, as discussed previously, will vary with applied voltages, temperature (which is related to the dissipations of the tube elements during test and to the heater power), and mechanical excitation. Some commercially available bench test equipments apply more voltage between elements than recommended, thereby causing false indications. Further, the operating conditions used in some test sets produce higher than rated element dissipations. This also increases interelement leakage which, in turn, causes additional false indications. Excessive voltages between the grid and cathode, which are only spaced a few thousandths of an inch apart, can produce voltage gradients of 50,000 V/Inch or more. This will actually cause arc-overs between the elements involved which may cause the tube to be permanently damaged.

The unregulated voltage supplies employed in some bench testers can compound the foregoing problems by introducing line voltage fluctuations as another variable.

All tube elements are capable of spurious emission, depending upon their temperature (dissipation) and the applied voltages. With AC shorts testers, element continuity is shown on one-half of a neon indicator lamp during the positive half cycles of the test voltage. Shorts are indicated by lighting the other half during that part of the negative half cycles when the instantaneous voltage exceeds the firing voltage of the neon lamp. Figure 8 shows one lamp circuit and a graphical representation of the action during one cycle of supply voltage. When an element swings negative with respect to adjacent elements, it can emit and cause the indicator to show a short circuit. Such an indication, however, is irrelevant in any application except those with AC supplies.

(b) MECHANICAL

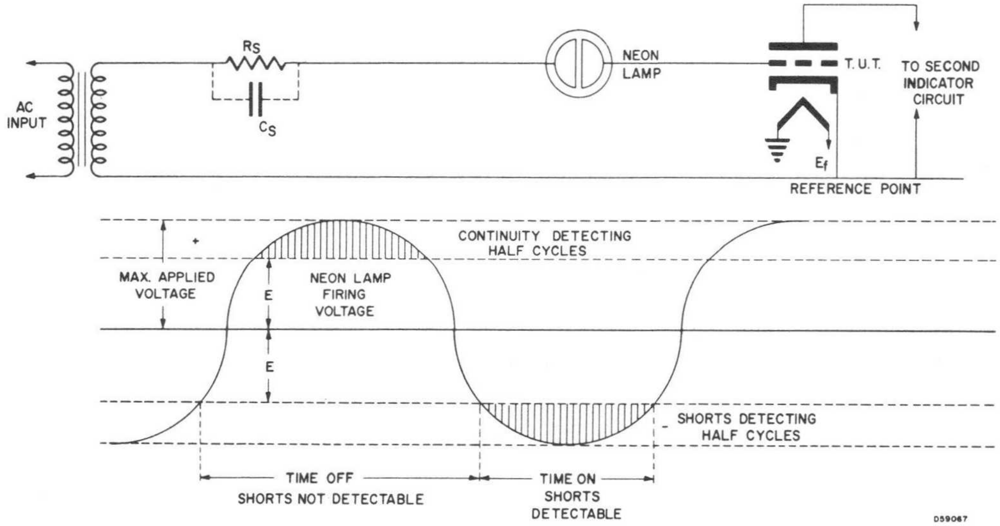


Figure 8—Circuit of one indicator lamp and action during one cycle of short and continuity tester.

Tapping to induce shorts indications in potentially troublesome tubes is common practice when mere insertion in the test socket is not revealing. It is known that practically any tube, if tapped sufficiently hard, will produce shorts indications in a sensitive shorts tester. Thus, the mechanical exciter is a major variable in shorts testing. If devices other than those specified are used to tap the tubes, tremendous irregularities will be noted in the results obtained. Pencils, pens, screwdrivers, hammers, alignment tools, finger nails, and other such appurtenances should not be used since they all deliver a shock wave (both G-level and shock duration) substantially different than that desired.

Because of the numerous uncontrolled variables which enter into flicker shorts testing, EIA has in recent years attempted to formulate a standard test to reflect actual equipment manufacturers needs, yet control all of the variables affecting the results. This involved the development of a shorts simulator, which was used to analyze many different kinds of circuits and to define boundary conditions beyond which leakage phenomena begin to affect proper circuit operation. Figure 9 shows a plot of the boundary conditions. Any flicker short which falls within the shaded area can be disruptive for its duration.

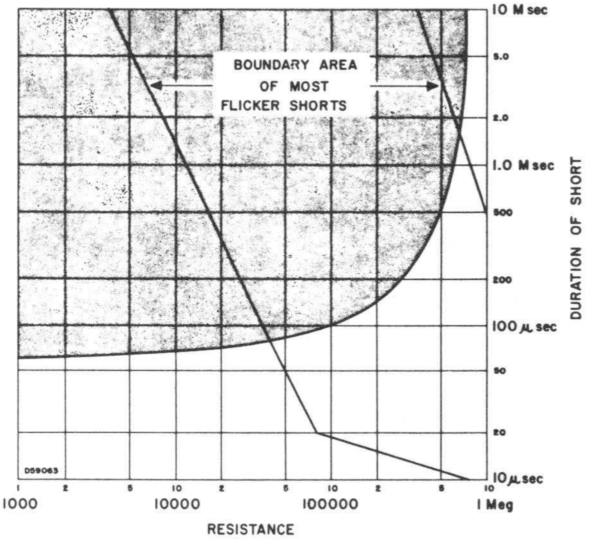


Figure 9—Boundary area of most flicker shorts.

There are many different tester circuits that can be used, but the recommended one is shown in Figure 10. A definition of the shorts it will detect is also shown by the curve in Figure 9.

A study of the flicker shorts normally encountered in receiving tubes indicates they are within the boundary area outlined in Figure 9, when mechanically excited in the specified manner. It is evident that using the recommended test circuit and the specified tube tapper will eliminate tubes that are legitimate sources of trouble. Deviation from recommended procedure, however, can render all results invalid.

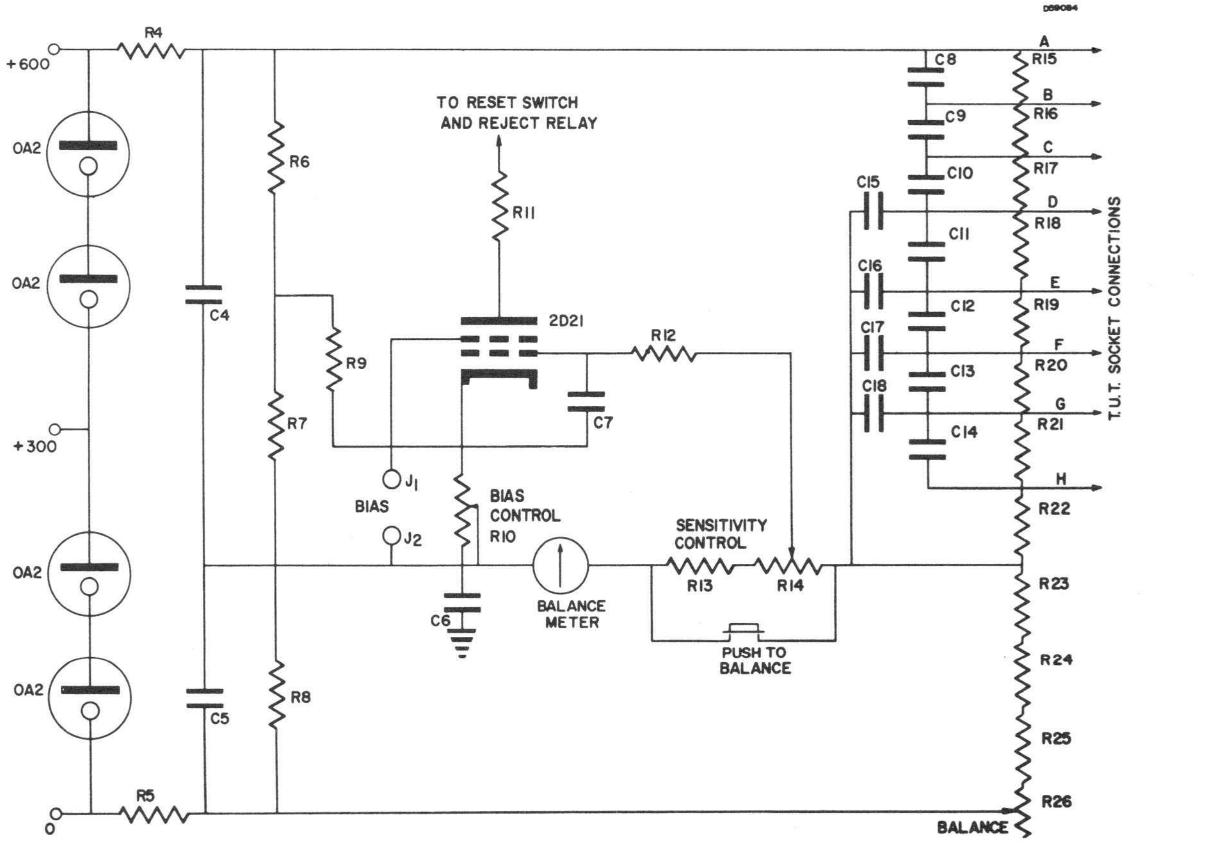


Figure 10—Basic DC Shorts test circuit.

The shock wave of the recommended Teflon tube tapper is shown in Figure 11. In contrast, note the pattern developed by a steel tapper which is typical of those sometimes used in the field.

The tappers used by the tube industry are complex mechanical devices designed for high volume testing. If, for lack of mechanical equipment, tapping must be done by hand, the Sylvania standard V-tapper shown in Figure 12 is an acceptable alternate. The V-tapper is, in essence, two MIL-E-1 tappers in one holder. This tapper restricts the stroke to exactly two inches as specified in MIL-E-1.

CATHODE INTERFACE IMPEDANCE

This phenomenon is of most interest in industrial service, particularly in computers, where a very long life is mandatory, and where the tube may be operated with the plate current cut-off for much of the time. Cathode Interface Impedance, however, is of concern in a few entertainment tube types where extreme performance demands have precipitated designs with extremely high cathode temperatures.

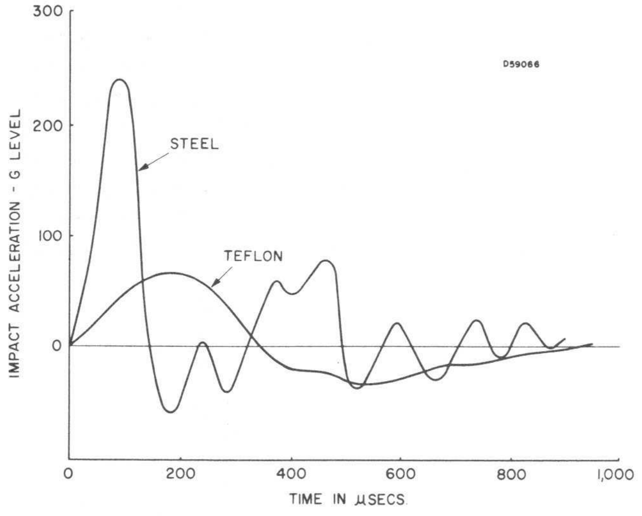


Figure 11—Shock wave of recommended teflon tube tapper versus steel tapper.

Variation in the transconductance or gain of a tube with changing frequency is a major effect observed when cathode interface impedance is present. In application, variations in the gain of wide band amplifiers and loss of power in pulse and trigger circuits are sometimes evidence of cathode interface impedance. It has been determined that the major interface impedance difficulties are caused by the formation of barium orthosilicate. Other interface compounds also have low conductivity but give relatively little trouble; e.g., barium aluminate, barium tungstate and barium titanate. As the term "interface" implies, this compound develops between the cathode coating and cathode sleeve in the form of a resistive layer or film. In ohmic value, measurements have shown a range of from one ohm to several thousand ohms depending upon electrical operating conditions, cathode temperature and the degree of development.

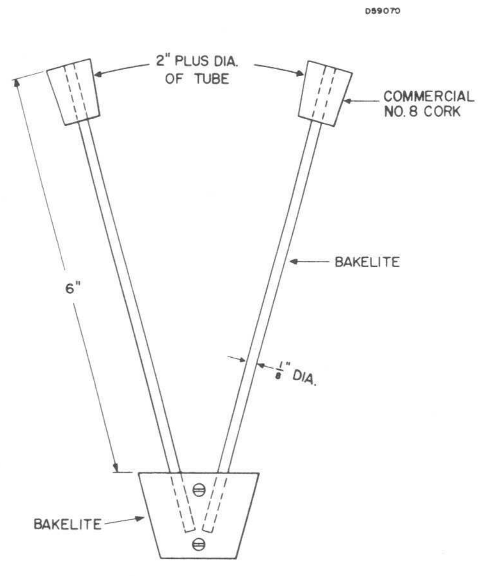


Figure 12—The Sylvania standard V-tapper restricts the tap-stroke to exactly two inches.

Several factors determine the rate of development, effect and measured value of interface impedance including the following:

(1) High cathode temperatures produce a faster growth of the interface compounds; therefore, interface impedance difficulties are multiplied by long periods of operation at high heater voltages, Figure 13.

(2) The effective interface impedance is temporarily reduced at higher cathode temperatures; therefore, high heater voltages will temporarily reduce the value of interface

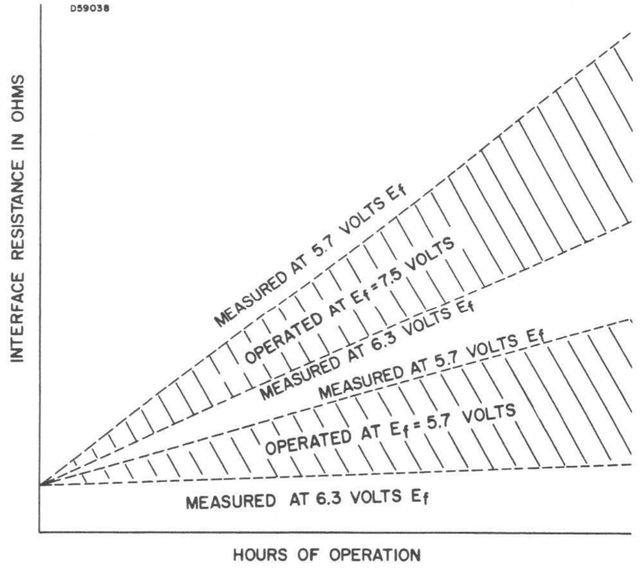


Figure 13—Typical formation of Interface Resistance under cut-off condition of cathode current. Courtesy of WADC.

resistance. Conversely, once present, interface resistance will build-up exponentially with a temporary reduction in heater voltage.

(3) The operating conditions of the tube also determine the effective impedance of the interface compound, since it varies with the level of current drawn through the interface.

(4) The level of interface impedance can be changed for a short period of time by drawing heavy current through the interface. This tends to activate the interface, giving a higher conductivity for a short time. However, the interface returns again to its previous level in a short time.

The effect of interface impedance can be approximated by placing a parallel resistance-capacitance network in the cathode lead of a tube. In actual practice it will be found that the interface resistance is more complex than that approximated by a single resistive-capacitive network. Thus, a closer approximation requires a series of these resistive-capacitive networks in the cathode lead, Figure 14.

As can be seen from the equivalent circuit, interface will allow high frequencies to go through with very little attenuation whereas the lower frequencies will be attenuated by a factor which is a function of the resistance in the resistive-capacitive network. In practice, where pulses are used for testing purposes, the leading edge of the pulse will show a "spike" when applied to a tube with high interface impedance and the trailing edge of the pulse will be at a lower level or plateau. Where sine wave frequencies are used for testing, the high frequency sine waves receive more attenuation, depending upon the amount of resistance in the interface impedance.

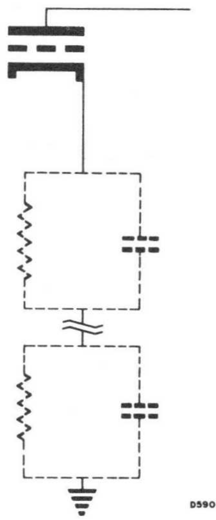


Figure 14—Approximate equivalent circuit for Interface Impedance.

In the Frost System of measurement, resistive and inductive components are placed in series with the cathode lead. Excitation is supplied by a square-wave generator, Figure 15. The complementary resistance and inductance network is varied until an output wave shape is obtained which is flat for all frequencies. This is combined with a gain measuring device to obtain complete attenuation of all pulse frequency components except the distortion

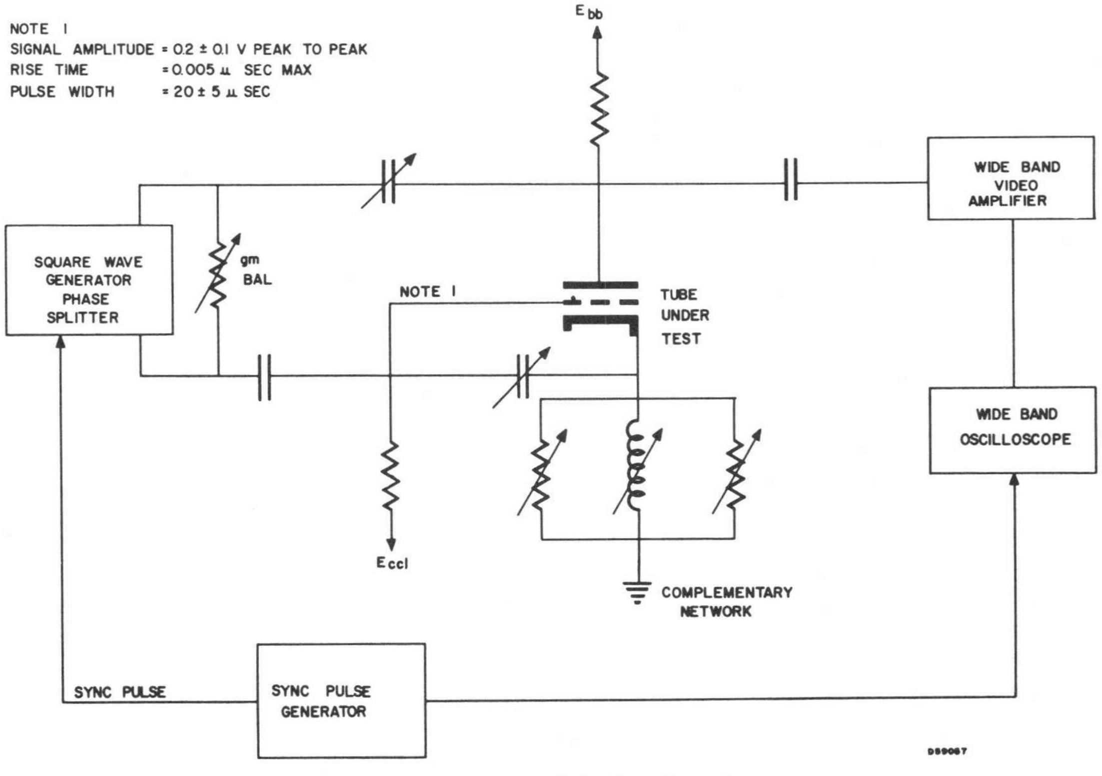


Figure 15—Partial diagram of "Frost" circuit for measuring Interface Impedance.

which is produced by the interface impedance. By bucking the positive and negative going pulses on the oscilloscope, a balance is reached when a single straight line is obtained. The resulting resistive and inductive components in the cathode leads give the information necessary for computing interface capacities. The resistance inserted in the complementary network is essentially equal to the interface resistance.

Some tube types now have specification controls on interface resistance. Interface resistance measurements of a sample of tubes produce a random order of interface values which is widely dispersed; therefore, it is impossible to apply normal statistical techniques for calculating mean or standard deviations of interface values with any degree of certainty. In order to maintain the tubes within specification limits, the interface resistance level of the bulk of the tubes in any sample must be maintained far below the specified limit. Interface resistance controls as presently established will allow only a very small number of tubes from a large life test sample to exceed the specified interface resistance level.

Since the compounds which cause the difficulties have been determined, tube manufacturers endeavor to control the presence of these elements in components and processes. All present day emission coatings contain a fair percentage of barium and oxygen; therefore, the only element which can be controlled in the case of barium orthosilicate (Ba_2Si0_4) is the silicon. Present-day active cathodes seldom have silicon contents in excess of .03% and some critical tube types use cathode materials which have a silicon content of .01% or less. The barium orthosilicate layers still form but their thickness and maximum impedance are limited by the available silicon within the volume of nickel alloy which makes up the cathode. Other cathode materials give good interface resistance effects which are due to elements which maintain the electrical activity of the barium orthosilicate layer.

The tube manufacturer controls cathode interface on tube designs for applications where it is important, to the fullest extent of current knowledge and "state of the art". The equipment designer can also do much in his own behalf:

(1) When aware of the importance of this phenomenon, select a tube type which is specified and controlled for Cathode Interface Impedance.
(2) Since high cathode temperature accelerates Cathode Interface Impedance, take every precaution to maintain rated heater voltage.
(3) Maintain a small stand-by current flow from the cathode during the period when the tube is inactive for signal passage.

NOISE

There are many sources of noise which bring about undesirable effects in electronic circuits. These include externally generated noises which find their way into circuits via the antenna, power lines or electromagnetic pick-up in one or more stages of the equipment. Other noises, generated within the equipment, can come from the resistors or condensers, intermittent contacts, unintended leakages, or magnetically induced noises from the transformer. Tubes can also be the source of internally generated noises. This discussion will be confined to the various vacuum tube noises.

There are numerous kinds of vacuum tube noises; the importance of each being dependent upon the particular application involved. A listing of such noises include:

Shot Noise
Induced High Freq. Noise
Ionization Noise
Partition Noise
Radiated Noise
Microphonism
Insulation Resistance Fluctuations
Hum
Spurious Oscillations

Shot Noise

Shot noise is noise generated by the random emission and arrival of electrons at the plate of the tube.

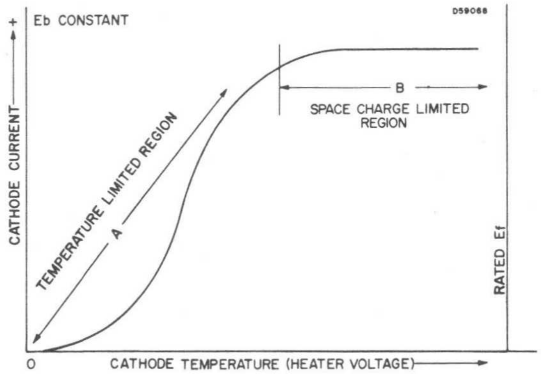


Figure 16—The operating modes of vacuum tubes can generally be classed in two groupings with respect to emitter temperature.

The electron stream is believed to exhibit slight variations in density, causing the electrons to arrive at the plate in a random manner. The DC element currents, normally measured, represent an average of a large number of electrons which arrive at the plate in a given period of time.

