DEFINITIONS

CLASS A AMPLIFIER:

The Class A Amplifier is an amplifier in which the grid bias and the exciting grid voltage are such that plate current flows approximately 360 electrical degrees of the cycle. The ideal Class A Amplifier operates on the linear portion of the plate current vs grid voltage characteristic in such a manner that the wave form of the plate current is an exact reproduction of the exciting grid voltage. The Class A Amplifier is characterized by low efficiency, low output and low percentage of harmonic distortion.

CLASS AB AMPLIFIER:

The Class AB Amplifier is an amplifier in which the grid bias and the exciting grid voltage are such that plate current flows for appreciably more than 180 electrical degrees but less than 360 electrical degrees of the cycle. This class of amplifier, sometimes designated as "Class A' (prime) Amplifier" is characterized by efficiency, output and percentage of harmonic distortion intermediate to those of Class A and Class B Amplifiers.

CLASS B AMPLIFIER:

The Class B Amplifier is an amplifier in which the grid bias and the exciting grid voltage are such that plate current flows approximately 180 electrical degrees of the cycle. The grid bias is approximately equal to the plate current cut-off value, and the power output is proportional to the square of the excitation grid voltage. The Class B Amplifier is characterized by medium efficiency, medium output and medium percentage of harmonic distortion.

CLASS BC AMPLIFIER:

The Class BC Amplifier is an amplifier in which the grid bias and the exciting grid voltage are such that the plate current flows slightly less than 180 electrical degrees of the cycle. The Class BC Amplifier is characterized by an efficiency, an output and a percentage of harmonic distortion intermediate to those of Class B and Class C Amplifiers.

CLASS C AMPLIFIER:

The Class C Amplifier is an amplifier in which the grid·bias voltage and the exciting grid voltage are such that the plate current flows for considerably less than 180 electrical degrees of the cycle. The Class C Amplifier is characterized by high plate-circuit efficiency, high power output and a high percentage of harmonic distortion.

NOTE: The suffix $_1$ added to the letter or letters of the class identification denotes that grid current <u>does not flow</u> during any part of the input cycle. The suffix $_2$ denotes that grid current <u>flows</u> during some part of the cycle.

AMPLIFICATION FACTOR:

The amplification factor μ is the ratio of a small change in plate voltage to a small change in control-grid voltage under the conditions that the plate current remains unchanged and that all other electrode voltages are maintained constant. It is a measure of the effectiveness of the control-grid voltage relative to that of the plate voltage upon the plate current.

PLATE RESISTANCE

The plate resistance r_p is the ratio of a small change in the alternating plate voltage to a small change of the in-phase component of the alternating current produced thereby, all other electrode voltages being maintained constant.

TRANSCONDUCTANCE:

Transconductance g_m from one electrode to another is the ratio of a small change in the magnitude of the alternating currents' in-phase component that flows in the second electrode to a small change in the alternating voltage of the first electrode, all other electrode voltages being maintained constant.

CONVERSION TRANSCONDUCTANCE:

Conversion transconductance s_c is the ratio of a small magnitude of single beat-frequency component $(F_1 + F_2)$ or $(F_1 - F_2)$ of the output electrode current to the magnitude of a small control-electrode voltage of frequency F_1. This is under the conditions that all direct electrode voltages and the magnitude of the electrode alternating voltage F_2 remains constant and that no impedances at the frequencies F_1 or F_2 are present in the output circuit.

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CONVERSION PLATE IMPEDANCE:

Conversion plate impedance is the ratio of a small change in the plate voltage of a frequency converter to a small change in its plate current under the conditions that all direct voltages remain constant and that no impedances to the oscillator frequency or to the measurement frequency are present in its plate circuit.

CONVERSION GAIN:

Conversion gain is the ratio of the magnitude of the intermediate frequency voltage developed at the output circuit of the frequency converter, to the magnitude of the exciting voltage applied to the signal grid.