The operating modes of vacuum tubes can generally be classed in two groupings with respect to emitter temperature. Thus, reference to Figure 16 shows that in area A, with a constant voltage on the anode, there is a very rapid increase in the current flow with increasing cathode temperature (which is a function of heater or filament voltage). In this temperature limited region, all electrons emitted from the cathode are immediately drawn to the plate, either singly or in bunches. After the cathode reaches a certain temperature, it is capable of emitting more electrons than the plate can attract for a given plate voltage. At this point, the large number of electrons in transit between the emitter and plate create a space charge of sufficient magnitude to repel any further electron flow to the plate. Region B is thus called the space charge limited region. *Reference should be made to the section entitled Grid Currents for further discussion on this subject.*

Shot noise effect is most pronounced in the temperature limited region. Advantage is taken of this fact in that special temperature limited diodes are used for noise generators to facilitate the measurement of noise figures in electronic circuits. *There are many references on this subject, including Sylvania Engineering Information Service, Vol. 1, No. 1, Nov. 1951, entitled "A NOISE GENERATOR FOR UHF TV."*

When vacuum tubes are operated in the space charge limited region, the shot noise effect is very substantially reduced. It does, however, exist to some extent and must be considered in those particular applications where extremely low level signals are involved. In general, an equivalent grid resistance is derived which is directly related to shot noise, and with this value inserted in the equivalent circuit, the designer can proceed on the assumption of a noise-free tube. *Additional information on this subject can be found in the Sylvania Engineering Information Service, Vol. 5, No. 3, Sept. 1958, entitled "INPUT IMPEDANCE, ITS COMPONENTS AND ITS RELATION TO OTHER TUBE CHARACTERISTICS."*

In most applications, the presence of shot noise is undesirable. To insure adequate design, the circuit designer should insure that the heater potential remains within the minimum specified limit. In the design and manufacture of vacuum tubes, precautions are taken to insure that at minimum rated heater potential, the tube will remain in the space charge limited region. Below minimum rated heater potential there will be a spread in heater potential at which the tube becomes emission limited. Further, with life, the "knee" tends to slide upwards toward minimum heater potential. Thus, if the circuit design employs lower than minimum rated heater potential, the tubes may initially operate in the temperature limited region or slump into this mode early in life.

Induced High Frequency Noise

The foregoing types of noise are of concern in the audio and low radio frequency ranges. At very high frequencies and ultra high frequencies, there is a conductive component of noise caused by the transit time of electrons from cathode to plate and by the introduction of cathode lead inductance. These effects cause a high frequency noise component to be induced in the grid which, in turn, influences the electron current, thus giving rise to an extra component of noise. This induced high frequency noise is independent of the normal noise components discussed previously, and both of these high frequency components vary as the square of frequency. In the very high and ultra high frequency ranges, this extra equivalent grid noise resistance must be accommodated. *Again reference should be made to Sylvania Engineering Information Service, Vol. 5, No. 3, September 1958.*

To minimize the effects of induced high frequency noise, the designer can take the following precautions:

(1) Select a tube type which has sufficiently high equivalent grid resistance for the intended application.

(2) Since transit time is a function of plate potential, sufficient plate voltage should be provided to minimize this effect. A limit will be reached based upon the maximum dissipation capabilities of the tube; since high frequency tubes normally have a high transconductance per milliampere of plate current ratio.

(3) Select a circuit configuration that minimizes cathode and grid lead inductances as much as possible, e.g., attempt to make them part of a tuned circuit; or else, select tube types with multiple connections to cathode and grid.

All of the above-mentioned sources of noise within a vacuum tube are well documented and means for their inclusion in circuit design formulas are available. They are principally a factor in stages where signal levels are extremely low, and the internally generated noises become an appreciable portion of the signal output. After the initial stages, the signals generally are of sufficient amplitude that the former noise sources cease to be a major factor in circuit performance.

Ionization Noise

When gas is present in a receiving tube, there will be a noise component generated due to electrons colliding with the molecules of gas. These molecules become ionized, with the extra electrons going to the plate or other positive elements, and the positive ions going to the most negative element—usually the grid.

Like shot noise, ionization noise is desirable in some cases and undesirable in others. For example, thyratrons represent a copious noise source which can be coupled into subsequent stages of amplification and utilized as another type of noise generator. The frequency spectrum and amplitude of the noise output can further be influenced by the presence of controlled magnetic fields.

In event that a tube is used for this type of service, precautions should be taken to select one such as Type 6D4 or the 5643 which is controlled to produce a certain amount of random output noise. Otherwise, wide variations in amplitude and frequency spectrum, as well as variations in the amount of control that the magnetic field exercises upon the output will be encountered.

The Bibliography includes several references *which show how ionization noise in vacuum tubes can be related to an equivalent grid resistance that can be applied in the course of circuit design.*

With modern tube manufacturing techniques, this source of noise is not generally of significance in receiving tubes. However, in certain industrial applications utilizing extremely low level input signals, it could conceivably be a major factor. In such applications several measures can be taken to insure successful circuit designs, including:

(1) The proper selection of tube type—select a tube type that is specially processed and/or controlled to a much lower level of gas current than practical with the high volume, inexpensive entertainment tubes. The manufacturer's literature generally calls attention to special features.

(2) Allow a safety factor above and beyond the manufacturer's initial gas specification limit to accommodate a possible increase in gas current with life.

(3) Hold the grid circuit resistance as low as practical consistent with the performance requirements.

(4) Keep the various tube element dissipations as low as possible, since high internal tube temperatures can cause the release of occluded gas.

Partition Noise

Partition noise is caused by the random division of current between elements in multi-grid tubes. This is the reason why pentodes generally are considered somewhat "noisier" than triodes.

If a pentode is chosen because of its higher gain capabilities, partition noise can be minimized by:

(1) Selecting a tube type which offers the best plate-to-screen-current ratio at the desired operating conditions. The amount of latitude in this choice will be limited by the quantitative values of plate current and transconductance required for the application.

(2) Using plate and screen potentials which provide the most favorable plate-to-screen current ratio consistent with circuit performance requirements.

Radiated Noise

Radiated noise is generally associated with the higher power receiving tubes such as audio output and deflection amplifiers. While the exact sources cannot be stated with certainty, three sources are:

(1) PLATE FAMILY "CROSSOVER" POINTS.

Radiated noise may result from RF noise generated within a tube that is operating in a region of the plate family which exhibits "crossover". A "crossover" is formed when two or more bias traces intersect; i.e. do not follow the same line below the knee of the plate characteristic. Crossover should not be confused with the discontinuity that produces snivets which is another form of radiated noise found in television receivers, as defined under General Application of Pentodes. Crossover points, as shown in Figure 17, are bistable in that they may have one value of plate current at two or more values of bias.

If the path of operation of a tube passes through one of these points, noise or parasitic oscillations are likely to be generated by the abrupt changes in plate current. Figure 18 shows the path of operation for a typical pentode. The discontinuities indicate that the tube is operating in a "crossover" region. If the noise which is generated is of the proper frequency and magnitude, it will be picked up by the antenna of the receiver, re-detected, and sputtering or crackling will result in the sound output.

Figure 19 shows the path of operation for a typical pentode (without crossover) at maximum signal. Here the tube is driven to zero bias and cut-off as indicated by the distorted waveform, but, no discontinuities are evident. However, the tube does not have to be driven to full output to produce radiated noise if the operating point selected causes a path of operation through a discontinuity at less than maximum signal. The same effects are likely to occur at the lower signal.

In some cases, severe discontinuities or crossovers in the plate family will cause noise of such an amplitude that it will appear in the output without any need of being radiated. Noise of this nature will produce an audible sputtering, similar to that caused by "Motorboating", but higher in frequency.

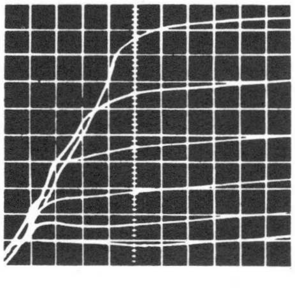


Figure 17—Cross-over points are formed when two or more bias traces intersect.

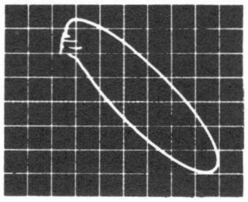


Figure 18—The discontinuities in the path of operation indicates the tube is operating in a "crossover" region.

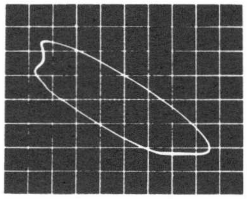


Figure 19—Path of operation for a typical pentode at maximum signal. Although the tube is driven to both zero bias and cut-off, no discontinuities are evident.

Steps which will preclude the possibility of radiated noise include: (1) orientating the tube as remote as possible from any built-in antennas and (2) adjusting the load line such that it doesn't pass through possible areas of "crossover".

(2) ELECTRON BOMBARDMENT OF THE GLASS ENVELOPE.

In the higher power tube types where there is considerable current flow, some electrons escape from within the mount cage to bombard and produce varying electrical charges on the glass walls of the tube envelope. This is generally of little or no significance in the power stages, since the induced voltages are very small compared to the signal level. A noise signal is radiated, however, that is of sufficient amplitude to be troublesome if the receiver antenna is mounted very close to the audio power-output tube.

Tube manufacturers take every precaution to minimize radiated noise. However, with the millions of tubes of a given type which are produced and all of the variables which enter into all of the parts used, in all probability, a certain percentage will exhibit some radiated noise. When given due consideration in equipment design, this characteristic is inconsequential; if ignored, however, it can promote a severe problem in the production of the particular equipment. Since the amount of noise picked up by the antenna varies inversely as the square of the distance from the source, the circuit designer can do much in his own behalf to avoid this particular problem by mounting built-in antenna systems as remotely as practical from any of the higher power tubes.

(3) BARKHAUSEN OSCILLATIONS.

Barkhausen oscillations are another radiated noise phenomena. They were particularly troublesome in the early days of TV; but since have become a relative rarity. In this particular case, the horizontal deflection tube produces radiation by a different mechanism. During a portion of the scan cycle, the plate goes negative with respect to the screen grid, and in some sets, below the potential of the beam-plates. Any electrons which happen to be in transit between the screen and the plate at the time this occurs find the electrostatic field reversed, and tend to go back towards the screen. In very short order, the plate again swings positive and the electrostatic fields are again reversed. This sets up an oscillatory condition in the region of the beam-plates between the screen and the plate which could be detected by a built-in antenna. Potential problems of this nature can likewise be minimized by installing the built-in antenna as far from the power tubes as possible, consistent with the "package" design.

Microphonism

Microphonism is caused by mechanical excitation and consequent relative movement of the tube elements. Assume that a speaker is mounted adjacent to the tube that drives it. Speaker sounds strike the tube, causing vibration of the tube elements and displacement of the tube parts relative to each other. As the tube elements move back and forth, they cause variations in plate current that are proportional to the mechanical excitation which, in turn, appears as more sound output from the speaker to further excite the tube.

Microphonism can generally be broken into two basic categories; sustained and damped.

(1) Sustained microphonism is typified by the above example wherein the mechanical feedback is sufficient to start the oscillatory condition. It is a function of the physical tightness of the tube, the electrical gain of the tube, and the amplitude of the mechanical feedback. Thus, a high gain system requires relatively little feedback excitation to establish sustained microphonism, whereas, a system having low electrical gain will require a more intense mechanical excitation. Microphonism of this description is generally associated with audio systems.

(2) Damped microphonism is a phenomena that is not self-sustaining; i.e., mechanical excitation causes an undesirable output which ceases with the disappearance of the exciting force. Thus, jarring the cabinet can cause undesirable bongs, crashes, pings, etc., in the audio output or cause the picture in a television set to break up momentarily. It differs from sustained microphonism in that there is insufficient feedback for sustained micro, but is more or less a simple cause-and-effect relationship wherein a mechanical excitation causes an undesirable effect on the output for the duration of such excitation.

The parts of a hypothetically perfect vacuum tube would be completely rigid with relation to each other; hence, it would be impossible for them to move and microphonism would not be a problem. The tube manufacturer's ability to eliminate microphonism from vacuum tubes is limited to the mechanical tolerances which can be applied to the fabrication of the mica, ceramic and metal parts. Thus, microphonism is minimized through rigid quality acceptance and quality control procedures.

To achieve further protection against microphonism, the equipment designer should isolate critical tubes from mechanical excitation as follows:

(1) Break-up mechanical feedback paths by removing acoustic devices such as speakers or vibrating parts such as motors as far from the audio signal circuits as possible.

(2) Mechanical feedback is not necessarily only a function of the proximity of the speaker or motor to the audio tubes. It is conceivable for the exciter to be quite remote, but mounted on the same chassis with the tubes. In such

cases, the exciter will tend to induce mechanical vibrations in the chassis which will be transmitted to the tubes. The gauge of metal used in the chassis, the rigidity of the mount of both speaker and tube, and the introduction of any intervening chassis stiffeners, shock mounted sockets, etc., will affect the microphonic properties of the particular equipment design.

(3) Selection of tube type will have much to do with the microphonic properties which are encountered. In applications where microphonism is of primary importance, tubes featuring low microphonism should be employed. While a less expensive tube with equivalent electrical characteristics may be available, trouble may result because of inadequate control over microphonism.

(4) Where all precautions in chassis design and layout have been observed and the best tube designs available do not satisfy the requirements, shock-mounting the particular tube socket is suggested. Such procedure essentially introduces one more barrier to attenuate mechanical excitation.

Microphonism is one of the most difficult tube properties to measure. It is known that any tube will exhibit microphonism if sufficient mechanical force is applied, hence, the mechanical excitation in the test must be closely specified. It is further known that the output level is dependent upon: the gain of the tube under test; subsequent stages; the specific application; and will be a function of the particular tube type.

Figure 20 illustrates the standard Sweep Microphonism test. The test equipment consists of a special adapter (including a tube socket) which is vibrated by means of an electromagnetic transducer. This test permits analysis of the individual frequencies at which the tube structure tends to resonate and introduce microphonism. In addition, the described test serves as a basic reference point for comparing the circuit demands of a particular design with the capabilities of the tube type in question. If tubes which are satisfactory for microphonism are generally found to be inadequate in the circuit design, either a better tube is required or some circuit modification is indicated.

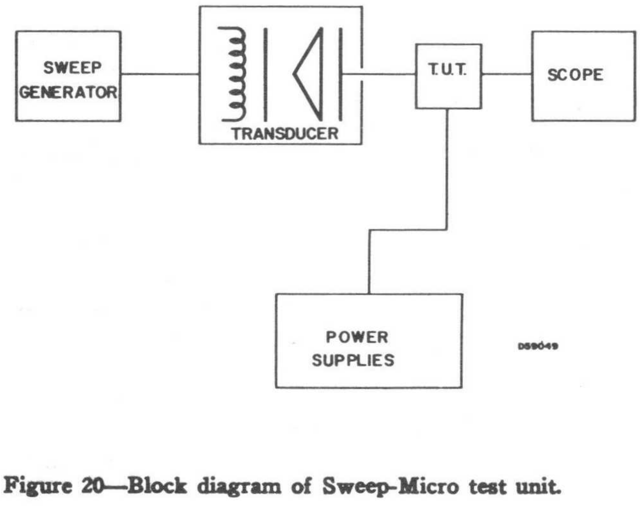


Figure 20—Block diagram of Sweep-Micro test unit.

In production testing of finished electronic equipment, the aforementioned basic reference tests would be extremely unwieldy. It would be most desirable to test the overall system with the tubes "in application". In such cases, it is recommended that judicious choice of mechanical exciters be used. First and foremost, acceptance or rejection should not be based upon tapping the tubes. In field use, this is certainly not typical of the way in which mechanical excitation would be delivered to the tube. Preferably, a light blow should be delivered to the chassis with a small rubber hammer, or better yet, turn the volume control up and listen for ringing; in the case of television receivers, watch for picture break-up. Since these conditions generally represent the most severe mechanical environment the tubes would be subjected to in the field, they probably represent as fair a test as any. In the case of instrumentation, or industrial equipments that may be subjected to prolonged vibration, it would be preferable to vibrate the finished equipment rather than tap the individual tubes.

Insulation Resistance Fluctuations

In the section on Inter-Element Leakages, leakage sources including some of the physical characteristics and means for avoiding circuit problems were discussed. Insulation resistance has another physical property which can be the source of electrical noise. Regardless of quantitative value, many tubes will show fluctuations in insulation resistance when mechanically jarred. This is caused by changes in the points of contact between the element supports and the mica spacers. Thermal expansion and contraction of the tube parts will also produce the effect.

Figure 21 shows a hypothetical example of a simple triode which has a high value of grid circuit resistance. For sake of simplicity, assume a plate-to-grid inter-element leakage of 1000 megohms with insulation resistance fluctuations of ±50 megohms. It is readily apparent that the inter-element leakage between plate and grid forms a voltage divider with the grid circuit resistance which will influence the amount of grid bias. With 200 volts on the plate, it is conceivable that the ±50 megohm inter-element leakage fluctuations can induce as much as 0.2 volts fluctuation in grid voltage with a 10 megohm grid resistor. The fluctuation tends to be very erratic in nature and is principally of concern in applications where the signal level is low, and the frequencies are likewise very low (less than one cycle per second).

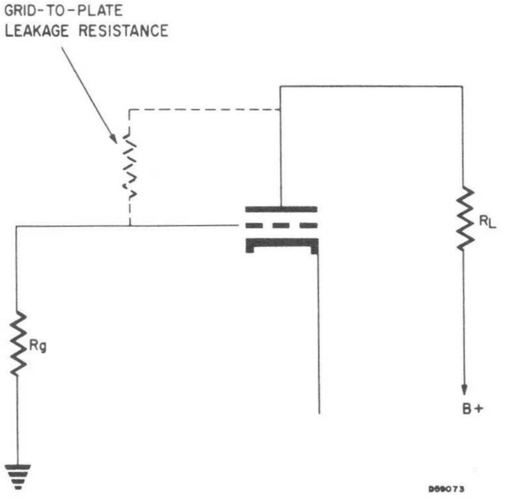


Figure 21—Hypothetical example of how inter-element leakage between plate and grid forms a voltage divider network with the grid circuit resistance.

Although the above example is somewhat exaggerated to more vividly portray the phenomenon, it is apparent that low values of grid resistance will substantially aid in minimizing any noise emanating from this source. The only other alternative is to select a tube type whose initial insulation resistance is quantitatively so high that the voltage divider action can be disregarded for all practical purposes.

The Life Test End Points of the tube types under consideration should also be checked; since most tubes exhibit a slump in insulation resistance values with life even though the initial limits may appear satisfactory.

Hum

Hum is always somewhat of a problem in the audio frequency range; particularly in sensitive preamplifier circuits such as those used in high fidelity equipments. *This subject was previously discussed in detail under the section entitled Heater-Cathode Leakage.*

Spurious Oscillations

Spurious oscillations may be the product of regenerative feedback by devious magnetic and capacitive paths both external to and within tubes. When externally produced, shielding of tubes, coils and other components or a more remote arrangement of parts may be necessary to overcome the feedback path. Lead dress frequently can be a major external source of regenerative feedback and should be carefully controlled in critical cases.

Spurious oscillations within the tube include the radiated noise phenomenon described previously, parasitic oscillations and oscillations at the intended frequency of amplification caused by using the tube beyond its safe maximum usable gain.

Parasitic oscillations are caused by unintentional high frequency oscillator circuits being formed by the inter-element capacities and lead inductances or unintentional capacitive or magnetic coupling with external circuit elements.

Parasitic oscillations can best be eliminated by: proper selection of tube type to provide the lowest possible lead inductance; the manner in which the pins are grounded for such RF frequencies; and by the introduction of parasitic suppressor resistors—generally unbypassed resistances of small value in series with a critical tube element.

In those cases where regeneration stems from exceeding the safe maximum usable gain of the tube, the best corrections include loading the circuit down—this reduces the gain and may require additional stages of amplification; or select a different tube type with reduced plate-to-grid capacity—which in essence, means selecting another tube type with a higher maximum usable gain.

BLUE GLOWS

Blue Glows are not tube detriments per se. They are, however, suspects in the eyes of many receiving tube users for lack of a full understanding of their origins. There are several types of Blue Glow which can be described as follows:

Fluorescence—this type of glow is usually violet in color and most noticeable around the inside surface of the glass bulb. It is most pronounced on power tubes and is the product of electron bombardment of the glass taking place within the tube. It generally has no adverse affect upon receiver performance, and in fact, tubes displaying this phenomenon are particularly good with respect to gas content.

Mercury Vapor Haze—is a blue-violet glow associated with those tube types which rely upon mercury vapor for proper operation. In such cases, the blue glow should be evident indicating proper operation.

Gas—produces a blue haze, generally confined to the vicinity of the mount structure. The proper function of gas types such as thyratrons, voltage regulator and voltage reference tubes, requires the presence of this glow as an indication of proper tube operation. Some voltage regulators use neon instead of argon and as a result exhibit a pink-orange glow. It is, however, a distinct detriment in vacuum receiving types, where the presence of gas in large amounts can cause malfunction of the equipment.

Design for Production

The majority of electronic equipments designed are ultimately aimed toward production. In addition to the obvious objectives of adequate performance at the lowest cost, the factors that influence reliability must be considered. In the final refinement of the product for production, circuit requirements versus component capabilities must be checked and rechecked, correcting any differences and in general smoothing out the rough spots that will cause a high number of production and field failures. This is one of the most difficult phases of engineering, entailing thorough technical knowledge, common sense and good business acumen.

In the course of smoothing out a new design for production, the design engineer must be aware of many aspects of tube application beyond a mere knowledge of the electrical characteristics of the tube type employed. Some of the items which must be carefully examined are (a) ratings, (b) initial spread in electrical characteristics, (c) initial spreads in detrimental characteristics, (d) effects of line voltage variations upon tube performance, (e) effects of external control settings upon operating conditions, (f) effects of life upon tube performance.

Tube ratings are briefly defined as the limiting values of operating conditions beyond which satisfactory tube life and performance may be seriously impaired. As discussed under the section entitled "Electrical Considerations", there are three rating systems currently in use for entertainment and industrial receiving tubes. The circuit designer must be well acquainted with each of the three rating systems to fully appreciate the extent of his responsibilities and any special precautions that must be observed in meeting the limits. *For further information, the reader is referred to the Joint Electron Device Engineering Council Bulletin J5-C3, "THE DESIGN MAXIMUM RATING SYSTEM FOR ELECTRON TUBES".*

The electrical characteristics of any receiving tube design will vary in relation to the mechanical tolerances obtainable for the individual tube parts. Even though the parts are controlled to within a fraction of one thousandth of an inch, the net result of such tolerances, singly and in combination, result in a very definite spread in each electrical characteristic about its rated value. The distribution curves for such spreads take three distinct and predictable forms.

Figure 1 shows a normal bell-shaped distribution curve centered about the rated value of the electrical characteristic in question. Most of the controlled electrical characteristics are of this nature, including plate current, transconductance, etc. Occasionally, a skewed distribution curve is encountered as shown in Figure 2. One example of such a distribution is the transconductance of the No. 2 control grid in dual control pentodes. Still a third form of distribution, known as the J-shaped distribution, is illustrated in Figue 3. Detrimental properties normally assume such a spread. The circuit designer who is refining a product for manufacture must be aware of these spreads in his product. Spreads in important electrical characteristics are published as part of Sylvania's Consumer Acceptance Specifications and are on file in the libraries or with the components sections of most major manufacturers.

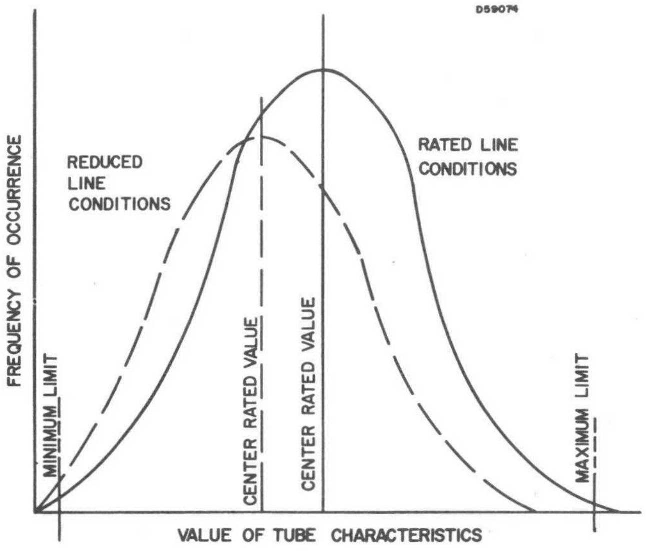


Figure 1—Normal bell-shaped distribution curve at rated and reduced line conditions.

The implications of the initial spread in characteristics are quite obvious. Failure to recognize tube characteristic spreads when refining a new product for manufacture may result in a high number of line rejections. Further, at any time a particular circuit can not accommodate a full initial production spread, it represents a harbinger of considerable field difficulty and a high percentage of in-warranty failures, when one considers that tubes will change during life.

With few exceptions, the power sources utilized to operate electronic equipments will be found to vary with time, loading, and other circumstances. Table I describes the range in voltages which are encountered from three typical power sources from which most electronic equipments obtain their energy.

For each of the three types of power sources shown, the equipments must be designed to operate over the full range of voltages. It follows, then, that the receiving tubes must be capable of adequate performance under the lowest voltage supply condition and still be within their ratings at the highest voltage conditions. If deficiencies are noted

TABLE I
ALLOWABLE RANGES OF SUPPLY VOLTAGE

AC Line Operated Equipment			
	Low Line	*Nominal Line*	*High Line*
	105 Volts	117 Volts	129 Volts
Automotive Equipment		*Low Battery (Generator Not Charging)*	*High Battery (Generator Charging)*
6-Volt System		5.0 Volts	8.0 Volts
12-Volt System		10.0 Volts	15.9 Volts
Dry Battery Equipment		*Minimum*	*Maximum*
"A" Battery (1.5 V cell)		1.1 Volts	1.6 Volts
"B" Battery		—	Rated Block Voltage +10%

at low line conditions, a different tube type or circuit modification may be necessary. Further, the designer should determine whether tube ratings are exceeded when operated under the high line condition. If this occurs, then it would be anticipated that tube life will be seriously foreshortened. As a matter of interest, Sylvania's program for life testing tubes in TV receivers shows that tube failures at high line conditions are accelerated by 240% over normal line conditions. This only serves to highlight the urgency of insuring that tubes are maintained within ratings at the high line voltage conditions.

Figure 1 shows what occurs to a typical normal distribution of an electrical characteristic at reduced line voltage. In general, the electrical characteristics such as plate current and transconductance will be reduced by a certain amount as compared to the normal operating condition. This further emphasizes the fact that if the circuit can not utilize the full production spread of the various electrical characteristics at normal operating conditions, it is a sure sign of field trouble since a mere reduction in line voltage can immediately produce below par performance.

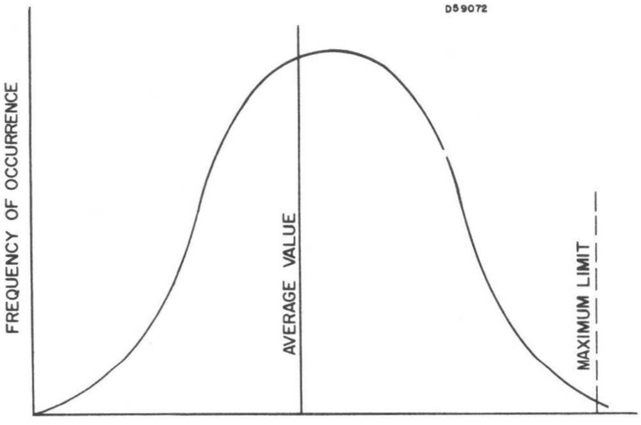


Figure 2—A skewed distribution curve.

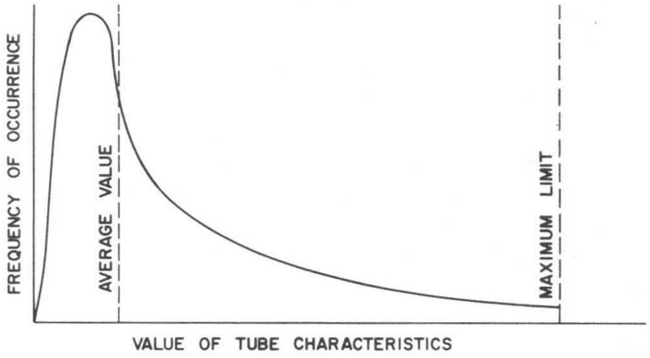


Figure 3—A J-shaped distribution curve.

Figure 4 shows what happens to a typical electrical characteristic of a receiving tube with life. In most cases there is a definite slow rate of slump-off for the various electrical characteristics throughout tube life. Dependent upon how much safety margin is designed into the circuit initially, the tube can very shortly slump-off to an unacceptable level of performance or it may have a very long and satisfactory life.

The point at which a circuit becomes unacceptable is very much dependent upon the circuit function within the particular equipment. Thus, a 25% or 30% slump in transconductance in an IF tube in a television receiver or home radio will produce a comparable reduction in the overall gain. A reduction in overall gain will probably never be noticed by the consumer since there is usually a very sufficient reserve of gain being attenuated by the automatic gain control system. A slight reduction in gain would probably only be noticed in the

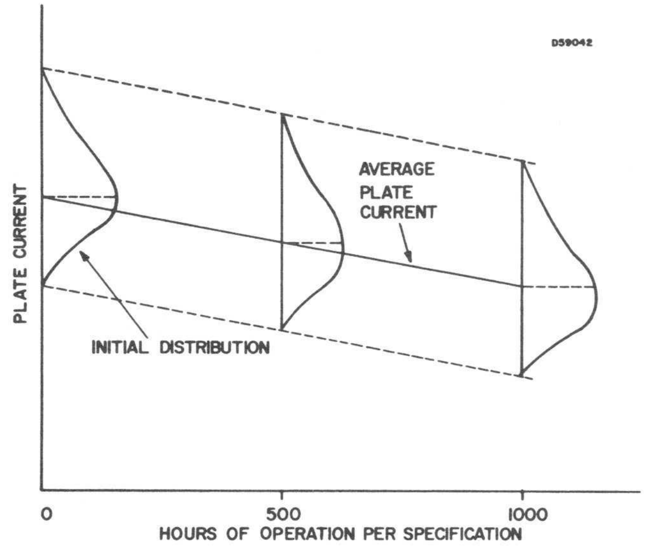


Figure 4—Typical trend of Plate Current distribution on static life test.

most extreme fringe areas where the equipment is running "wide open" at all times. On the other hand, visual presentation devices such as the picture output of a television set or the meter in a Vacuum Tube Volt Meter could be very susceptible to problems caused by very small changes in electrical characteristics. This stems from the higher acuity of the human eye in the former case and the precision demanded for measurement purposes in the latter.

The following steps can be taken to insure adequate, long life performance even in the critical stages where changes in performance are readily detected:

(1) The incorporation of DC degenerative mechanisms such as cathode resistors, and screen resistors in the case of pentodes. These devices tend to very substantially decrease the spreads in tube characteristics under the operating conditions and also minimize the effects of any shift in electrical characteristics with life and line voltage changes.

(2) The introduction of an automatic current regulator or some form of automatic gain control, will do much to insure uniformity among tubes, both initially and with changes during life.

Both of the aforementioned techniques entail the initial design of a circuit of more than needed performance capability and the introduction of some technique for attenuating this performance. Then, with lower limit tubes and life "slump-offs," the attenuation automatically decreases to maintain performance at the desired level.

(3) Conservative tube operation with respect to element dissipation and voltage ratings will also help to insure long and stable tube life.

The circuit designer can best attack the problems of studying tube performance capabilities and ratings versus circuit requirements in a methodical manner. Table II entails a listing of all the pertinent ratings and electrical characteristics as contained on the manufacturer's data sheets. *It should be noted that the actual circuit operating conditions and tube requirements for adequate performance are checked at various line conditions to permit the comparison with the rated maximum limit.* Unless the circuit is performing under the same identical operating conditions at which the manufacturer rates the tube, there will be no direct comparison available for electrical characteristics. In this case, it will be necessary to relate the operating conditions to the rated values or to simply obtain a group of tubes representing all of the brands to be used, (if possible, representative of several lots of each brand) and run them through the socket to determine if the performance is adequate. If not, then a further study of the critical electrical property is in order.

The circuit analysis should also show any possible tube detriments, either controlled or otherwise, which may influence performance. These should be compared with the controls currently used by tube manufacturers and, if there is any inconsistency, further resolution is necessary.

While it may be physically impossible to run many life tests on a prototype chassis to determine whether or not a potential field problem exists, the need for such testing should be noted and given due consideration.

The designer should ask himself each of the following questions.

(A) Will this equipment be within all of its ratings under the worst probable operating condition?

(B) Will this tube still be able to provide adequate performance with a 25% or more reduction in important electrical characteristics?

(C) If the circuit is a critical one for changes in performance, is there sufficient degeneration incorporated to minimize such variations, both initially and with life?

(D) Is there adequate protection in the circuits so that the failure of one circuit will not precipitate damage or failure to other circuits?

A negative to any of these questions is a sure sign that this particular circuit requires further investigation before ever going to the production floor.

Application Notes

With a methodical approach and due consideration to all of the foregoing aspects, it becomes possible for the circuit designer to screen his design for potential problems and perhaps eliminate most of them before they ever arrive at the state where they can be damaging.

TABLE II

TUBE RATINGS AND PERFORMANCE CAPABILITIES VERSUS CIRCUIT REQUIREMENTS

	Tube Manufacturer's Data		*Circuit Requirements**	
Ratings				
Heater Voltage	Max.	Min.	Max.	Min.
Plate Voltage (dc)	Max.		Max.	
Peak Forward	Max.		Max.	
Peak Inverse	Max.		Max.	
Grid No. 2 Voltage	Max.		Max.	
Grid No. 1 Voltage	Max.	Min.	Max.	Min.
Peak Negative Grid No. 1 Voltage	Max.		Max.	
Heater-Cathode Voltage	Max.		Max.	
Plate Dissipation	Max.		Max.	
Grid No. 2 Dissipation	Max.		Max.	
Average Cathode Current	Max.	Min.	Max.	Min.
Peak Cathode Current	Max.		Max.	
Grid No. 1 Circuit Resistance	Max.		Max.	
Bulb Temperature	Max.		Max.	
Characteristics				
Heater Current	Max.	Min.	Max.	Min.
Plate Current	Max.	Min.	Max.	Min.
Grid No 2 Current	Max.	Min.	Max.	Min.
Heater Warm-up Time	Max.		Max.	
Interelectrode Capacitances	Max.	Min.	Max.	Min.
Transconductance (life-test end point)	Max.	Min.	Max.	Min.
Transconductance (at reduced Ef)	Max.	Min.	Max.	Min.
Amplification Factor	Max.	Min.	Max.	Min.
Dynamic Plate Resistance	Max.	Min.	Max.	Min.
Power Output (life test end point)	Max.	Min.	Max.	Min.
Detriments				
Electrode Insulation (life test end point)		Min.		Min.
Grid Current at Rated Ef (life test end point)	Max.		Max.	
Grid Current at Elevated Ef (life test end point)	Max.		Max.	
Heater-Cathode Leakage	Max.		Max.	
Plate Current Cutoff	Max.	Min.	Max.	Min.
RF & AF Noise, Noise & Micro	Max.		Max.	
Delta Characteristics with Life (Ib, Sm, Po)	Max.		Max.	
Delta Characteristics with Heater Voltage	Max.		Max.	
Contact Potential Current	Max.		Max.	
Interface Resistance	Max.		Max.	

**Should reflect extremes produced by variations in supply voltages and tolerances of all component parts.*

General Application Information

BIASING CONSIDERATIONS

The bias arrangement used in any particular electrical circuit can be one of the most important aspects of tube application with respect to obtaining a high degree of reliability. There are many biasing arrangements used in currently popular circuits, including: (a) fixed bias, (b) self bias, (c) combination of fixed and self bias, (d) grid leak bias, (e) signal bias, (f) other combinations of the foregoing arrangements. Figure No. 1 illustrates the basic circuit diagram of each of these bias arrangements.

Reliability considerations involved in the selection of a particular bias circuit includes: (a) its effect upon initial spread in electrical characteristics, (b) in minimizing effects of supply variations upon tube performance, (c) minimizing effects of slumping tube characteristics upon performance, (d) hum and heater-cathode leakage considerations, (e) the amount of grid resistance which can be used, (f) the amount of circuit protection afforded by the particular circuit arrangement, (g) the performance level attainable with the particular tube, (h) the amount of grid current drawn (if any), and (i) cost.

Table I is a condensed cross reference which permits a comparison of five of the more popular biasing circuits for each of the major considerations involved.

TABLE 1

BIASING ARRANGEMENTS

	Fixed-bias	Self-bias	Partial; Fixed & Self bias	Grid Leak Bias	Signal Bias
Initial Spread in Characteristics	Broad	Narrow	Narrower than fixed bias	Narrow	Depends on application
Effect of Supply Variations Upon Performance	Maximum	Least	Better than fixed bias	Least	Depends on application
Effect of Life on Performance	Maximum	Minimum	Better than fixed bias	Minimum	Depends on application
Hum/Heater-Cathode Leakage	Good	Precautions should be taken	Better than self bias	Good	Good
Grid Resistance	Low as possible	Higher values permissible	Higher than fixed	Higher values permissible	Depends on application
Grid Current	None	None	None	Small amount	Can be large and may be a limitation
Performance Attainable	Permits utilization of maximum performance capabilities of tube	Negative DC feedback reduces DC gain but adequate by-passing permits full utilization at audio and higher frequencies	Full capabilities are obtainable except for DC	Full	Full
Circuit Protection	None	Good	Some	Seldom needed	Need is dependent upon application
Cost	Bias supply must be available	Need cathode resistor and condensers	Requirements of both fixed and self	Minimum of components	Minimum of Components

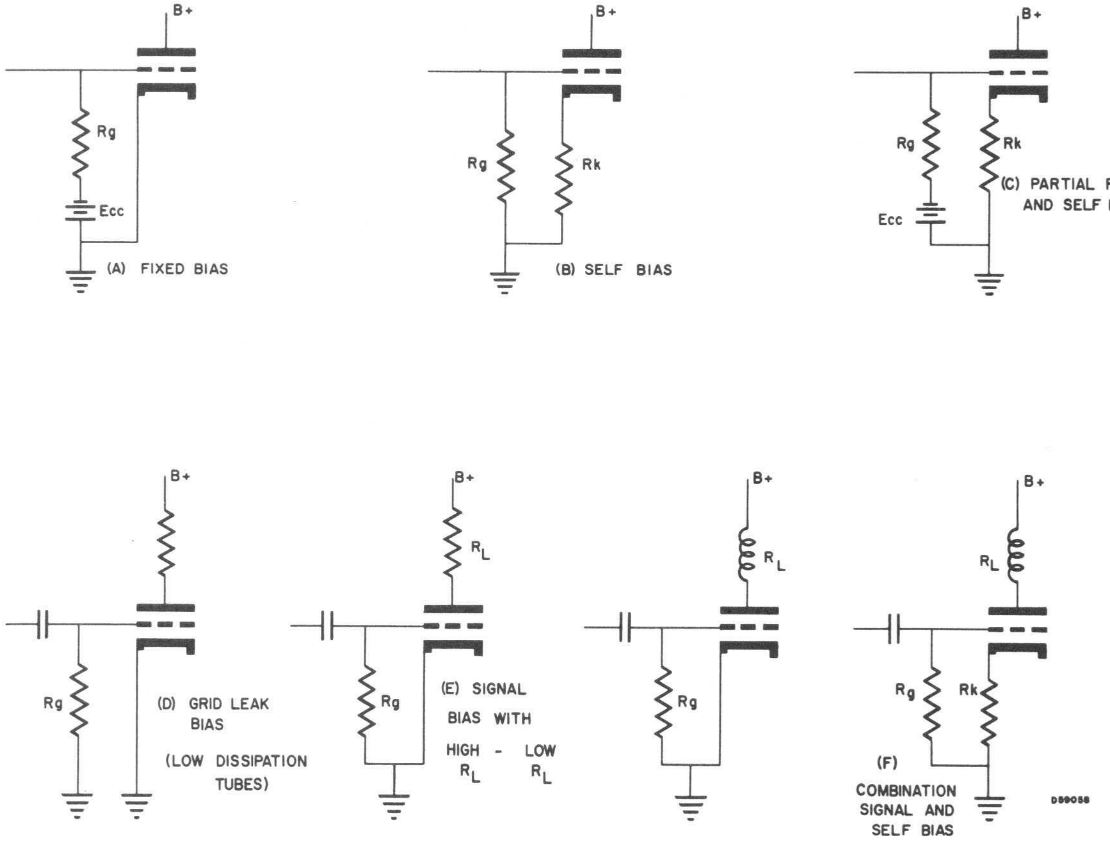


Figure 1—Popular biasing arrangements.

Fixed Bias—First let us consider the use of fixed bias. In this arrangement, a "hard" bias voltage is applied to the circuit. With constant voltages applied, there is no DC degeneration whatsoever in the circuit except that which may be derived from the plate load resistance and series screen resistance. Although DC degeneration from these two sources does tend to narrow initial spreads in electrical characteristics such as plate current, transconductance, screen current, etc., the effect is less than that with cathode bias. Not only are the initial characteristic spreads the broadest; but, since the bias is obtained from a "hard" supply, the effects of supply voltage variations including bias voltage and heater voltage will be at their maximum. Any change in tube characteristics with life will immediately be reflected by an equivalent or corresponding change in performance. Thus, fixed bias provides the widest spread in performance in production and field service.

Since there is no cathode resistor in the fixed bias arrangement, the introduction of hum into the circuit via heater-cathode leakage should be eliminated. Fixed bias permits the designer to obtain the optimum performance capability of a given tube type, initially, within limits which are dictated by maximum allowable grid resistance and whatever other precautions are deemed necessary. As discussed in the section on Gas Currents, comparatively lower values of grid resistance must be used with fixed bias to preclude a runaway condition and destruction of the tube—This is one measure of circuit protection which must be recognized. Dependent upon the source from which the fixed bias voltage is derived, other protective measures may also be required. Bias may be lost for some period of time, either during equipment warm-up, or from malfunction of another circuit in the equipment. Since there is no cathode bias available to limit the plate current in event that the fixed bias is momentarily lost, the plate dissipation can become considerable, causing the release of occluded gas and eventually a "runaway" condition. To provide protection against such eventualities, in addition to a reduction in grid resistance, the circuit designer can insure reliable circuits by using fairly high values of plate (and screen) resistors. B supply potential should be sufficiently low so that even under the worst possible condition there is insufficient element dissipation to cause tube destruction.

Cost-wise fixed bias can be the least expensive when a bias supply voltage is already available in the equipment. Fixed bias may look very attractive from this viewpoint in some cases. However, unless the circuit is essentially non-critical for variations in performance over a very wide range of tube characteristics, and unless sufficient circuit protection is injected via other means, fixed bias can be the most costly arrangement in terms of line rejections and in-warranty field returns.

Self Bias—Self biasing essentially introduces a DC negative feedback which tends to make the circuit self-compensating for variations in tube characteristics.

Figure 2 graphically demonstrates how the range of cathode currents is reduced by the use of cathode bias as compared to fixed bias. The two dotted transfer curves represent the range of characteristics obtainable with a given tube type, reflecting the production spread which can be encountered with that tube type. The use of fixed bias provides the spread denoted by "A". The addition of a cathode resistor reduces the range of cathode currents to the spread denoted by "B". "C" allows for the ±20% resistor tolerance and represents the worst possible spread in cathode currents obtainable due to tube and resistor variations. It should be noted that this spread is still substantially reduced in contrast to the use of fixed bias.

Since self bias arrangements essentially introduce dc negative feedback, one would expect a reduction in gain in dc amplifier circuits. However, at audio frequencies and above, full performance is obtainable. The use of by-pass capacitors, partial by-pass (to provide for a greater uniformity of Rin and Cin versus bias changes) or un-bypassed cathode resistors are well documented in circuit design handbooks and will not be discussed here.

The compensation effect of self bias, as it influences tube spreads is shown in Figure 3. A group of tubes, when measured under fixed bias conditions, provides a typical spread as shown by Curve A.

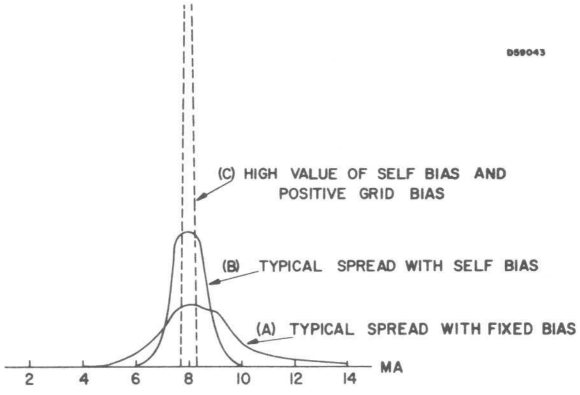


Figure 3—Typical cathode current distribution for various bias arrangements.

With the introduction of self bias and its automatic compensating dc negative feedback properties, the much tighter spread in characteristics is demonstrated in Curve B. Going further, Curve C demonstrates an extreme case where a very high value of cathode bias resistance is used plus the introduction of a positive dc grid bias. It is evident from Figure 3 that a much narrower range in circuit performance would be anticipated where self bias is utilized, as compared to fixed bias.

The same dc negative feedback effects which provide greater uniformity for the initial characteristics also help to minimize variations in tube performance with supply voltage variations. Thus, if cathode current tends to slump-off either with changes in heater voltage or a reduction in the B supply voltage, the reduced current immediately causes a reduction in bias. This tends to bring the operating level of cathode current back closer to

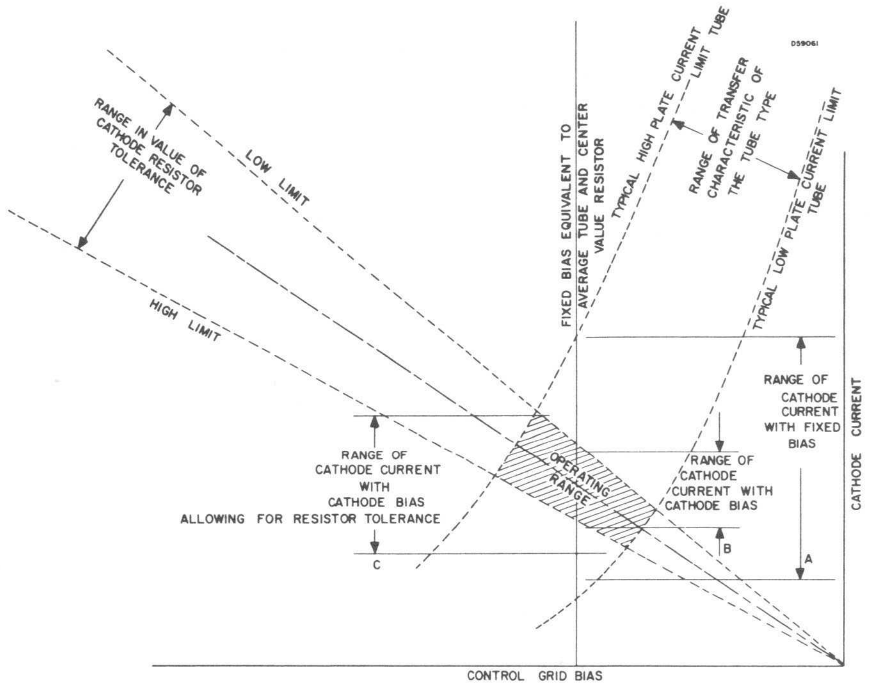


Figure 2—Graphic demonstration of how the cathode current spread is reduced by the use of cathode bias as compared to fixed bias.

the intended value than would be the case with the "hard" fixed bias arrangement. Likewise, slump-off in tube characteristics during life are affected in the same way. Thus, the use of self bias tends to narrow initial spreads in characteristics which should provide greater uniformity of tube performance in that particular circuit and be reflected in a lower percentage of production line rejections. Further, the reduced effects of supply voltage variations and of slump-off on life should substantially reduce in-warranty returns for the above mentioned reasons.

As noted in Table No. I, the introduction of cathode resistance opens the possibility of hum due to heater-cathode leakage. *Some of the precautions which should be taken in circuits where this may be critical are discussed under the section entitled Heater-Cathode Leakage.* Potential problems arising from heater-cathode leakage will, of course, vary with the amount of cathode resistance utilized. The designer must consider all of the aspects of tube application as listed in Table I in the selection of any given bias arrangement. Thus, in an audio preamplifier, the customary high values of R_L contribute to a high degree of tube uniformity, as well as being good tube protection, hence lower values of Rk can be used for sake of low hum.

The use of self bias provides built-in circuit protection against the loss of bias by other causes external to the circuit itself. Since self bias provides a built-in limitation to the maximum amount of plate and screen current and/or dissipation which can be drawn, a higher maximum value of permissible grid resistance may be used without jeopardizing circuit stability. Since the introduction of any occluded gas would tend to increase bias, there is less tendency for a tube to "run away". The data sheets for each tube type generally denote a higher maximum permissible grid resistance for use with self bias.

The self bias arrangements dictate the use of cathode resistor(s) and perhaps by-pass capacitors which may add to the initial cost of the circuit. However, this may be a small cost in comparison with savings from low production line rejections and low in-warranty returns.

Combination Self and Fixed Bias—Occasionally, circuit designers utilize a combination of self and fixed bias in their circuits. This is essentially a compromise between the two foregoing arrangements, and is usually done because of a performance consideration. It is principally used in those cases requiring high peak current levels which dictate a minimum of cathode resistance. Such arrangements help to reduce the initial spread in characteristics somewhat as well as minimize the effects of supply variations and tube slump during life. This compromise generally provides for less cathode resistance than the full self bias arrangement, and hence is somewhat less susceptible to hum and heater-cathode leakage.

The fact that self bias exists in the circuit provides a degree of circuit protection and thus permits higher values of grid circuit resistance. However, this can be overdone. For example, the combination of self and fixed bias is sometimes used in vertical deflection amplifiers; but, there is also a temptation to reduce drive requirements by using very high values of grid circuit resistance. Since high peak current levels are necessary, the actual amount of self bias is very limited. Some circuit protection is there, but in event of loss of signal or change in the value of fixed bias due to a change in other circuits, it is very conceivable that a "run-away" condition can develop. Thus, while the combination of self and fixed bias does provide some of the reliability merits of the self bias arrangement, these can be completely cancelled by the insertion of too high a value of grid circuit resistance.

Cost-wise, the bias supply must be available; and the use of cathode resistors and perhaps capacitors will also enter into the cost of the circuit.

Grid Leak Bias—Figure 1, Circuit D is a typical schematic for a grid leak bias arrangement. In this circuit arrangement, a high value of grid resistance is utilized (up to 10 megohms) to derive the bias. Figure 4 shows the typical grid current curves for a triode. A load line representing the value of the grid resistor is superimposed upon these curves

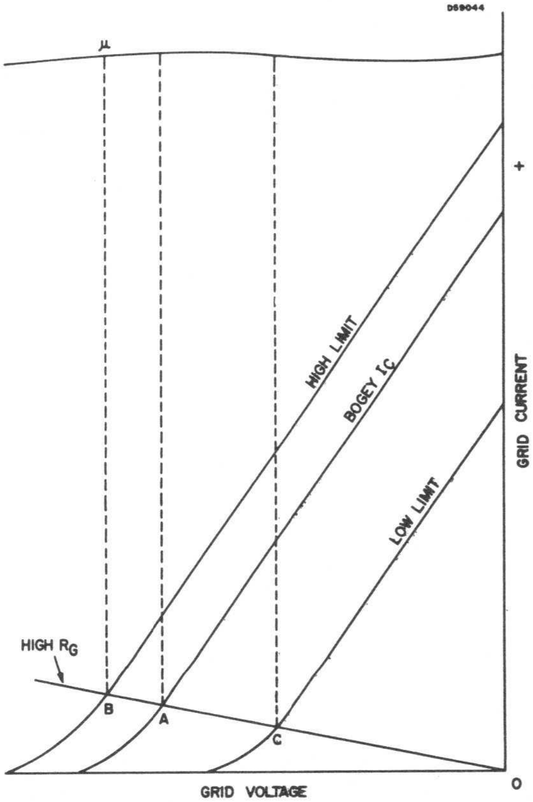


Figure 4—Variations in contact potential bias with tube aging and changing potentials.

and the point of intersection (A) will be the value of bias applied to the tube. As discussed under the section entitled Grid Currents, the contact potential point at which this tube is operating will tend to vary substantially with line voltage and life. Thus, bias spreads from B to C can be encountered. In this circuit it is desirable to utilize a large value of grid circuit resistance to obtain as much bias as possible, i.e., the greater the bias obtained by this means, the larger the signal that can be applied without undue distortion. As shown by Figure 4, the amount of bias obtained will be a function of the value of grid resistance; although, beyond about 10 megohms, further increases in grid resistance are inconsequential.

Grid leak bias is only recommended for use in circuits which also have a large value of plate load resistance and in pentodes, screen resistance as well. The grid leak bias arrangement is only usable with small signals, since the bias will only be in the vicinity of approximately one volt.

Circuit uniformity is quite good with the grid leak bias arrangement, and supply voltage variations and slump-off in tube characteristics on life have a minimum effect upon performance. The principal applications are in low level audio amplifiers using conventional tubes and circuits employing low B supply (12 volt) types. Reference to circuit design handbooks will show that these applications are dependent upon the amplification factor of the tube more so than on any of the emission functions including transconductance and plate current. Further, the plate and/or screen current resistors required for such circuits have a dc negative feedback effect similar to that described previously for self bias and tend to improve uniformity. This circuit exhibits very low hum from heater-cathode leakage due to the absence of a cathode resistor. It is particularly desirable in entertainment devices due to its low cost, since a minimum number of components are used. Grid Leak bias also provides a high degree of performance uniformity. However, the circuit designer must recognize the limited areas of application in which it can be used.

Signal Bias—Signal bias is another fairly popular biasing scheme. Reference to Figure 1, schematic E, shows two variations of this arrangement where one employs a high and the other a low impedance plate load.

Signal bias is obtained by injecting sufficient signal voltage to the grid to cause the tube to drive into the positive grid region momentarily. In so doing, grid current is drawn through the grid resistor causing it to develop a dc bias in proportion to the amount of drive. In the case where a high impedance plate load resistance is utilized, the reliability considerations are very much the same as for grid leak bias. This circuit arrangement offers a relatively narrow spread in characteristics due to dc degenerative effects of the plate and/or screen resistor. Such arrangements will be relatively impervious to supply voltage variations and slump-off in emission characteristics on life, since the circuits will be essentially dependent upon the amplification factor. Further, the circuit is relatively immune to hum due to heater-cathode leakage; high values of grid resistance are permissible; and good circuit protection is offered.

The use of signal bias with low values of plate load resistance can provide a very serious situation from the viewpoint of circuit reliability unless adequate precautions are taken. This particular circuit arrangement tends to be very much dependent upon the emission characteristics including plate current, screen current and transconductance. Signal bias has little or no dc degeneration to compensate for initial spreads in characteristics, effects of supply voltage variations, and slump-off on life. Further, there is no protection against "runaway" due to development of gas. Such a condition may be compounded by the fact that as grid current is drawn, the control grid is heated to the point where it may conceivably become an emitter in its own right. Further, if the driving signal is lost for any reason, the tube will operate at or close to zero bias, which further increases the possibility of "runaway". Unless a low value of grid circuit resistance is utilized to preclude "runaway", and the B supply potential is sufficiently low to preclude exceeding element dissipations in the event of loss of signal bias, any application utilizing this scheme exclusively is in jeopardy at all times.

There are other variations of biasing circuits which are essentially combinations of those discussed previously; the use of signal bias with low plate load impedance combined with some self biasing would be a good example. Each arrangement is essentially a compromise between or among the arrangements discussed herein, and the relative advantages and disadvantages can be derived by reference to the foregoing material.

PARALLEL OPERATION OF TUBES

As the best compromise in meeting space, equipment-performance, and tube-rating limitations, circuit designers may be faced with problems which necessitate operating tubes in parallel. Examples of such applications include power output amplifiers, power supply rectifiers, and power series-passing tubes.

Considerable caution should be observed when this method of tube operation is employed. A simple example with two typical pentodes in parallel with fixed bias will illustrate the potential problems.

Paralleled Pentodes

The characteristic curve at $Ec1 = -20$ volts and $Ec2 = 300$ volts is shown by the bogey line in Figure 5. Under the same set of applied voltages, a sampling of acceptable tubes will yield character-

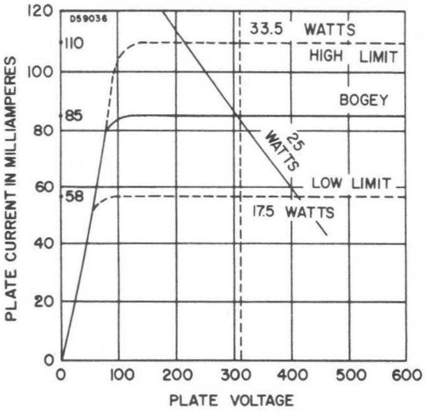


Figure 5—Spread in pentode plate characteristic curves which must be accommodated by circuit design.

istic curves ranging from the one marked "high limit" to the one marked "low limit". These latter (dotted) curves represent the spread in tubes which must be accommodated by the circuit design. A dissipation limit curve of 25 watts is also shown.

Taking a hypothetical application where two tubes are paralleled at approximately Eb = 300 volts, Ec1 = -20 volts, and Ec2 = 300 volts, we observe that a bogey tube will operate at 85 ma and 25 watts. If two tubes are paralleled, they will theoretically dissipate 50 watts. Unfortunately, not all tubes are bogey tubes and we seldom obtain an equitable load split. By reference to Figure 5, we find that in a case where two extreme tubes are paralleled, one tube can handle as much as two-thirds of the load and be substantially beyond its ratings while the other tube is coasting with only one-third of the load. In practice, this usually results in rapid failure of the overloaded tube and a shift of the total load to the remaining tube, which also fails shortly thereafter.

Another potential problem with paralleled pentodes is the possibility of parasitic oscillations that are triggered by stray voltage pulses which can arise from many sources. As a result of these oscillations under fixed-bias conditions, both tubes will, in all probability, exceed dissipation limits with a good chance of destruction. One obvious precaution, if fixed bias must be employed, is to employ tubes at a fraction of their maximum dissipation and cathode-current limit and to introduce parasitic-oscillation suppressors into the circuit. In some cases, this may mean that additional tubes must be paralleled.

The degenerative effects of plate, screen, and cathode resistors will improve the uniformity of tube performance in parallel circuits if self bias is feasible. The cathode resistor is most effective in this respect. Each tube should have its own separate resistors. Tubes should still be operated at dissipations and cathode currents that are below the maximum, but the derating need not be as severe as for fixed-bias operation.

In some cases where paralleled tubes have a common grid resistor, the maximum recommended resistance value should be decreased inversely in proportion to the number of tubes in parallel.

Paralleled High Vacuum Rectifiers

Although the foregoing example employed a pentode for simplicity, the same conditions occur in triodes and rectifiers as well. Duplication of the foregoing example with two high vacuum rectifiers, typical of those found in television receivers, will readily demonstrate this point.

The curves shown in Figure 6 represent the spread in plate characteristics for a single section of a typical high vacuum full-wave rectifier operating at the maximum rated DC plate current of 135 ma. A bogey tube, under this condition, has a DC measured tube drop of 32 volts. Theoretically, two tubes operated in parallel should almost double the output capabilities of single tubes. However, for the extreme case shown in Figure 6 where it is assumed that both the low and high limit tubes operate with a DC measured tube drop of 32 volts, we again find that one tube will assume the majority of the load which usually results in rapid tube failure.

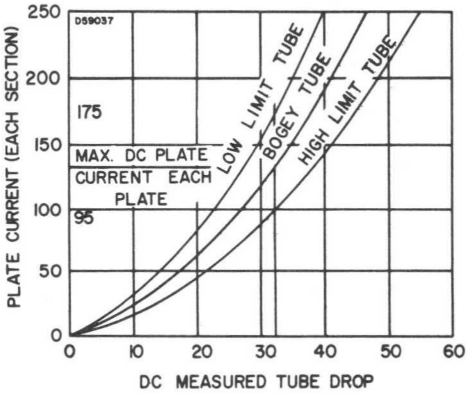


Figure 6—Spread in rectifier plate characteristic curves which must be accommodated by circuit design.

This effect can be minimized by inserting current limiting resistors in the plate circuits of the paralleled tubes. These resistors tend to equalize the difference in tube drop thereby producing a more equitable load split.

Very few applications employ tubes in parallel at the test conditions contained in specifications; hence, it is seldom possible to perform an accurate analysis from published data. It is important, however, for equipment designers to ascertain that their designs will adequately handle the normal spread in tubes at the particular operating condition involved.

SERIES STRING OPERATION OF 450 AND 600 MA TUBES

Series heater strings have been employed for sometime throughout the television industry. Several advantages of series string operation include possible cost reduction by elimination of a filament transformer, and possible direct rectification of line voltage without recourse to a step-up transformer. Also the savings in space and weight allows more flexible chassis design which results in sets that are more compact and portable.

Prior to the introduction of series string tubes, it was necessary to use series parallel strings, or shunted tubes, to obtain the proper static heater voltage distribution in the series string. Then, because of the non-uniformity of thermal characteristics, excessive surge voltages could appear across the heaters of the lower heater current tubes. When a negative temperature coefficient device had to be used to eliminate these surges, the receiver would take almost two minutes to stabilize.

This has been taken care of by the development of separate lines of 450 and 600 ma heater current tubes which perform all the necessary functions in modern television receivers. Heater current tolerances have been narrowed to ±4% on all types. The tube types whose prototypes previously had heater currents less than 600 ma have increased wire size and decreased heater voltage. These features tend to make the heaters more rugged and improve their reaction to voltage or power surges. Controls have also been instituted on the thermal characteristics of the heater of all series-string television tube types to minimize such surges.

Heater Warm-Up Test to Control Thermal Characteristics

Since heater voltage surges in series string operation are principally due to differences in thermal characteristics of the heater structures of the tubes, this characteristic must be controlled in the production of series string tubes. The generally accepted method is the "heater warm-up time" test. In this test, the measured time is that required for a heater, originally at room temperature, to reach 80% of its rated voltage after four times the rated voltage is applied to the heater in series with a fixed resistor. This fixed resistor is specified as three times the rated hot resistance of the tubes' heater. The heater warm-up time for all tube types in both the 450 and 600 ma lines has a value of 11 seconds. This figure is simply a figure of merit and should not be confused with the time required for the tube or receiver to become operative.

The importance of such a test for evaluating the thermal characteristics of the heaters is readily apparent when considering a tube with fast warm-up time in a series string of tubes exhibiting slower warm-up properties. The fast heating tube will receive an excessively high voltage surge across its heater until the remaining heaters assume their share of the applied voltage. Heater warm-up time measurements by this test method will indicate the probable occurrence of surge voltages on heaters in series string, although not the magnitude nor time of this occurrence.

Steady-State Voltage Distribution in Series Heater Strings

While heater current is not too critical under the constant voltage conditions with transformer heater supplies, it is very important under the constant current conditions of the series string because the division of heater voltage is determined by the hot resistance of the individual tubes. To minimize these effects in series string operation, heater current limits on the 450 and 600 ma line of tubes have been narrowed to ±20 and ±25 ma respectively.

Development of Composite Operating Curves

Figure 7 is a composite Ef — If characteristic curve of typical Sylvania 450 ma tube types which will aid in the analysis of series string conditions and enable prediction of approximate operating points or power inputs of individual tubes in a 15 tube string for line voltages between 105 and 130 volts. Although this discussion refers primarily to 450 ma series string tubes, a similar curve is presented for 600 ma types in Figure 8.

Referring to Figure 7, the Ef — If curve for a bogey tube, by nature of its designation, passes through 450 ma at 100% rated heater voltage. Ef—If curves for low and high current limit tubes are parallel to, but displaced from the bogey curve as determined by the heater current limits, 430 ma and 470 ma, at 100% rated heater voltage. The characteristics of other than bogey tubes will, therefore, be represented by a family of curves, which parallel the bogey curve, ranging between the limit curves.

The maximum range of string current at rated line voltage is dependent upon the heater current production limits, since the string current range cannot be greater than the heater current spread of the tubes composing the string. String currents at high and low line conditions, I min. — I max., Figure 7, are based on predetermined supply voltage limits and strings composed of only high or low current limit tubes.

The total enclosed area of Figure 7, therefore, represents the maximum possible theoretical operating conditions between low and high line, divided as shown. A tube may possibly operate from 81-120 percent rated heater power at rated line conditions, or 67-138 percent at low and high line. These conditions, however, are the extremes since the current of the tube in question, must be at one limit and the string current at the other limit.

Probable Operating Conditions of a 15-Tube String

The probable area within which these 450 ma tubes will operate will be smaller in comparison to

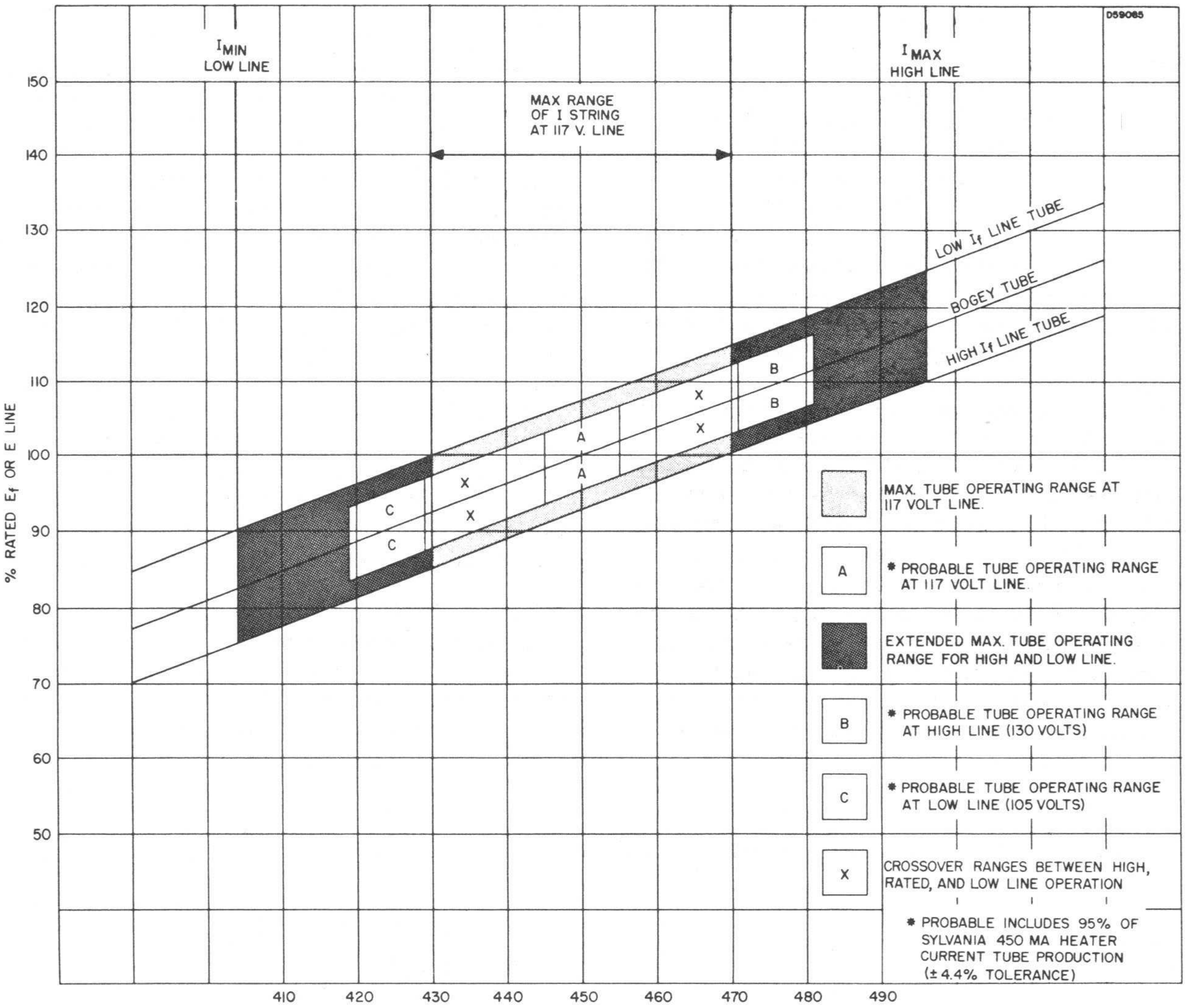


Figure 7—A composite Ef—If operating curve of Sylvania 450 ma series string tube types.

the total area and will be determined by the heater current spread of the tubes and the probable variation of the current in series strings composed of these tubes. Statistical analysis indicates that 95% of the 450 ma tube production should fall within ±13 ma of the design center rating for heater current. As a result, the string current for 99.7% of the probable combinations of tubes, for an arbitrary 15 tube series string, will fall within ±5 ma of the same design center.

Although variations in 15 tube complements will theoretically affect the probable range of string current, practically, this effect is negligible. For a larger number of tubes in a series string, this ±5 ma figure will decrease proportionally, while for a smaller number, the converse is true. These conditions of probable operation at rated line conditions are graphically represented by area A on the Ef—If characteristic of Figure 7 for a 15 tube string. Areas B and C, which represent the probable range of tube operation for high and low line conditions, were determined in a similar manner. While these areas of probable operation, A, B, or C, individually represent only 15% of the area of possible operation for rated, high, and low line conditions, these areas of possible operation overlap on a concurrent presentation. Areas B and C of probable operation at high and low line will slide through the areas X into area A as the line voltage approaches normal. Therefore, the range of probable operation for 95% of the 450 ma tube production used in 15 tube strings will be only 43% of the maximum possible operating range considering low line to high line operation, or 15% of the possible range considering any single line condition.

To determine the probable operating point of a tube on this Ef — If presentation, the string current at rated line and the heater current at rated heater voltage of the tube in question must be known. This heater current value will determine which of the family of Ef — If curves, all parallel to the bogey characteristic, should be used for this tube. The string current may be determined for a change in line voltage from the following formula:

$$I_a = I_R - K + \left(\frac{K}{E_R}\right) E_a$$

Where Ia = string current
Ir = string current at rated line
Er = rated line voltage (117 V.)
Ea = actual applied line voltage
K = 0.270 for 450 ma types
0.315 for 600 ma types

The intersection of the string current line and the individual tube current characteristic will be the approximate operating point for this tube.

While tighter heater current tolerances have reduced the probable string current variations, the foregoing discussion points out the possible variations in heater excitation that may still exist on individual tubes in series string operation.

Since it is impractical for the tube manufacturer to reduce heater current tolerances less than the present limits, a knowledge of possible and probable heater power variations is especially necessary inasmuch as it may affect the design of critical circuits where high performance and tube life are important. Design of circuits where noise figure, scan, sensitivity, and high voltage are critical, must therefore be more conservative for series string operation than for operation from a filament transformer.

Comparison with Constant-Voltage Operation

It is possible that the steady-state heater power variations in a series string may be in excess of those encountered in a constant-voltage arrangement. Let us consider the probable maximum heater power variation of 450 ma types at heater current limit conditions of ±20 ma (represents at least 95 percent of production), when operated from a voltage source feeding the tube directly. Assume also, that the line voltage variation is comparable to that shown for the 15 tube string, ±10%. Reference to Figure 7 indicates that a low limit tube (430 ma) when operated at 90 percent rated voltage, will draw approximately 405 ma and the resultant heater power will be approximately 81 percent rated value. Substitution of the upper current limit and high line conditions indicates a probable operating range of 81 to 120 percent rated heater power. The corresponding range for a 15 tube string is 67 to 138 percent rated value, or 30 percent greater.

Surge Currents

A surge of heater current occurs in a tube at the instant voltage is applied regardless of the type of heater voltage supply. This surge is the result of voltage being applied to heaters whose "cold" re-

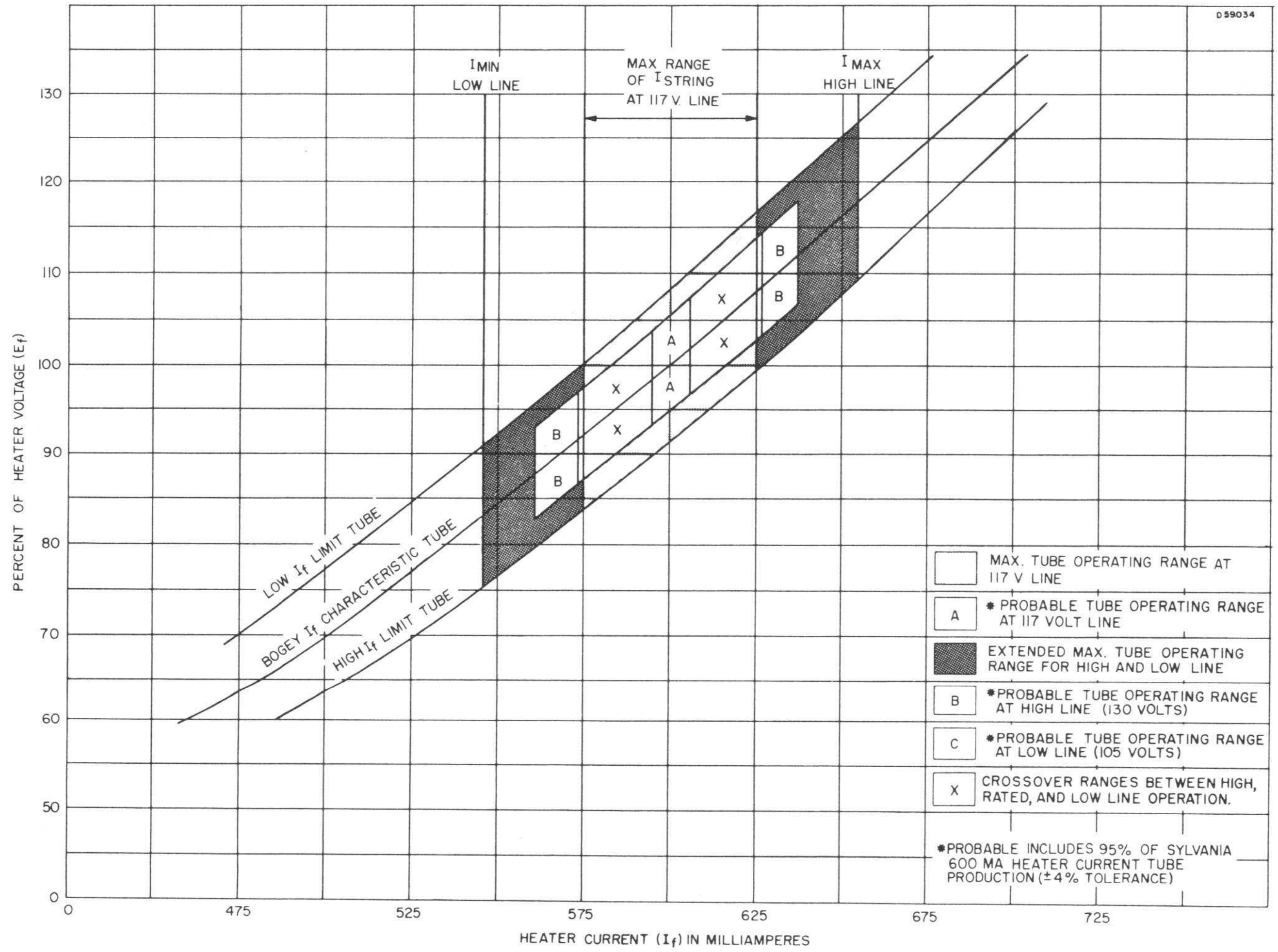


Figure 8—A composite Ef—If operating curve of Sylvania 600 ma series string tube types.

sistances are approximately 15% of their "hot" values at rated voltage. In ac operation, the maximum possible surge current occurs when the supply voltage is applied at the time of its most positive or negative peak.

Although these surge heater currents decay rapidly during the first one-quarter second, they may be negligible in series string operation where there is a series resistor.

Receiver Operation with Series Heater Strings

Although still not as fast as in transformer operation, series strings composed of tubes with 450 or 600 ma heaters, and fixed series resistors, show a great improvement in time required for stable receiver operation over strings utilizing thermistors to eliminate voltage surges.

Peak heater-cathode voltages on the tubes operated in series (cascode operation), or tubes operated as voltage dropping elements (audio output) may reach values in excess of 300 volts at rated line conditions depending on their location in the series string and their dc cathode potentials. Good practice is to place these tubes near the low voltage end of the string to reduce the peak voltage added to the normal dc component with the heaters operating off ground.

Conclusions

Conclusions that may be drawn from the foregoing discussion include:

(1) Series string operation of tubes in TV receivers can have distinct advantages appearing in the form of cost reductions and dimensionally smaller sets.

(2) Series strings composed of 450 or 600 ma tubes with controlled thermal characteristics have greater life expectancy from a heater burnout viewpoint than older types used in shunt or series parallel, due to the minimization of surge conditions and improved steady state distribution.

(3) A receiver using these series strings and a series resistor requires less time to operate normally than one which must use a thermistor.

(4) Closer heater current tolerances have minimized possible heater power variations in series strings, but conservative design of critical circuits is still necessary to counteract the effects of high and low line operation.

(5) A series resistor in the string will reduce or practically eliminate peak power surges across the tubes at the moment voltage is applied.

PENTODES

Figure 9 shows a typical pentode plate family with boundary conditions within which the tube should be operated for good reliability. Boundary conditions A and C represent the contact potential region which generally occurs at biases of approximately one volt and less. In this region, the specific value of grid circuit resistance will affect the amount of bias applied to the tube.

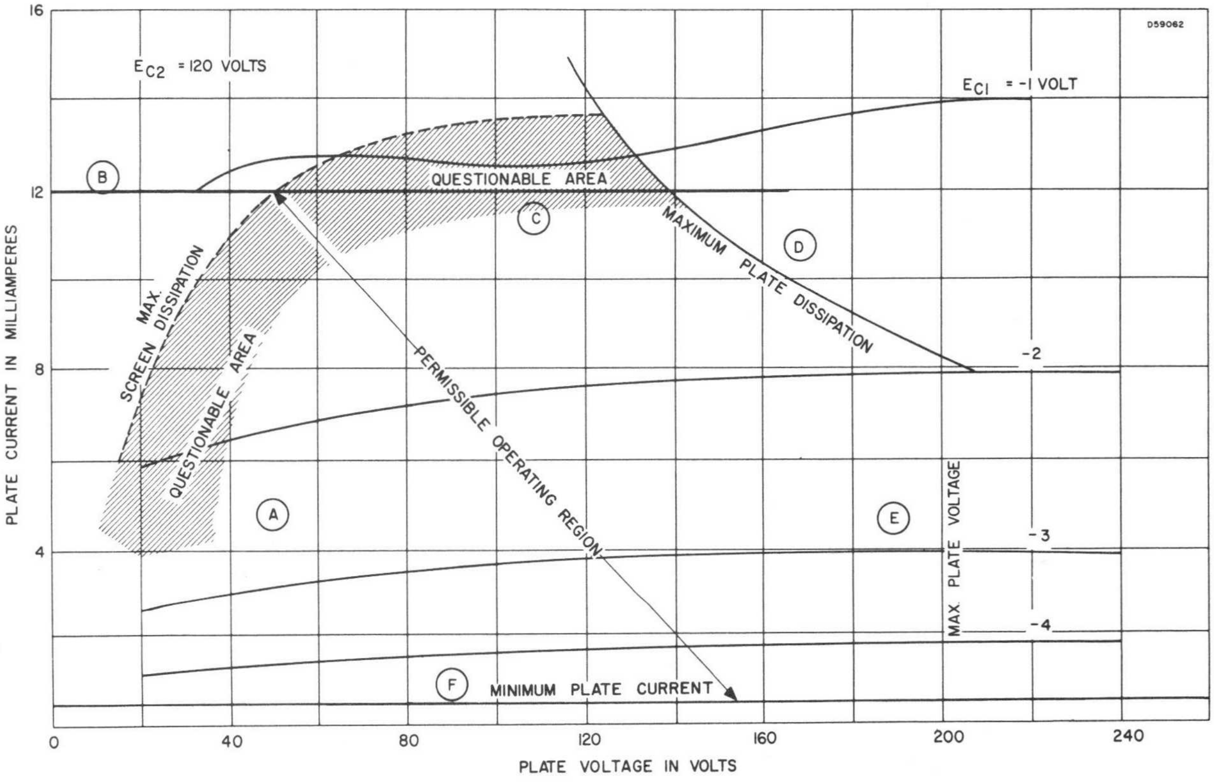


Figure 9—Typical pentode plate family showing boundary conditions for reliable operation.

There are a few circuits where tubes can be operated successfully in the contact potential region. In cases where grid leak bias is used, the circuit performance becomes a function of amplification factor rather than transconductance or plate current, and any instability in these properties will have only secondary effects. *Refer to the section entitled Contact Potential for additional information on this subject.*

Even though such circuits have specific application, several tube types are specifically designed to operate successfully from low B+ (hybrid auto types) in the contact potential region. However, in the design and manufacture of such types, contact potential is a major tube parameter, and is very carefully controlled.

In large signal applications, the tube is driven into the contact potential region from a more negative DC bias. The circuit designer should employ only those tubes designed and controlled for this type of service. For these particular tube types, the effects of contact potential are controlled by means of zero bias plate current specifications.

Beyond the aforementioned special cases, the circuit designers who resort to extremely low bias in hopes of attaining a higher measure of performance will probably find that performance is unstable with line voltage variations and life. Wide performance variations from tube to tube will also be found.

High current tube types frequently have a maximum current rating; either for plate current or cathode current, or both. When determining permissible operating areas, such a boundary condition should be entered on the plate family as shown in Figure 9, area B. If the tube is rated in terms of cathode current, the normal split of current between plate and screen for the type should be determined, from which a maximum plate current rating can be derived. The operation of a tube beyond its maximum cathode current capability generally causes a rapid deterioration of the cathode, and hence, short life.

In large signal applications, the ratio of peak to average currents will vary for the type of service involved. A good rule of thumb to determine whether or not such a design is reliable, is to determine the average current over one complete cycle. If this is within the maximum rated cathode current, in all probability the application will be satisfactory. It should be noted that some tube types which are specifically designed for large signal applications frequently have a maximum peak current rating. This rating should be observed in preference to the aforementioned rule of thumb.

Figure 9, Area D, defines the maximum permissible plate dissipation rating. This can be derived by sketching the locus of the values of Eb x Ib which equal the maximum rated value of dissipation for the tube type in question. Operation beyond the maximum dissipation rating can lead to many troubles, including gas, spurious emissions and other phenomena as described in earlier sections.

In pulse applications, the plate dissipation averaged over one complete cycle would be comparable to the maximum rated dissipation for DC conditions.

Maximum rated plate voltage would simply be a vertical line at the maximum value for the type in question. Some of the potential areas of tube trouble caused by excessive plate voltage (Area E) were discussed previously.

Except for plate current cut-off, electron tubes are not normally controlled for plate current at the low levels denoted by area F, Figure 9.

Variations in the operating characteristic in this region are much greater than those encountered at normal operating conditions.

Linear Regions of Operation

A study of the transfer characteristics of most tubes reveals that there are actually two linear regions, as shown in Figure 10. The linear region "A" is the one commonly employed and recommended for conventional operation. However, on the "tail" of the transfer characteristic there is another somewhat linear region, labeled "B", where there is low current drain. Operation in the upper portion of region "B" and particularly near the lower knee of the curve will result in increased vibrational noise output. Thus, it can be seen that this type of "starvation" circuitry would also radically increase the microphonic tendencies of the tube.

Electrical instability is another source of trouble which arises from operation on the "tail" of the transfer characteristic. In Figure 11 are shown the plate resistance curves for three values of heater voltage for a triode. Fixed bias operation is the extreme condition for instability at any operating

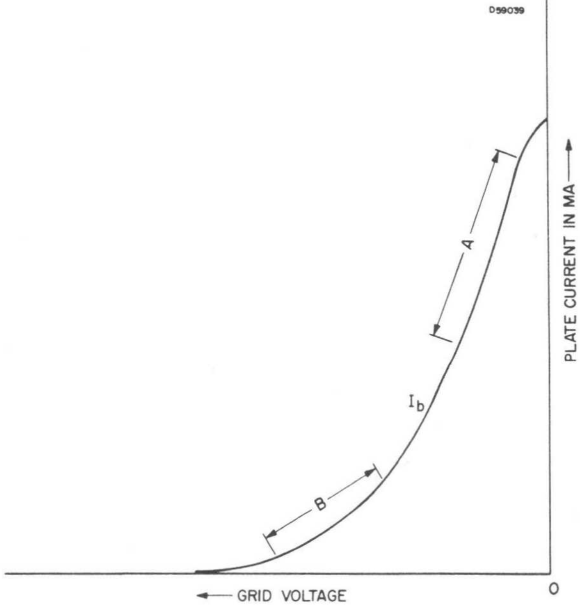


Figure 10—Average transfer characteristic showing linear regions of plate current for (A) normal operation, and (B) the linear region employed in starvation circuits.

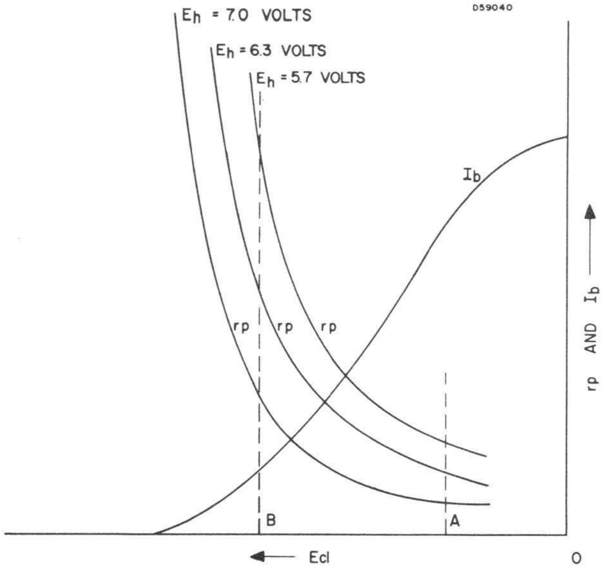


Figure 11—Effects of heater voltage variations upon plate resistance characteristics. A = normal operation, B = biasing level employed with starvation circuitry.

point. Thus, two bias points are shown; one for operation in linear region "B" and the other near normal ratings for linear region "A". Note that with deviations in heater voltage alone, extremely wide variations in plate resistance are encountered. However, near the normal ratings, these variations are much smaller. The reason for the high percentage change in characteristics is that operation occurs beyond the knee of the plate resistance curve, and small changes in operating conditions are reflected by wide changes in tube characteristics. Operation near normal conditions, however, occurs on the flat portion of the curve, where variations have less effect. Although some circuits may be more critical for another tube characteristic, variations in plate resistance are strong indications of large variations in other characteristics as well.

During life, the plate resistance curve will shift toward zero bias. The effects noted for heater voltage variations will also be true for life. Still additional trouble can be experienced during life, since the formation of cathode interface resistance is greatly accelerated when very little or no plate current flows for an appreciable period of time.

A more reliable approach would be to utilize a tube which is designed and controlled during manufacture for plate current operation in the intended region. One obvious exception to this would be applications which require a very wide dynamic range of operating capability. Again there are receiving tubes designed and properly controlled for such applications and such tubes are to be recommended even though other less expensive tubes "apparently" have similar characteristics at the normal rated conditions.

Screen Rating Chart

Many pentodes employ a screen rating chart similar to that shown in Figure 12, included as part of the ratings. It is known that high dissipation and high screen voltage simultaneously tend to greatly accelerate screen emissions, whereas if either one of these operating conditions is reduced, the other can be increased. Accordingly, the screen rating chart shows that up to 50% of maximum rated grid No. 2 voltage, it is quite permissible to operate up to the maximum rated grid dissipation. If the screen were to be rated under a combination of maximum conditions simultaneously, then the 50% of maximum rating would of necessity become the 100% rating. However, to give the designer a wider lattitude of operating conditions, the chart permits operation at higher values of grid No. 2 voltage with a corresponding decrease in screen dissipation. As long as operation is within the boundaries shown on the rating chart, the probability of screen emission occurring is greatly reduced. The rating chart should be regarded as a rating, just as the figures shown as maximum ratings in terms of finite numbers on the data sheets.

Effects of Series Screen Resistance

The circuit designer is always seeking methods of reducing wide variations in circuit performance. The major tube characteristics of concern usually are transconductance and plate current which not only have an initial spread but vary with supply voltage and life. In some respects, the effects of variations are more easily minimized in a pentode or tetrode than in a triode. Some methods, including the effect of cathode bias have previously been reviewed. In addition, a resistance in series with the screen of tetrodes and pentodes tends to maintain the screen current at a selected value and thus offers several advantages: (1) The maximum dissipation

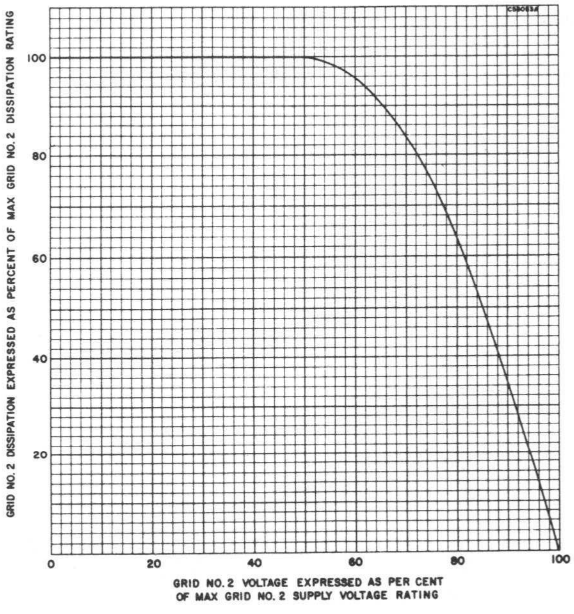


Figure 12—Standard Screen Rating Chart.

of the screen grid can be limited to a safe value. (2) The tube is protected to a degree in the event drive is lost. (3) When there is adequate screen grid resistance in the circuit, higher values of control grid resistance can be used with a greater degree of reliability. (4) In many types, the series screen resistance reduces variations in plate characteristics—although this is not always true.

The mechanism whereby screen circuit resistance limits dissipation is self-evident. If the value of the screen resistance is sufficiently high, when there is a tendency for screen current to rise for any reason, there will be an additional voltage drop through the screen resistor, reducing the screen voltage and hence tending to reduce any increase in dissipation.

Shown in Figure 13 are two mechanical configurations of the control and screen grids commonly used in the construction of electron tubes. Unaligned grids are fairly common in Rf, mixer and If applications. In this type of construction, the screen grid has maximum exposure to the cathode and any small shift or sag of the screen has little or no effect upon exposure. There will always be a finite number of electrons intercepted, having a definite relation to the plate current. In such designs, the introduction of the series screen resistor tends to maintain a constant screen current. It introduces a DC degenerative effect, very similar in nature to that discussed for Cathode Self Biasing. Figure 14 shows how the plate current spread is reduced by the introduction of a series screen resistor. This reduced spread in characteristics is also noted with supply voltage variations and tube aging.

Figure 13 (B) shows the other typical grid construction wherein the control grid and screen grid are aligned to form the plate current into a high intensity beam, thus providing a high plate-to-screen-current ratio. This is typical of beam power tubes used for horizontal and/or vertical deflection, and many audio power output applications. In this case, deviations from perfect alignment cause difficulties. When the screen grid laterals become mechanically distorted or moved with relation to the control grid, they tend to intercept a number of electrons at the expense of plate current without materially changing the cathode current. In such tubes, the screen grid current does not increase in proportion to screen voltage. Since the introduction of a screen grid dropping resistor tends to maintain a constant screen current at the expense of accelerating potential, the screen grid current is simply compressed with no improvement in plate current spreads. Although the spread in plate current could conceivably increase, rigid controls of plate-to-screen-current ratio eliminate tubes in which the grids are not properly aligned.

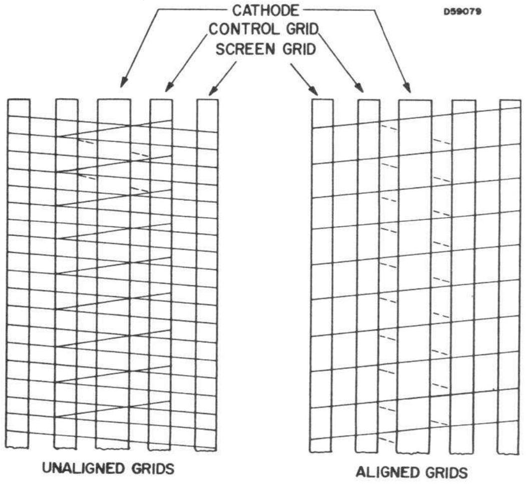


Figure 13—Two common types of grid construction.

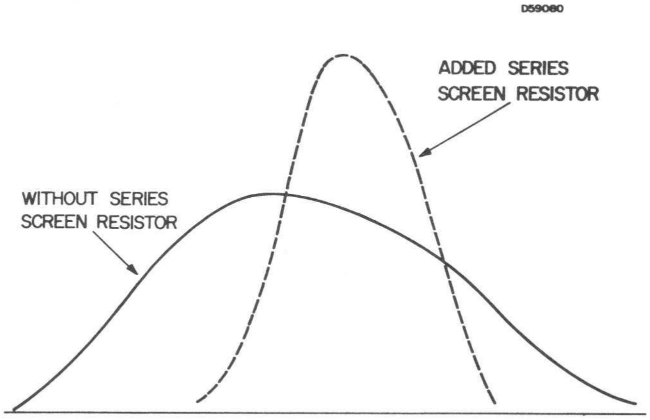


Figure 14—Typical plate current distributions. A = Without series screen resistor. B = Added series screen resistor.

Although the introduction of a screen dropping resistor does not perform uniformly in the aligned grid beam power pentode tube types, it still has considerable merit from the viewpoint of protection in terms of limiting screen grid dissipation, and providing greater stability at relatively high values of control grid resistance.

Plate Knee Characteristics

With any pentode, it is possible to encounter plate characteristics similar to that shown in Figure 15. In the proximity of the "knee" of the pentode zero bias plate characteristic, there can be a sudden dip in the curve known as a "dynatron" kink which is related to plate emission. Design features such as beam suppressor plates or suppressor grids and rigid manufacturing controls are all aimed at reducing or eliminating this characteristic. Another phenomena which can occur in low knee type beam power pentodes is the discontinuity shown in Figure 16, which produces the "snivets" phenomena occasionally associated with horizontal deflection amplifiers.

The dynatron kink or snivet knee characteristics can best be avoided by providing proper plate voltage so that with a given load line the tube will not be driven into this region. With a lower load resistance, less voltage can be used successfully in

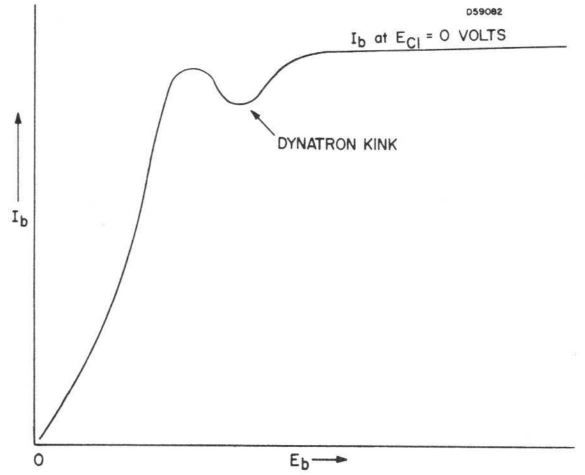


Figure 15—Dynatron Kinks are sudden dips in the plate characteristic curves in the vicinity of the knee.

the B supply. In some cases operation in this region is unavoidable, for example, horizontal deflection tubes. In these cases, avoid using any tube type which is not specified and controlled for this service, since the possibility of a high knee, dynatron kink, or snivet knee becomes substantially greater. *Further information on this subject can be found in the Sylvania Technologist article "A NEW APPROACH TO HORIZONTAL DEFLECTION TUBE TESTING," Vol. 10, No. 3, July 1957.*

The voltage applied to the screen should not exceed the plate voltage, particularly if low values of control grid bias are likely, to preclude wide variations in characteristics including possible negative resistance effects as well as a probability of excessive screen dissipation. Further, where connectors are used and there is a possibility of the plate supply being disconnected, some means should be provided to remove the screen grid voltage at the same time the plate voltage is removed to prevent excessive screen dissipation, severe deterioration of electrical characteristics and probably destruction of the screen.

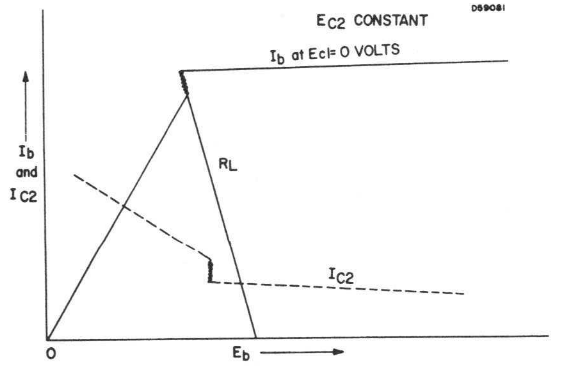


Figure 16—Knee discontinuities of a horizontal deflection amplifier.

TRIODES

Figure 17 shows a typical triode plate family with boundary conditions and questionable areas of tube operation. The shaded area in Region 1 is located near the zero bias line. Tube characteristics in this region are subject to considerable variation primarily due to grid currents resulting from contact potential and gas current. As a result, tube characteristics in this region may vary more widely than indicated by the specification limits. Grid currents may, in addition, cause loading of the input circuit. There are two exceptions to the above discussion. Triodes designed to operate from relatively low B supply potentials, such as the "hybrid" auto types, are controlled in manufacture to operate in the contact potential region. In this case such applications are permissible, but it should be noted that a conventional tube type designed for higher supply potentials should not be utilized in the contact potential region. RC coupled amplifiers employing high resistance plate loads are an exception to this general rule. Even though a similarity of electrical characteristics may be noted, the manufacturing controls for such operation will, in all probability be non-existent.

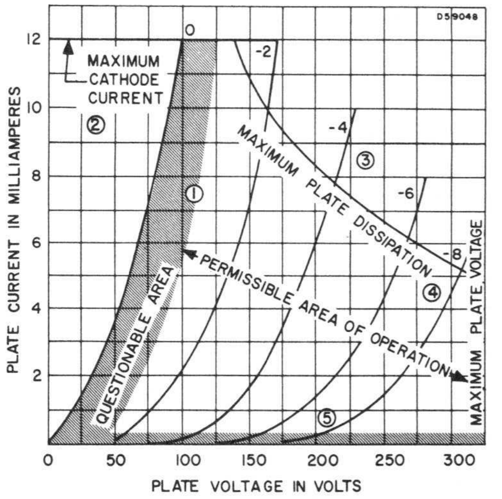


Figure 17—Typical triode plate family showing boundary conditions and questionable areas of operation.

Reference 2 of Figure 17 is the maximum rated cathode current which is usually carried as one of the basic tube ratings in those cases where the particular type in question is liable to be used at high cathode current levels. For pulse applications, the average current over one complete cycle should be below the rated average plate current, in event that a peak current is not specified for the type.

Reference 3 of Figure 17 denotes the maximum rated dissipation for the tube type. If this rating is exceeded, short life, excessive gas, spurious emission and other adverse phenomena may develop. For pulse applications, if the average plate dissipation over one complete cycle is maintained within the maximum rated value, the application will probably be reliable. Reference 4 of Figure 17 denotes the maximum rated plate voltage for the particular type in question.

Region 5 denotes an area of low current. Operation in this region can be very uncertain particularly with fixed bias, since currents may vary widely from tube to tube or between sections of dual types. Except for RC coupled amplifiers, it would be more desirable to select a tube type which is designed and controlled in manufacture to operate at low plate current levels. In some cases, a wide dynamic range of currents may be required; but if such application is at all popular, there should in all probability be tubes designed and controlled in manufacture for such applications.

RECTIFIERS

The maximum permissible operating conditions of rectifier tube types are very much interrelated, and are generally shown by three or more rating charts. Operation of a rectifier within its ratings implies that it is being used within the permissible areas of each and all of the rating charts. Operation outside of the boundaries of any rating chart means absence of any assurance of reliability. Consideration of all ratings and rating charts is therefore important in the choice of an operating point.

Discussion of Rating Charts

The chart shown in Figure 18 defines the permissible operating area for the Type 5U4GB for both choke and capacitor input circuits by the maximum rated DC output (per plate in double diodes) and the RMS plate voltage. Point E represents operation with capacitor input filter and is located at an RMS plate voltage equal to the rated value per plate. The majority of applications operate in this region and normally all initial tube tests and life tests are applied at this point. At this point, the tube is operating close to the maximum safe plate current.

Point C represents operation with choke input filter and is established at the same output current as the capacitor rated Point E; and is based on the use of a large filter, 10 Henries or larger. Under this circuit condition, the surge and peak currents are of minor importance. Plate dissipation is lower than at Point E; therefore, the supply voltage rating can be increased to a point limited by electrolysis or voltage breakdown.

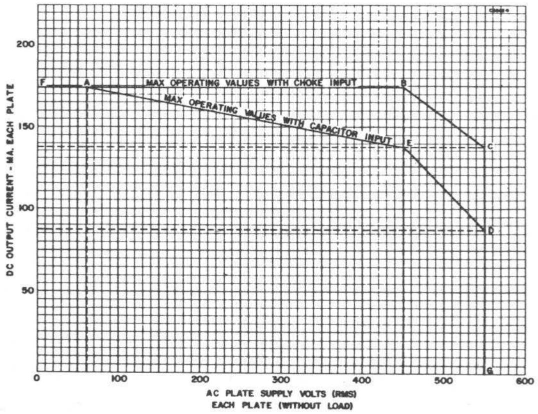


Figure 18—Type 5U4GB Rating Chart I.

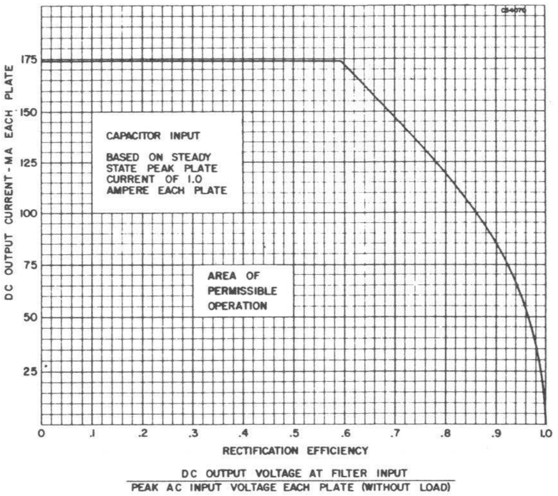


Figure 19—Type 5U4GB Rating Chart II.

Point B is set up at the same input voltage as Point E except that a choke input circuit with a "minimum" choke is used. The minimum choke condition occurs when the ripple of the output current is of the same amplitude as the DC output or when the output consists of a series of half sine waves. Point B is chosen to have the same dissipation as Point E.

Point D is set up at the same voltage and dissipation conditions as Point C and therefore has the same electrolysis and voltage and breakdown safety factors. The DC current value for Point D is obtained by equating the dissipation at this point to the dissipation at Point C and finding the corresponding load current.

The supply voltage at point A is determined by the tube drop of the tube type being charted. It is the lowest voltage at which the designated plate current can be drawn through the tube. At this point, the output voltage is zero, since the total input voltage is lost across the tube. The current at point A is chosen to be of the same value as that of point B. It is limited because of tube dissipation and cathode or filament DC current capabilities.

Rating Chart 2 is a plot of DC load current per plate vs. rectification efficiency for the Type 5U4GB for capacitor input filter operation, and as such, it defines an area of permissible operation. Rectification efficiency is defined as:

$$\frac{\text{DC Output Voltage}}{\sqrt{2}\,(\text{RMS supply Voltage per plate})}$$

Rating chart 3 shows the permissible operating

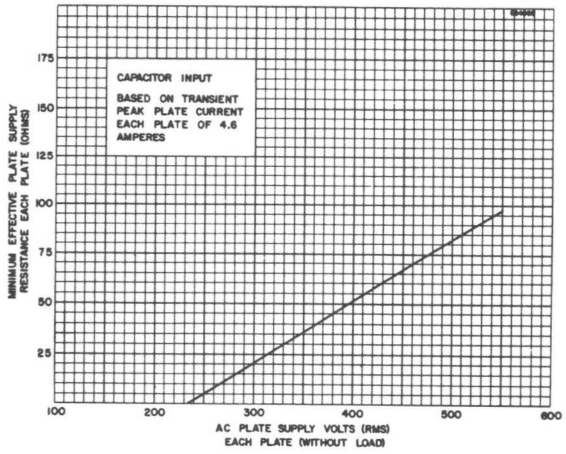


Figure 20—Type 5U4GB Rating Chart III.

area in terms of the minimum allowable resistance effectively in series with each plate of the Type 5U4GB for any allowable AC plate voltage. This boundary condition is derived from the maximum instantaneous surge current capability of the tube. Effective series plate supply resistance per plate, Rs, may be calculated from the circuit requirements as follows:

$$R_s = N^2 R_{pri} + R_{sec} + R_a$$

Where: N = Voltage step up ratio of plate transformer.

For Half Wave: $(N = \frac{N_{sec}}{N_{pri}})$

For Full Wave: $(N = \frac{N_{sec}}{2N_{pri}})$

R_{pri} = DC resistance of transformer primary.

R_{sec} = Average DC resistance of transformer secondary per section.

R_a = Added series resistance.

In application, the circuit designer should insure that the transformer has sufficient output voltage to accommodate the highest tube drops to be encountered with the particular tube type in question, and further, should allow for an increase in tube drop with life. Otherwise, only those tubes on the low side for tube drop will be adequate. This will incure a high percentage of line rejections, but probably more important, a very high percentage of inwarranty returns as the tube drop increases with life. Further, low tube drop can lead to excessive peak currents, DC currents, and surge currents, all of which can lead to rapid deterioration of the tube in service.

Orientation

The proper mounting position of directly heated rectifiers (filamentary type cathodes) must be considered to preclude the possibility of failures resulting from shorts due to "filament sag." The correct orientation is supplied by Tube Manufacturers as part of the mechanical description for each individual tube type. For example, horizontal operation of the Type 5U4GB is permitted provided pins No. 1 and 4 are in a vertical plane. When mounted in this manner, the tube plate is positioned such that a slight "sag" in the filament would occur in the same plane as the major dimension of the plate. Failure to take advantage of this precautionary measure may result in an extremely high percentage of inwarranty returns.

DIODES

In general, as the operating conditions of diodes approach the maximum ratings, the reliability of the design will be adversely affected since the ratings define limiting conditions beyond which there is an absence of reliable operating assurance. Figure 21 shows boundaries of permissible operation at questionable areas of operation for small diodes in rectifier service. Permissible steady state peak plate current is defined by boundary No. 1, while maximum DC output current is defined by boundary No. 2. Area No. 3 is a questionable one from the standpoint of uniformity and stability of plate current in low level signal rectifier applications. The manufacturers normally control idling current at the rated heater voltage condition, but there is little assurance that the same values will be maintained at other heater voltages. The idling current which flows in area 3 is very much related to initial electron velocity and the phenomena designated as contact potential in other tube types. *Refer to the section entitled Contact Potential for further discussion of this subject.* Circuits which require the tube to operate into low impedance loads in the idling current region will be extremely unreliable in that there will be variations from tube to tube: initially; with heater voltage changes; and with life.

Normal application of diodes in signal rectifier service including modulators, demodulators,

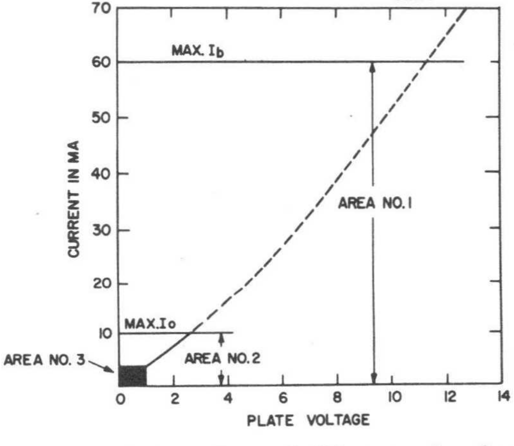


Figure 21—Boundaries of permissible operation for small diodes in rectifier service.

limiters, clippers, clampers, etc., could very easily cause operation in the questionable idling current region for very small signal applications. In such cases, a higher order of reliability can be achieved by insuring more signal gain prior to the signal rectification process.

Figure 22 is a typical simple detector circuit frequently found in many entertainment and industrial devices. It is readily apparent that a fairly high value of cathode resistance is located in the circuit between cathode and ground. Any heater-cathode leakage will form a voltage divider network with the cathode load impedance to introduce hum at the frequency at which the heater is operated. In detector service, signal levels can be relatively low with the result that the superimposed hum can become quite troublesome. In all probability, very little cathode current will be drawn in such circuits, due to the high load impedance. Therefore the heater voltage can be lowered slightly to reduce hum generated in detector circuits. Such a technique is not recommended, however, in cases where low load impedances are used and a high peak value of plate current may be required. *Refer to the section entitled Heater-Cathode Leakage for further discussion of this subject.*

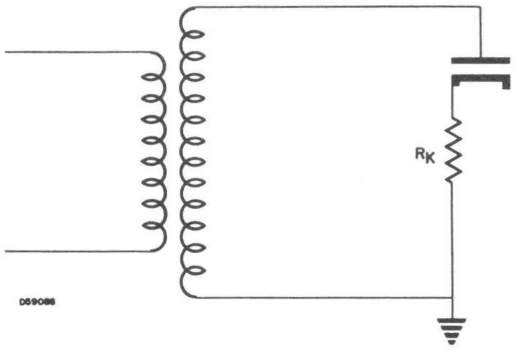


Figure 22—Typical basic detector circuit.

MULTI-SECTION TUBE TYPES

Multi-section tube types combine two tube structures within one envelope, such as dual triodes, triode-pentodes, dual diodes, diode pentodes, etc. In general, the considerations which apply to the individual sections as discussed previously also apply to combined forms. There are, however, other considerations worthy of note.

In the case of ostensibly identical sections in multi-sectioned tubes, particular attention should be paid to any application notes contained on the release data or the Tube Manufacturer's data sheets. In cases where the tube type is designed for a specific application, there may be special manufacturing controls on one section which do not apply to the other. A good example is the dual triode used in cascode service, such as the Type 6BQ7A. For this service, even though both sections have the same basic electrical characteristics, one will be specified as the driver and the other section as the grounded-grid amplifier. For the sake of standardization and the resulting minimum cost of this type, it is desirable not to control each section separately for both basic functions. Accordingly, section No. 1 is controlled in manufacture to have the proper characteristics for a driver stage; and, section No. 2 is properly controlled to give optimum performance as the grounded-grid amplifier stage. The equipment manufacturer who uses the opposite arrangement will find a much wider variation in performance in terms of gain, noise figure, and AGC characteristics.

In the early days of multi-section tube types, there were generally accurate "rules of thumb" to define sections 1 and 2. However, in recent years, many basing variations have appeared for numerous reasons. Currently and for the forseeable future, the only sure way to determine which is section No. 1 and which is section No. 2 is to refer in each case to the applicable basing diagram.

Cross coupling can be a problem in multi-section tubes because of the proximity of the two structures within the single envelope. Such coupling can come from interelement leakages between the two sections or capacitive coupling in higher frequency applications. The safest approach is to avoid using large and small signal applications simultaneously in a single tube. Preferably, if one of the sections must be used for a small signal application, then attempts should be made to find a small signal application for the other section. If one of the sections must be used for a large signal application, then another large signal application or one in which small amounts of interaction will not affect performance should be sought for the remaining section. The designer can further insure that this problem will be minimized by choosing a tube type having adequate inter-section shielding. The data sheets should also be checked to insure that inter-section capacities are sufficiently low for the intended application.

When two tube sections are incorporated into one envelope, the combined dissipations must be considered; for some types it is necessary to specify a maximum combined dissipation. In cases where this is done, the circuit designer should insure that the combined dissipations of both sections do not exceed this rating.

DUAL CONTROL PENTODES

The considerations for general application of dual control pentodes are very similar to those previously discussed for conventional pentodes. However, it should be noted that in this case, the No. 3 grid is now a control element. In applications where it is biased to cutoff, there will be no electron flow to the plate. Under this condition, the current normally drawn by the plate will be diverted to the screen. Unless adequate precautions are taken to protect the screen, the dissipation capability of this element may be exceeded by a substantial amount. In this case the screen, No. 1 control grid, and cathode tend to function as a triode. Protective measures include: (1) incorporate a sufficiently low screen supply potential to insure that the tube will not exceed ratings with the No. 2 control grid cut-off; (2) insert sufficient resistance in series with the screen to limit the maximum dissipation to a safe value.

Notes on Specific Applications

Discussions in this section will be confined to those particular applications which are particularly troublesome from the viewpoint of high production line rejections and field failures. This compilation is predicated upon laboratory investigations of such basic problems. For the particular applications cited, when knowledge of important tube parameters has been ascertained, the tube manufacturers have installed production controls to insure consistent performance. This discussion is intended to show what the circuit designer can further do to enhance the reliability of these particular applications.

VIDEO AMPLIFIERS

The video amplifier in television sets is essentially a large signal application. The important tube parameters for video amplifier service are zero bias plate current and a low knee characteristic as shown in Figure 1. Curve A shows high zero bias plate current and a low knee characterisic; Curve B shows high zero bias plate current and a relatively high knee characteristic; and Curve C shows a low knee characteristic but also low zero bias plate current. A hypothetical load line (No. 1) drawn from cut-off through zero bias for Curves A and B shows that, with Output A of curve A being used as a reference, a high knee characteristic will produce less video output (Output B) before the zero bias curve is ecountered. Further, Curve C which has lower zero bias plate current, also gives materially less video output (Output C) before the zero bias plate current is encountered. If a load line (No. 2) is drawn through the knee of curve C, video output is recovered; but, with a higher value of load resistance, band pass characteristics will suffer. The other important parameter for a video tube is cut-off voltage, which determines the sensitivity of the video amplifier stage. Adequate drive must be supplied to the video stage to accommodate variations in transfer characteristics for the particular tube type selected.

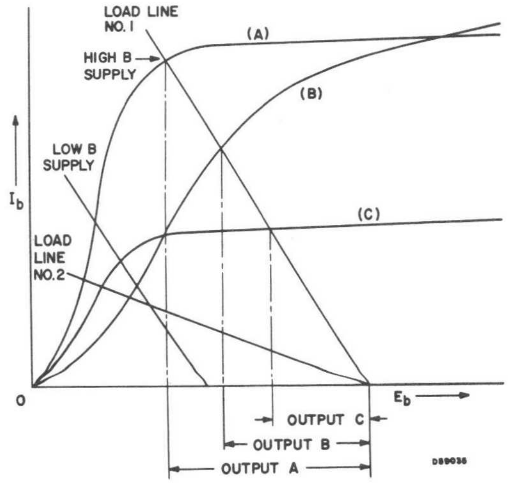


Figure 1—A comparison of video output is obtained by superimposing load lines for various plate supply voltages on the plate characteristic curves.

The foregoing discussion on the importance of the knee characteristic and zero bias plate current is directly related to the range of brightness from highlights to complete black picture presentation. If there is insufficient video output to accommodate full drive of the cathode-ray tube from cutoff to maximum high-light, a washed-out picture will result. For optimum reliability, the circuit designer should select a tube that is designed and controlled for video service. While other tube types of apparently similar characteristics may seem desirable from a cost standpoint, they may not be controlled for knee characteristic or zero bias plate current. As a result, the wide range in these particular tube parameters may seriously affect the rate of production line rejections. Further, if there is inadequate drive, there may be field complaints during the in-warranty period as the driver stage slumps-off with life.

For television receivers in the "luxury" class, circuit designers sometimes choose to use lower values of plate load resistance to obtain a wider video band-pass response. In such cases, a substantially higher zero bias plate current capability must be available if full video output is to be achieved. Again, proper selection of tube type will substantially affect the overall reliability of this stage.

A full range of video output can be obtained by providing adequate B supply. Reference to Figure 1 shows a constant load line for two values of B supply. It is quite evident that in the case of a low B supply there will be substantially less video output available. Thus, in designing video amplifiers, the circuit design should accommodate the full range in knee characteristics within the Tube Manufacturer's control limits.

The screen dissipation capability is frequently the limiting factor in obtaining maximum performance. Exceeding the screen dissipation capability can

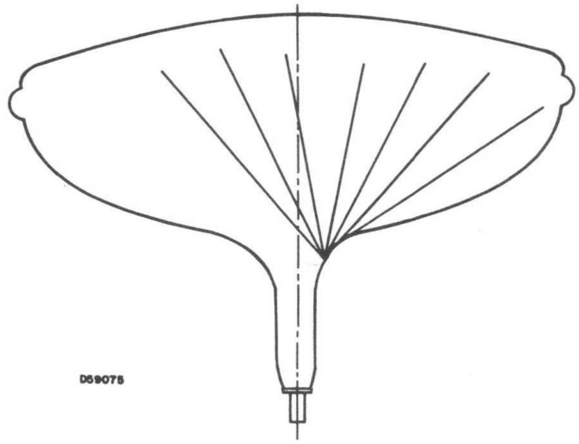


Figure 2—Cross-section of a picture tube in an over-scan condition.

cause excessive gas, grid warping or sagging, or perhaps even burnt laterals, resulting in an accelerated rate of failure. Particular attention should therefore be paid to the screen dissipation of video amplifiers to insure that they stay within the manufacturer's specified limits.

It should be noted that the video amplifier is not necessarily the only cause of a washed-out picture; although this is the usual assumption. Probably, this assumption is the result of the readily apparent relationship between video amplifier performance and picture contrast ratio. Reference to Figure 2 shows a cross section of a picture tube that is being over-scanned. In this case, some of the stray electrons in the beam strike the neck of the tube prior to the point where general neck shadow becomes evident. The electrons tend to spray onto the screen; excite the phosphors and reduce the contrast ratio between maximum brightness and black. Stray electrons which strike the side-walls of picture tubes produce a certain amount of background illumination which again reduces the contrast ratio by lighting-up dark areas of the picture. Figure 3 shows the basic relationship between the percentage scan and the contrast ratio. The actual ratio will tend to change somewhat with the particular bulb configuration, angle of scan, the shape of the faceplate, and the manner in which the cone is blended into the faceplate. However, the basic hyperbolic relationship exists—and any over-scan tends to minimize the contrast ratio.

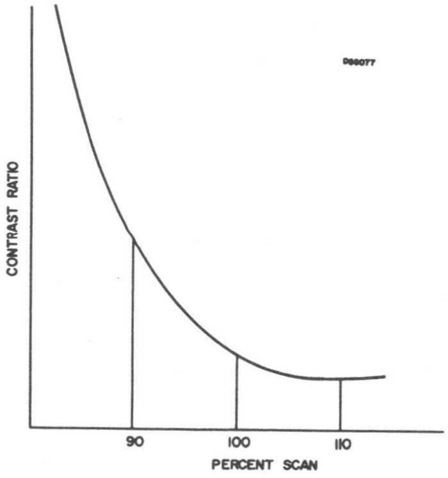


Figure 3—Basic relationship between percent scan and contrast ratio.

Therefore, in addition to a properly designed video amplifier, good deflection yoke design is mandatory for satisfactory contrast. Normally, a good design is defined as one which insures that no shadows occur on the tube face due to the beam striking the neck. However, a reasonable safety factor is necessary if the picture is to be moved with the centering controls especially during adjustment on the receiver production line. A designer should insure that the yoke seats as far forward as possible and has sufficient safety factor for ease of factory adjustment without fringing upon neck shadow. Such a yoke will not only provide ease in factory adjustment; but, will give a more satisfactory contrast ratio.

HORIZONTAL DEFLECTION AMPLIFIERS

In accordance with Sylvania's TV Reliability Studies, the horizontal deflection amplifier represents one of the most troublesome circuits in television receivers. There are several possibilities open for the circuit designer to improve the reliability of this stage.

The horizontal deflection amplifier is another large signal application of which important tube parameters are: zero bias plate current; plate-to-screen-current ratio at zero bias; the knee characteristic; and high voltage cut-off. The relationship between zero bias plate current and circuit performance is quite evident in that the peak current flowing through the deflection coils determines how much scan is available to the picture tube. The design should accommodate the full range of zero bias plate currents initially encountered and provide a sufficient safety factor to allow for line voltage variations and some slump-off in zero bias plate current to preclude problems within the warranty period.

High voltage cut-off determines the amount of drive required to operate the horizontal amplifier from cut-off—(which occurs when high voltage pulses exist on the plate)—up to the zero bias plate current region. The circuit designer should observe the production spread in high voltage cut-off and insure adequate drive to accommodate it.

Failure to anticipate some slump-off in the driver stage during life and with variations in line voltage will not only produce short scan initially, but will result in increased plate and screen dissipation. Since the screen will be the limiting factor in avail-

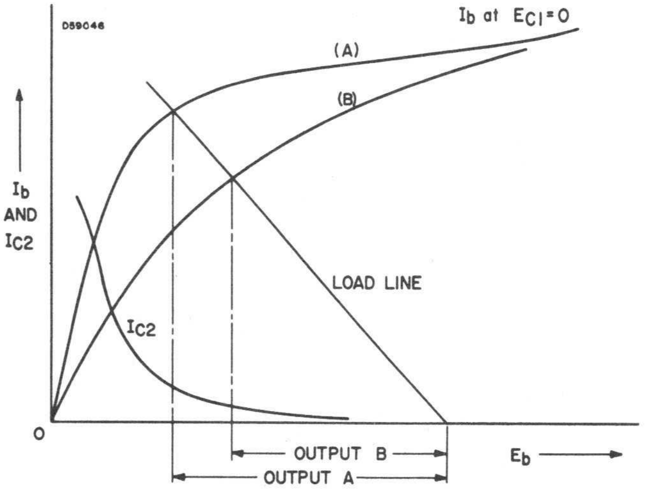


Figure 4—Knee characteristics of horizontal deflection amplifier tubes.

able output, a tube type should be selected which has a high plate-to-screen-current ratio.

The knee characteristic is important in that it determines the maximum output obtainable from the particular tube type. Figure 4, Curve A illustrates a low knee voltage characteristic and Curve B, a high knee voltage characteristic. It is evident that more output will be obtained from the tube with the lower knee voltage.

Although tube designs are all aimed at obtaining a characteristic similar to Figure 5, Curve B, some tubes occasionally have a knee discontinuity typified by Curve C. Curve A shows the normal rounded characteristic; and Curve B represents the ideal or sharpest knee characteristic normally available. The discontinuity depicted by Curve C causes a phenomenon commonly called "snivets." Oscillation occurs when the grid is driven to the zero bias condition and passes through the discontinuity. This, in turn, causes a spurious radiation which is picked up by the antenna input and transmitted to the picture tube; appearing there as a dark vertical line near the right side of the screen.

However, there are many things the circuit designer can do to preclude this being a serious problem. Within the horizontal deflection circuit, steps should be taken to prevent the load line from passing through such a discontinuity. Measures include provision of a slightly higher B supply voltage or the use of a slightly higher load. Coupling between the horizontal deflection circuit and the antenna can be minimized by keeping "built-in" antennas as remote as possible from the horizontal amplifier and by adequately shielding the stage.

The screen grid dropping resistor used in the horizontal deflection amplifier is probably one of the most important passive components in determining reliability. As previously mentioned, screen grid dissipation is the limiting factor in determining maximum output. Since the screen is quite commonly operated at its maximum dissipation limit, this limit can be exceeded in the field within warranty period. This is especially true in event of reduced drive or adjustments in width—control to accommodate slump-off in the horizontal deflection amplifier. Further, high line voltage can cause the screen to exceed its dissipation capability. The proper ohmic value of the screen grid dropping resistor is vitally important in providing some means for regulating the maximum screen current.

The amount of energy which must be dissipated by the screen grid dropping resistor offers a "sleeper" problem which is not fully appreciated. When the receiver is first turned on, prior to the time when the damper begins to conduct, there is essentially an open circuit to the plate of the horizontal deflection amplifier. During this period, the screen tends to draw substantially more current then when full operation is achieved. Thus, for a short period of time, the screen resistor will be required to dissipate an excessive amount of energy. To better describe the "sleeper problem" it would be well to examine some of the effects of variations in the ohmic value of this resistor. If it assumes too high a value for one reason or another, there will be insufficient screen voltage on the tube. This will result in short scan and decreased high voltage output. Since the tube will actually be running easier, this condition will not be damaging.

However, should the screen grid dropping resistor decrease in value, the screen voltage will rise. This will necessitate more drive to achieve full horizontal scan, and if such is not available, short scan and decreased high voltage will again result. In this case, the tube may be seriously damaged

Continuous surveillance of the renewal field reveals that changes in the ohmic value of screen resistors are probably the most significant causes for horizontal deflection amplifier failures. It is customary among servicemen to try a new tube

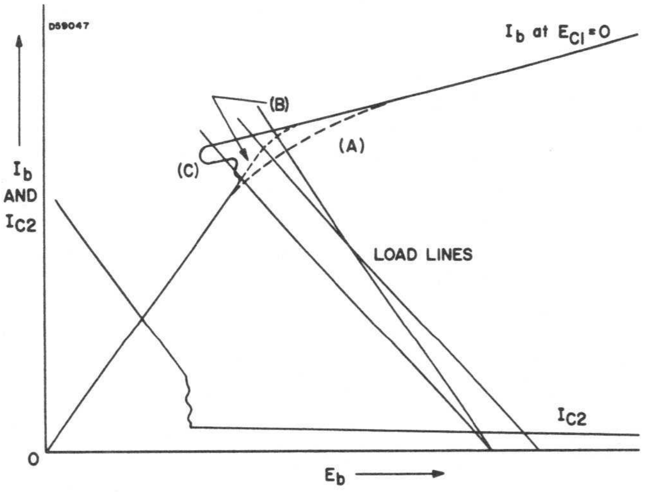


Figure 5—Plate characteristic causing a "snivet" condition.

first and assume that this was the cause of the trouble. However, if the screen grid dropping resistor has changed values, the new tube will be operating in excess of the screen dissipation capability and in short order will also fail. As a result, equipment manufacturers who provide replacement parts will find a very high percentage of in-warranty returns; and further, the particular brand of set can suffer seriously in reputation. The circuit designer can preclude the phenomenon of changing screen circuit resistance by employing a liberal safety factor to the dissipation rating of the resistor used for this application. This is not unreasonable considering its vital importance and the periodic surges of high power which occur every time the receiver is turned on.

VERTICAL DEFLECTION AMPLIFIERS

The vertical deflection amplifier represents another critical application in a television receiver. Because of the relatively low scan frequency of the vertical deflection system and the sensitivity of the human eye, any microphonism or non-linearity in scan wave-shape will be much more readily discernable than would be the case for audio presentations.

The tube types normally utilized for vertical deflection amplifier service appear quite similar to audio power output tubes with respect to average electrical characteristics. However, such similarities do not carry over in application. To insure good linearity, the cut-off characteristics and the shape of the transfer characteristics must be controlled quite carefully. Figure 6 shows several specification control points which are applied by tube manufacturers to the transfer characteristics of typical vertical deflection amplifier tube types. For adequate performance, the circuit design must accommodate the full spread in zero bias plate current. Sufficient safety factor should be allowed for variations in line voltage and slump-off during life. A tube should be utilized which is designed and controlled for vertical deflection service with adequate cut-off controls, to preclude a high incidence of non-linearity complaints.

There is considerable variety in the biasing arrangements used for vertical deflection amplifiers. The biasing technique utilized, in addition to determining the characteristics of the vertical size and linearity controls determines to a great extent the overall reliability of the vertical deflection amplifier. *For further discussion, refer to the section entitled Biasing Considerations.*

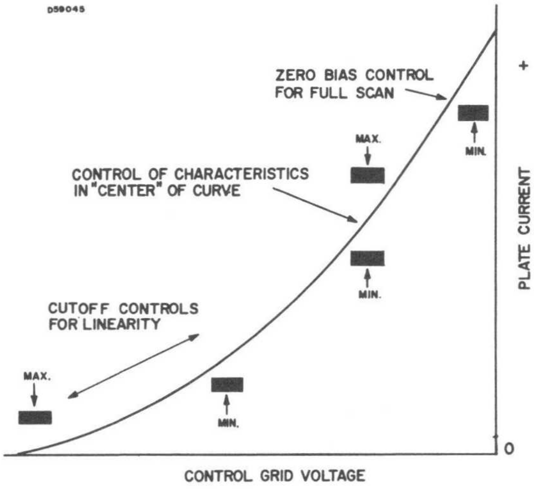


Figure 6—Typical specification controls which are applied to the transfer characteristics of vertical deflection amplifier tubes.

The vertical deflection amplifier is basically a power amplifier, and as such is conducive to a "runaway" condition. Thus, the grid circuit resistance should be as low in value as practical, and certainly within the manufacturers ratings, if consistently good life is to be expected throughout the manufacture of many thousands of receivers. In the case where pentodes are used for vertical deflection amplifiers, an adequate screen grid dropping resistor should be employed. This offers considerable merit from the viewpoint of tube protection in terms of limiting the screen grid dissipation and providing greater tube stability at relatively high values of control grid circuit resistance. In cases where the plate and screen potentials are the same, an adequate minimum cathode circuit resistance is specified

As mentioned previously, microphonism is of principle concern in vertical deflection amplifiers. In those tube types which are specifically designed and controlled for vertical deflection service, microphonism is maintained at the lowest level possible consistent with the manufacture of tubes in high volume production. This generally suffices for most applications, but with the advent of many styling innovations in television receiver cabinets, some rather unique chassis layouts have appeared. In some cases the vertical deflection amplifier is exposed to heavy acoustic feedback which tends to exaggerate microphonic tendencies. In such cases, the designer can do much to insure adequate performance by using a shock mounted socket to assist in the attenuation of feedback through the chassis. Further, if there is acoustic feedback coming directly through the air, some sort of baffling should be placed between the source and the vertical deflection tube.

Triode connected pentodes are occasionally used for vertical deflection amplifier service. In such cases, the designer should take precautions to insure that the maximum screen dissipation rating is not exceeded with this circuit configuration over the full range of tube characteristics. Failure to heed the precaution will ultimately result in problems with screen emission and/or the development of gas due to overheating of the screen.

HORIZONTAL AND/OR VERTICAL OSCILLATORS

The horizontal and vertical oscillator stages are not normally troublemakers. Principle areas of concern are: (A) Microphonism — any microphonic tendencies in the oscillator stage will be applied to the grid of the horizontal output amplifier and cause picture break-up. Selection of a tube type which has good microphonic properties, and appropriate measures for protecting it from acoustic feedback will minimize any microphonic tendencies. (B) Frequency instability — this stems from several sources. Actually, much depends upon the specific circuit. Probably two of the more important problems are excessive grid current; unstable grid current characteristics in the positive region which can cause frequency shift; and heater-cathode leakage, which has a similar affect. Proper selection of tube type for low, controlled values of these two tube detriments and the use of comparatively low grid and cathode circuit resistances should help to minimize any affects from these two tube properties. In some types of horizontal and vertical oscillators, the circuit is dependent upon a certain level of zero bias plate currrent capability of the tube. Also, the cut-off characteristics are somewhat critical in certain circuits. Here, proper selection of tube type will also have much to do with the ultimate success in that application.

Probably the most important concern with horizontal and vertical oscillator stages is whether there is a sufficient reserve in output voltage to accommodate variations in line voltage and slump-off in tube performance during life. It is particularly critical in this stage, since shortcomings in this respect will become readily apparent to the viewer.

DAMPERS

The damper diode is another of the most prominent stages contributing to receiver failure. By nature of the application, this close-spaced tube is subjected to heater-cathode and peak inverse plate voltages of several thousand volts. While tubes are available that are rated to withstand from 4400 to 5600 volts, the voltage gradients produced between elements approach the ideal maximum capabilities of the insulating materials used within the tube. Any deviation in the material from the optimum or the development of cracks in the heater coating, to a degree which might in other tube type be inconsequential, may promote arc-over and subsequent catastrophic failure of the damper. Even the slightest amount of back emission from the plate, under conditions of maximum dissipation and extremely high peak inverse voltage, can produce the same consequences.

As the deflection angles of picture tubes have increased in recent years, stresses upon the damper tube have become progressively higher. Further, closer spaced dampers in smaller envelopes have come into widespread acceptance. While these features complement trends in packaging of equipment, they adversely affect reliability by reducing the dissipation capabilities of the damper and promoting more marginal design with respect to insulator capabilities. Receiver manufacturers who have chosen to utilize the damper conservatively in relation to its ratings, have been rewarded with a low number of in-warranty failures.

The use of the extra pins on damper tubes as tie points for other circuits is an extremely dangerous practice. Some pins which are shown as IC (internal connection) on the basing diagram are reserved by the tube manufacturers for internal connections. In most cases, the data sheets supplied by tube manufacturers carry a note to this effect. These pins may be used to provide some extra cooling for one of the very hot elements inside the tube or to mechanically strengthen the structure. Even in cases where no internal connection is shown, the use of the damper tube's extra pins for tie points is still dangerous. Inevitably, such pins are adjacent to some high potential element and there is a great likelihood of arc-over or a corona condition developing from such an arrangement.

Warm-up time is a serious consideration in all damper diodes. Until such time as the damper becomes operational, the horizontal amplifier is without plate voltage. During this period, the screen functions as the plate of a triode and tends to draw excessive current which can seriously impair tube life. Thus, the damper tube selected should have a warm-up time comparable to that of the horizontal deflection tube being used.

FULL WAVE RECTIFIERS

In order to provide wider latitude in the application of such tube types, the tube ratings are normally specified by means of Rating Charts which provide combinations of voltage and current conditions under which the tubes can be used. These Rating Charts are described in the section entitled General Application of Rectifiers.

In general, the greater the safety factor incorporated in the design to insure that operation is maintained within the maximum ratings the greater will be the reliability of this stage. To insure a minimum of in-warranty failures, the equipment involved should be capable of utilizing the full spread in tube voltage drop; accommodating any increases in tube voltage drop at reduced line voltage and throughout life.

HIGH VOLTAGE RECTIFIERS

The voltage gradients involved in the high voltage rectifier tube are extremely high and capable of applying sufficient electrostatic pull to draw the filament to the plate and thereby produce a short circuit. It is mandatory that the circuit designer insure that the tubes are operated within their maximum rated plate voltages under the worst probable operating conditions as determined by adjustment of horizontal deflection amplifier controls and high line voltage.

The filament voltage of the high voltage rectifier represents a fairly critical operating parameter. Exceeding the maximum rated filament voltage will result in short life due to the development of small amounts of gas which precipitate arc-overs, and "sagging" filaments. If the filament voltage is too low, there will be insufficient emission to provide good rectifier action and high voltage output will be the result.

Problems with this particular stage are compounded by the fact that the filament voltage of the high voltage rectifier is normally derived from the fly-back transformer of the horizontal output stage. Thus, there is a tendency for a wide range in filament voltage as a consequence of line voltage variations and adjustment of the horizontal amplifier stage. If strict attention is not paid to the full range of filament voltage encountered under the worst probable conditions, both high line and low line, a high number of production line difficulties and in-warranty problems will be encountered.

Practices concerning the use of extra pins for tie-points are defined on the Tube Manufacturers' Data Sheets. Internally conected pins are tied to a corona ring to preclude the possibility of a corona or arc-over condition. Extra pins, if so designated may be used as tie-points for circuit components at or near filament potential.

CASCODE RF AMPLIFIERS

Sylvania's TV Reliability Studies have also shown the cascode stages to be one of the foremost serious sources of unreliability. This is brought about by the fact that performance requirements demand the use of small parts which are closely spaced and, in general, operated near their maximum safe capabilities. However, the most serious source of unreliability stems from the circuit configuration as currently conceived and used quite commonly by the industry. Figure 7 shows a typical cascode amplifier circuit in which the two triode sections are series connected. It is evident in this arrangement that the cathode of the grounded-grid section is at a potential approximately equal to the plate voltage of the grounded-cathode section. Normally, this is approximately 120 volts heater-cathode potential with the heater negative with respect to cathode.

The heater-cathode voltage rating of most cascode tubes normally permits their use in circuits similar to that shown in Figure 7. However, it should be noted that as with all other ratings, the nearer the rated maximum is approached, the higher the probability of failure. For maximum reliability, the heater-cathode voltage should be as low as possible.

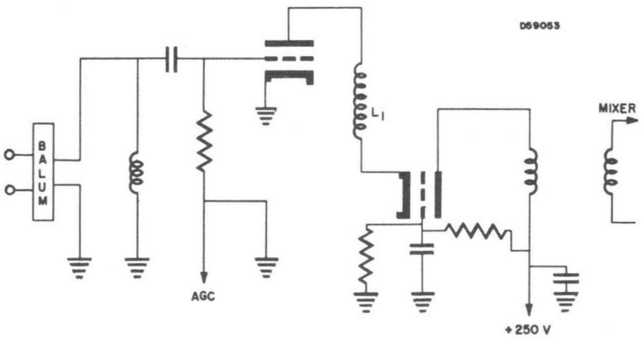


Figure 7—Typical cascode amplifier circuit in which the two triode sections are series connected.

Figure 8 shows a parallel voltage fed version of the cascode amplifier stage. In this circuit, the cathode of the grounded section is at approximately the same potential as the heater with respect to ground. With this arrangement, the two voltage divider resistors in the grid circuit of the output section are exchanged for two RF chokes and one additional coupling capacitor. This configuration eliminates one of the many stresses under which cascode stages operate and offers considerable merit from the viewpoint of enhancing the reliability of television receivers.

The requirement for the input stage of a cascode circuit in terms of the tubes electrical parameters are somewhat different than the requirements for the grounded-grid stage. If the tube manufacturer were to control both sections for both services, it would in all probability result in a higher cost product as well as less uniformity for the desired characteristics for either specific service. Accordingly, data sheets on cascode types indicate which section is to be used for the driver stage and which is to be used for the grounded-grid stage. The circuit designer who fails to observe such data might utilize the tubes in diametric opposition to the manner in which they are controlled and manufactured. This would result in a substantially wider spread in performance and possibly a high number of line rejections and customer complaints when the tubes must be renewed.

IF AMPLIFIERS

Sylvania's TV Reliability Studies showed that the

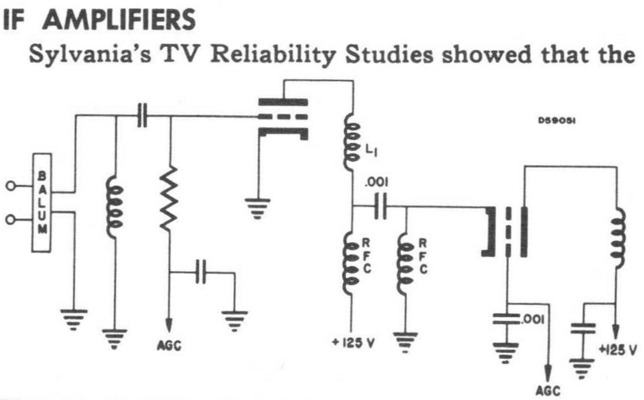


Figure 8—Parallel voltage fed version of the cascode amplifier.

replacement rate for IF-amplifier tube types is relatively low. However, there can be problems on the production line and in the replacement of tubes where sharp-cutoff pentodes are used, since the cut-off characteristics of these tubes can be highly critical. If the tubes in a particular set are not properly matched, clipping can occur under high signal conditions causing snow in the picture, despite the large signal. Although selection of tubes for cut-off will overcome the difficulty, this procedure can be complex and expensive. Further, when replacing tubes in the field it is quite possible to introduce a slight missmatch in the cut-off characteristics even though it did not exist in the receiver as shipped from the manufacturer's plant. The use of remote-cutoff pentodes does much to overcome this problem. Because of the "long-tail" transfer characteristic, it is extremely difficult to completely bias the tube to cut-off. While the gain may be reduced slightly and somewhat higher AGC voltages required, the incorporation of remote-cutoff pentodes improves reliability and eliminates all sorting and selection processes.

Mounting and Environments

Methods of mounting and environments encountered can be major factors in the overall reliability of receiving tubes in electronic equipment. It would be well to review some of the pertinent points which affect tube reliability.

MOUNTING

The socket, commonly serving the dual purpose of connector and anchor, is probably the most critical piece of hardware associated with the receiving tubes. Improperly built sockets (a rarity) or the misuse of sockets will in turn reflect upon the incidence of glass fractures in the tubes.

Figure 1 shows the EIA pin tolerance standards for miniature tube types. E7-1 is the base designation for the small button, 7-Pin, T-5½ types while E9-1 applies to the T6½ types. Pin-circle diameter and pin alignment is determined by the gauges described in Figures 2 and 3.

Figure 4 shows a typical cross section of a pin where it passes through the glass header. It consists of butt-welded nickel outer pin, dumet within the seal area and a nickel-plated steel inner pin. Dumet has the same coefficient of thermal expansion as the glass and bonds with glass very well. A "knot" or bead is deliberately formed at the weld. At sealing, glass is flowed around the bead and nickel outer pin. Upon solidifying, the glass forms a mechanical grip in this area rather than a glass-metal bond such as occurs in the dumet through the major portion of the seal.

If the pin is bent from the tip, it will chip away glass (Area A) up to the knot. However, if it is inserted in a socket that is just slightly off-size in pin-circle diameter, a steady stress is introduced in the glass area between the tube pins. Dependent upon the condition of the glass and the amount of stress introduced, the header can crack over a period of time in service.

To accommodate variations in pin-circle diameter in tubes and tooling variations in the pin clip and the socket body without introducing mechanical stresses in the header, most sockets allow for considerable floating action or "play" in the pin clips.

In application, improper use of sockets can produce many tube problems. Occasionally during

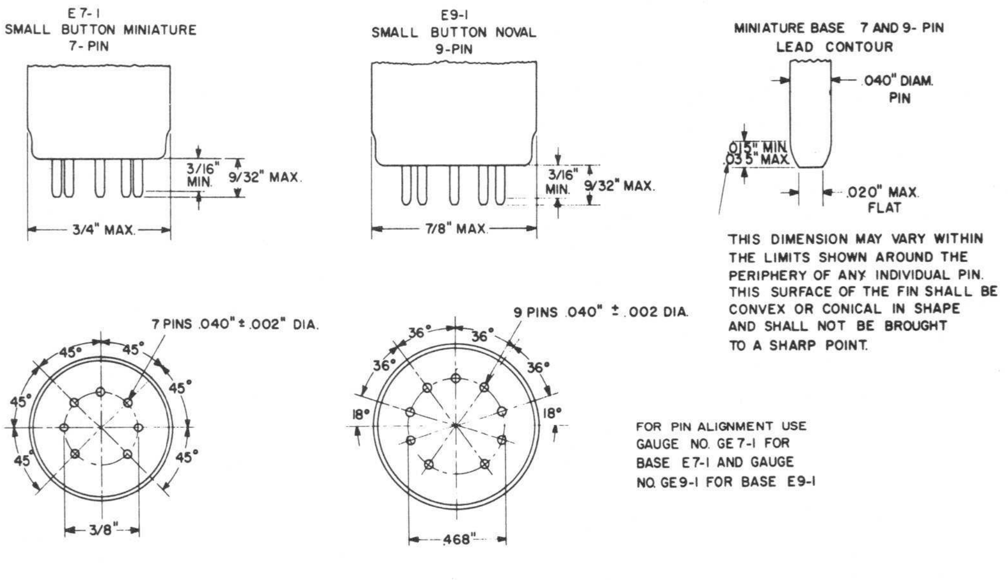
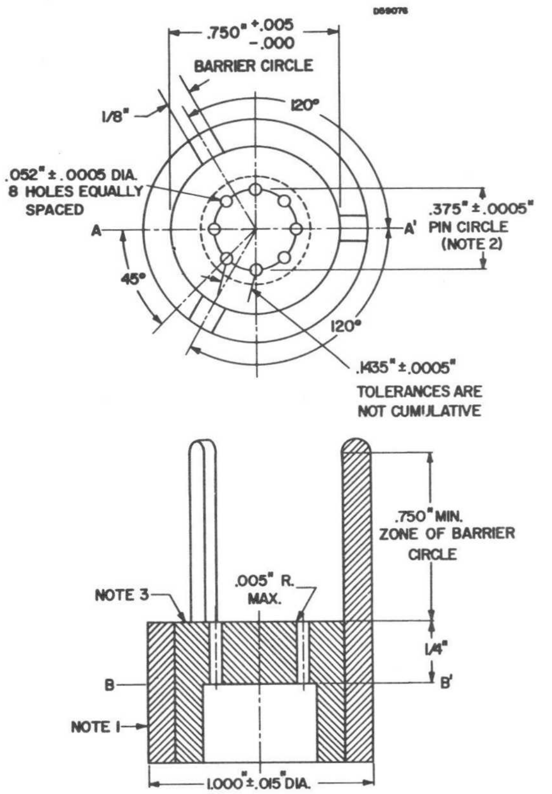


Figure 1—EIA standards for miniature tube type pin tolerances.



Note 1. Dimensions, Mounting Method, Mounting Flange, etc., below Plane B-B′ are optional.

Note 2. Eccentricity of pin circle with respect to barrier circle must not exceed .0025″.

Note 3. Pin circle diameter, pin spacing and pin hold diameter dimensions and tolerances apply to upper surface.

Note 4. The entire length of the pins shall, without undue force, pass into and disengage from the prescribed gauge.

Figure 2—Gauge used to determine pin-circle diameter and pin alignment for miniature button 7-pin tube types.

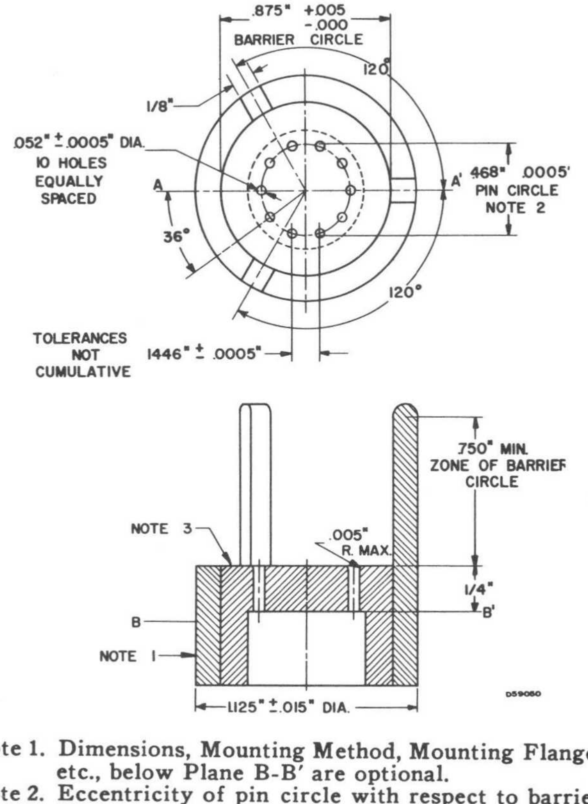
equipment manufacture the solder lugs on the bottom of the socket are twisted or bent in various ways—some to the center post, others away from it toward other circuit elements. This removes all of the "float" and at the same time pulls the pin clips out of the circular pattern. When tubes are subsequently inserted into such sockets, a high line rejection rate due to broken tubes may occur. Figure 4 shows how adjacent pins are placed under pressure to cause this. The actual rate of rejection depends on the extent of malformation of the pin clip circle and the strain pattern in the glass. This can also mean a high failure rate in field service within the warranty period of the equipment. Turning the receiver on and off essentially thermal-cycles the glass in tubes and may result in fractures under the stress of a malformed socket.

There are definite industry standards on sockets with regard to extraction pressures. With all the millions of sockets manufactured there will be variations in the strength of the individual pin clips, plus burrs, etc. It is conceivable that some individual sockets will cause excessive insertion or extraction pressures that can damage tubes—either bending pins at insertion or making removal impossible without "working" the tube around and possibly damaging the glass-metal seal.

The best safety precaution available to minimize socket misapplication is also one of the oldest. It entails the use of plugs with hard pins to duplicate the various standard tube headers. These are inserted in the socket before wiring. Then when the various solder lugs are connected, a faithful pin-circle diameter will be maintained. In those cases where the connections remove any floating action of the pin-clips, they will be properly centered to receive the tube.

The plug has an added desirable effect in that it will help to loosen any extra tight pin clips and flatten or dislodge burrs so that the socket will be better able to receive the tube without damaging it.

Occasionally special socket body materials are employed for certain unique electrical properties. Precaution should be taken to insure that they will not have adverse effects upon header temperatures of the tubes. Tubes operated at temperatures higher than that contemplated at the time the socket was designed can cause the socket body to warp, shrink or even cause localized melting at points of contact with the bulb. This leads to distortion of the tube



Note 1. Dimensions, Mounting Method, Mounting Flange, etc., below Plane B-B′ are optional.

Note 2. Eccentricity of pin circle with respect to barrier circle must not exceed .0025″.

Note 3. Pin circle diameter, pin spacing and pin hold diameter dimensions and tolerances apply to upper surface.

Note 4. Then entire length of the pins shall, without undue force, pass into and disengage from the prescribed gauge.

Figure 3—Gauge used to determine pin-circle diameter and pin alignment for miniature button 9-pin tube types.

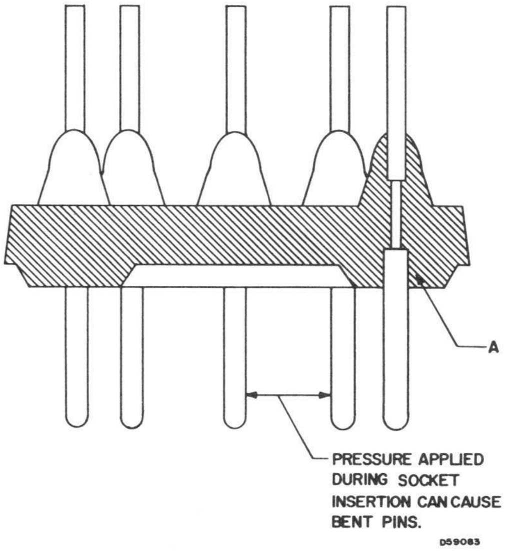


Figure 4—Typical cross-section of a miniature tube pin where it passes through the glass header.

header or results in release of corrosive agents which lead to poor contact between pins and pin clips.

ENVIRONMENTS

Although nowhere nearly as severe as those encountered in military and mobile industrial applications, environments can be a problem. Some of the variables encountered in field service are:

(a) ALTITUDE—Equipment should work in Denver and Death Valley as well as in the design labs.

(b) HUMIDITY—can vary from 0 to 100% depending upon geographic location and weather.

(c) SHIPPING—and storage—Shipping represents the worst mechanical shocks and vibrations the equipments will encounter; and storage represents the possibility of a corrosive or extremely dirty environment.

(d) TEMPERATURE—This is becoming quite a serious problem with the higher package densities and compact styling of much of the latest electronic equipments.

Altitude and humidity considerations are principally related to increased possibility of arc-overs or corona. In most receiving tubes, with the possible exception of subminiatures, maximum voltage ratings are determined by spacings of elements within the envelope; hence, such problems are more related to adequate insulation and lead dress than the tube itself. The principal concern with regard to tube reliability is that arc-overs and/or corona may present an overload to some tubes, thereby damaging cathodes and foreshortening tube life.

High voltage circuit elements tend to "draw" dust electrostatically and precipitate it upon themselves and surroundings. Such dirt, in conjunction with high humidity, can cause leakage paths within circuits and across tube bases and sockets. This is of principal concern when extra socket lugs resulting from no connection tube pins are used injudiciously as tie points.

Shipping produces assorted mechanical shocks and vibrations to the tubes and other components. In tubes, this can cause: (1) the holes in mica spacers to enlarge and/or shale with resultant changes in electrical performance (upsetting factory adjustments); (2) microphonism, because of the looser "fit" of metal parts in mica that results; (3) shorts or flicker shorts if the damage to the tube is severe; (4) degeneration of the tube for hum and heater-cathode leakage if the heater is damaged; and (5) broken bulbs if the tubes become jolted out of the sockets.

The best precaution against shipping damage is good packaging that will absorb jolts and vibration in shipment; with adequate packing inside the cabinet, to insure that the tubes remain in the sockets. Bulk shipments in containers too large for handlers to tumble or toss sometimes helps. With delicate instruments, it may be wise to pack tubes in special containers and install them in the equipment at its destination.

Storage damage is not common but does occur. With the exception of a few switch and potentiometer contacts, the vast majority of mechanical contacts in any electronic equipment are at the tube pins and socket clips (7 or more per tube).

A corrosive atmosphere such as found in some industrial areas can cause a non-conducting skin to form over the tube pins or socket clips. The resulting poor contact results in malfunction of the equipment. This is particularly important in the case of tube types with silver plated pins (for example—UHF oscillators) which corrode very easily. There is little the equipment designer can do about this situation in design; but, he should be able to recognize it and assist in improving storage conditions when it occurs.

The biggest single environmental factor of concern to industrial and entertainment equipment designers today is thermal conditions. Most equipment is used in a relatively narrow and comfortable range of ambient atmospheric temperature. In recent years, however, there has been marked trends which make the thermal environment substantially worse than it would appear at first glance. (a) Equipment has become more complex and displays ever increasing "performance" capability—witness the continuous jumps in deflection angles of TV picture tubes. This results in more dissipation within the package. (b) Package volume has been decreasing steadily to achieve generally smaller units to satisfy customers' styling tastes. (c) The aforementioned assorted styling variations impose limitations upon size of the receiving tubes used. As a result there has been a large scale adoption of miniature tube types, although circuit requirements still dictate the same performance and tube dissipations as if larger tubes were used.

The above trends result in higher package densities with more power to dissipate, thus leading to higher ambient temperatures within the package— as much as 30-50°C rise as compared to the atmospheric temperature. This is close to the maximum temperatures permissible with many conventional components such as capacitors. Further, resistors can run hotter than they should— a particularly serious matter in such cases as the horizontal amplifier screen resistor in TV sets where higher ambient temperatures can cause the resistor to change in value. In some cases, the higher ambient temperatures also affect the physical properties of printed circuit boards.

The miniature tube types must dissipate more heat per unit glass area than larger tubes and must operate in higher ambient temperatures within the equipment. Many of the good cooling techniques utilized in military service are too expensive to apply in entertainment equipment, with the result that bulb temperatures are becoming quite high.

High bulb temperatures can seriously hamper tube reliability since this condition: (1) accelerates the evolution of gas; (2) causes "runaway" if the Grid No. 1 circuit resistance is too high; (3) promotes sublimation, which causes interelement leakage; and (4) increases interface resistance, which causes a slump-off in tube performance.

There are four basic cooling mechanisms commonly used for electronic equipment:

(1) Convection

This is the principal cooling mechanism in entertainment devices. It entails having hot air rise from the equipment and out through vents, being replaced by cooler air drawn in through other vents. It has in general been adequate, to date, and there is much to be said for its simplicity and low cost—no equipment other than vents being required. It has its limitations, too. (a) In many cases, the dictates of styling relegate the vents to areas of the package which are of questionable utility. (b) There must be a certain temperature rise within the package for convection cooling to function. The effectiveness of this technique will be dependent upon the size and location of the vents and heat generated, but in any event there will be limits to the amount of heat that can be disposed of without excessive rise in the ambient temperature of the package. (c) With ever-increasing package densities there are more possibilities of "hot spots." These are pockets of air that are trapped or seriously impeded in flow so that the localized ambient temperature (and component temperatures) can be considerably in excess of the average temperature within the package.

Undoubtedly convection heat transfer will continue as a strong favorite for entertainment devices. However, close attention to layout to preclude "hot spots" is recommended. Incorporation of large and scientifically located vents is most helpful. In this connection, perforated or mesh materials provide a large percentage of venting area and can be formed and painted to blend with package styles. Such design precautions will do much to insure good tube reliability and low in-warranty equipment failure.

(2) Radiation

Radiation, either knowingly or otherwise, is a mechanism of heat transfer from tubes in electronic equipment. The transmission properties of glass are such that a large percentage of energy radiated from internal tube elements can pass through the glass. This energy is intercepted and converted to heat by other bodies in the proximity in varying amounts, depending upon how closely they approach a black body. Shiny surfaces largely reflect such radiation until it is ultimately absorbed by a darker one. This mechanism literally "spreads the wealth" to adjacent components, raising their operating temperatures somewhat, dependent upon the means by which they dispose of heat.

It should be noted that tube shields, if improperly designed, can cause trouble. Shiny interior surfaces reflect radiant heat back into the tube plate causing it to run hotter than if no shield is used. Fortunately, such shields are used predominantly with RF tubes which normally operate at relatively low dissipation levels anyway, and there are heat conduction principals involved (to be discussed later) which *can* minimize any adverse effects.

In some cases, control of the radiated heat from tubes provides an excellent means of cooling the equipment and minimizing the temperature inside the package. A good example is cases where metal cabinets are used. If the inside is blackened it will absorb considerable heat which will be conducted to the external surface, where it will be discharged into the atmosphere. In cases where the tops of such cabinets are painted a light color, chrome plated or anodized aluminum, the cabinet itself will function as a large radiator. An ideal arrangement would be to use perforated anodized aluminum tops with blackened insides, which facilitates convection cooling and can also be used to re-radiate the internal radiant heat into the atmosphere.

(3) Conduction

Conduction cooling is a mechanism whereby a heat pickup device is attached to a tube, thereby providing a good thermal path to a heat sink that is exposed to the surrounding atmosphere. The heat pickup device is normally a tube shield. It should be a contact type shield since air is basically not a good conductor and its presence between tube and shield can seriously hamper heat transfer. Preferably, the inside of the shield should be darkened—although not the bulb itself. There should be a good thermal bond to the chassis. Normally the shield base is riveted to the chassis and this will suffice. If the chassis is exposed to the outside air, it can then function as the radiator or "heat sink." If it does not, or has only very limited exposure, then it in turn should be thermally in contact with some other heat sink—such as metal cabinets in the case of instruments and some entertainment devices.

Conduction cooling is extremely effective in holding tubes very close to the ambient atmospheric temperature if properly applied. However, this method of cooling is rather bulky and increases costs which makes it unattractive in many places such as TV sets or home radios. It is difficult, although not impossible, to apply in the case of printed circuit boards. If adequate means are not provided to discharge the heat into the atmosphere, deleterious results can be produced. For example, if heat is conducted away from tubes to a chassis which is inside a plastic or wood cabinet with no conductive heat sink exposed to the atmosphere, the chassis temperature will rise to a point where the passive circuit components may be impaired.

Conduction cooling can be attractive for electronic instruments where added reliability is worth the added cost, and where metal cabinets can function as heat sinks.

(4) Forced Air

Forced air cooling is quite common and needs no explanation. It is effective although, with increasing packaging densities where layout must be considered lest hot spots or areas where the flow of cool air is impeded should develop. Attention should also be paid to the vent locations to insure that air flows to all parts of the chassis where it is needed. Use of forced air cooling is confined to the more expensive and complex industrial equipment.

TUBE HANDLING

The final Finishing operation performed by the tube manufacturer on receiving tubes entails a last minute automatic check for broken bulbs, gas and shorts or opens. The bulbs are cleaned, pins are straightened, and the tubes are sealed in cartons designed to protect them from damage in transit. Nevertheless, there is always a certain amount of production line shrinkage encountered by the equipment manufacturer and a certain number of in-warranty failures that can be attributed to damaged tubes. Except in isolated cases where a "latent" defect was not detected in the Finishing operation, most of the damaged tubes are the byproduct of improper handling after shipment from the manufacturers plant. Some precautions—most of them self evident—are:

(1) Pouring tubes from the boxes into hoppers on the production lines—this practice may result in broken tips and bent pins, as well as internal damage such as cracked heater coating. It is recommended that the tubes be removed individually from the box. For most types, tubes are shipped in trays with double "eggcrate" dividers. If the upper divider is removed, tubes are readily accessible.

(2) Use of a tool to extract tubes from boxes and insert into sockets. This is always a good idea, but tool design and the technique for its use should be carefully controlled. The tool should not have hard metal surfaces bearing upon the glass bulb, since this can easily cause cracks or scratches (leaks) which may not show up until later. There should be no pressure on the tip, although inevitably there will be pressure on the dome during insertion in the socket. Again, there should be no metal bearing upon the dome, since there would be a limited number of point contacts between the tool and the tube. Pressure concentrated on such limited points may result in possible fracture of the dome. A soft pad would distribute pressure more evenly across the entire dome.

Some tool designs have relatively large handles for operator convenience. If operator technique is not good, the large handle can result in extensive damage. The operator can place a considerable amount of weight on the tool; and a 100 pound operator versus a 5-gram tube isn't a very fair fight. If the pins are not perfectly oriented, with respect to pin clips, they will bend and perhaps crack the glass. If the pressure is great enough, the bulb can crush when the tube "hits bottom".

A good tube handling technique would be preliminary insertion of a plug in the socket to align the pin clips, loosen extra tight pin clips and scrape or flatten burrs in preparation for tube insertion.

Some equipment manufacturers choose to tap tubes as part of their check-out procedures. Here again use of hard surfaced tappers can damage the glass envelopes. Rather then using screwdrivers, pencils, etc., a standard cork tipped mallet about 6″ long is to be recommended. *A good tapper design is shown in the section entitled Inoperatives (Short and Continuity).* This precaution can do much to save damaged tubes as well as eliminate a probable false rejection criteria since the shock wave shapes encountered with such screwdriver tapping are seldom if ever approximated by any normal service environment.

Since the finished chassis just barely fits into the cabinet in some of the latest compact designs, extreme caution is required on the part of the packaging operator. If the chassis is slightly off center in any dimension in such cramped arrangements, the tubes may strike projections with possible damage ranging from cracked bulbs to having them partly dislodged from the sockets only to fall out later in shipment. If the package is in anyway a tight fit, a final assembly jig is recommended to guide the chassis into the proper seating. In addition to precluding damage, such techniques can very well speed up final assembly.

In Conclusion

As stated at the outset of this discussion, the material contained herein is not new or unique. It is principally a reminder to the circuit designer of facts he probably knows already or should know. Nevertheless, the discussion is predicated largely upon actual case histories within the industry in general where lack of full understanding of receiving tubes and their capabilities or forgetfulness or oversights by circuit designers have produced situations where the user did not obtain the most good from the tubes. It is believed that adherence to the principals described herein will aid in good sound tube application with attendant low line reject rate and satisfactory in-warranty failure records for the equipment.

BIBLIOGRAPHY

Boden, E. H.—Progress In TV Receiver Reliability—Paper Presented at the 1957 Radio Fall Meeting

JEDEC J5-C3 Publication—The Design-Maximum Rating System For Electron Tubes

Peterson, A. W.—Application Of The Design-Maximum Rating System—Sylvania EIS, Vol. 5, No. 1, May 1958

Acheson, M. A.—The Unreliable Universal Component—Sylvania EIS, Vol. 3, No. 2, July 1956

Boden, E. H.—A Noise Generator For UHF TV—Sylvania EIS, Vol. 1, No. 1, November 1951

Gausman, T. E.—Input Impedance, Its Components And Its Relation To Other Tube Characteristics—Sylvania EIS, Vol. 5, No. 3, Sept. 1958

Sember, W. J.—Radiated Noise In Home Radios—Sylvania EIS, Vol. 6, No. 3, November 1959

Lankard, G. M.—A New Approach To Horizontal Deflection Tube Testing—Sylvania Technologist, Vol. 10, No. 3, July 1957

WADC Technical Report 55-1 Oct. 1957, Techniques For Application Of Electron Tubes In Military Equipment

ARINC Research Corporation—Improved Techniques For Design-Stage Prediction—Vol. 1, No. 2, April 1959

MIL-E-1 And Inspection Instructions For Electron Tubes

Equipment Sales Offices

CHICAGO

E. M. Sorenson
2001 North Cornell Avenue
Melrose Park, Illinois
EStebrook 9-2525

DALLAS

D. J. Flynn
100 Fordyce Street
Dallas 2, Texas
RIverside 1-4836

DAYTON

W. W. Anderson
333 West First Street
Dayton 2, Ohio
BAldwin 3-6227

FLORIDA

W. J. Hopkins
Suite "C"
1520 Edgewater Drive
P. O. Box 7248, Orlando, Florida
GArden 4-8245

FORT WAYNE

L. R. Fisher
4740 Coldwater Road
Fort Wayne, Indiana
T3-1145

LOS ANGELES

F. E. Gilbert
6505 East Gayhart Street
Los Angeles 54, California
RAymond 3-5371

MASSACHUSETTS

R. F. O'Hare
100 Sylvan Road
Woburn, Massachusetts
WElls 3-4784

NEW YORK

R. A. Starek
1000 Huyler Street
Teterboro, New Jersey
ATlas 8-9484
From N.Y.C. CHickering 4-8820

NEW YORK - UPSTATE

N. C. White
Seneca Falls, New York
LOgan 8-5881

PHILADELPHIA

S. R. Sisak
4700 Parkside Avenue
Philadelphia 31, Pennsylvania
GReenwood 7-5000

SAN FRANCISCO

D. L. Kleinendorst
1811 Adrian Road
Burlingame, California
OXford 7-3500

WASHINGTON

J. D. Conroy
1120 Connecticut, N.W.
Washington, D. C.
FEderal 7-6600

CANADA

M. D. Brooks
6233 Cote De Liesse Road
Montreal 9, Quebec, Canada

SYLVANIA

Subsidiary of GENERAL TELEPHONE & ELECTRONICS