VOLTAGE GAIN:

The voltage gain of an amplifier stage is the ratio of voltage developed across the plate impedance to the exciting grid voltage.

VOLTAGE AMPLIFIER:

A voltage amplifier is an amplifier whose primary purpose is to obtain a voltage gain without regard to the power delivered into its output circuit.

PHASE INVERTER:

Phase inverter is an amplifier whose purpose is shifting the phase of an incoming signal voltage by 180 degrees to provide a driving voltage in combination with the original signal for a push-pull amplifier.

POWER AMPLIFIER:

Power amplifier is an amplifier whose primary purpose is to deliver power into a load circuit.

PUSH-PULL AMPLIFIER:

A push-pull amplifier consists of two similar amplifiers so arranged, that the output voltage of one is 180° out of phase with the other. Push-pull amplifiers are characterized by increased power output for a given total harmonic distortion as this type of connection cancels the even harmonics.

UNDISTORTED POWER OUTPUT:

The undistorted power output is defined as the power output delivered by a vacuum tube into a resistance load, under the conditions that the total generated harmonic distortion with a sinusoidal excitation voltage shall not exceed an arbitrary criterion of permissable total harmonic distortion of five per cent.

POWER OUTPUT:

The power output is the AC power developed in an external non-inductive resistor of rated value connected in the plate circuit of the amplifier. The maximum power output is limited by an arbitrary criterion of permissible total harmonic distortion.

POWER SENSITIVITY:

Power sensitivity of an output tube is the ratio of the undistorted power output to the square of the exciting grid voltage. The unit of power sensitivity is the mho or μmho.

MODULATION:

Modulation is the process by which some characteristic of a periodic wave is varied with time in accordance with a signal.

DEMODULATION:

The process of recovering a modulating signal (in a detector) from a modulated wave.

INTERMODULATION:

Intermodulation is the production in a non-linear circuit element of frequencies corresponding to the sums and differences of the fundamentals and harmonics of two or more frequencies which are transmitted through that element.

CROSS MODULATION:

Cross modulation is the modulation of the carrier of the desired signal by a modulating voltage of an undesired signal.

AMPLITUDE DISTORTION:

Amplitude distortion results from non-linear amplification in such a manner that the output wave form is not exactly proportional to the amplitude of the input signal, and harmonics of the signal are generated in the amplifier.

FREQUENCY DISTORTION:

Frequency distortion results when the frequency components of the input signal are not amplified with equal magnitude.

PHASE DISTORTION:

Phase distortion results when the phase relation of the frequency components in the output differ from the phase relation of the frequency components in the input.

PLATE
620-1

PEAK FORWARD ANODE VOLTAGE:

Peak forward anode voltage is the maximum instantaneous voltage appearing across the anode and cathode in the direction in which the tube is designed to conduct current.

PEAK INVERSE ANODE VOLTAGE:

Peak inverse anode voltage is the maximum instantaneous voltage appearing across the anode and cathode in the direction opposite to that in which the tube is designed to conduct current.

TUBE VOLTAGE DROP:

In a vacuum tube, the tube voltage drop varies with the current and is the anode voltage produced by a specified plate current. Tube voltage drop in a gas or vapor-filled tube is the anode to cathode voltage during the conducting period.

MAXIMUM PEAK PLATE CURRENT:

Maximum peak plate current is the highest peak current that the plate of a vacuum tube can safely pass in the direction in which the tube is designed to conduct the current.

CATHODE CURRENT:

Cathode current is the total electronic current passing to or from the cathode through the vacuous space.

SYMBOLS OF TUBE CHARACTERISTICS

C_{gk}	Grid to cathode capacitance (input)
C_{pk}	Plate to cathode capacitance (output)
C_{gp}	Grid to plate capacitance
E_b	Average or quiescent value of plate voltage
E_{bb}	Plate supply voltage
E_c	Average or quiescent value of grid voltage
E_{c1}	Average or quiescent value of #1 grid voltage
E_{c2}	Average or quiescent value of #2 grid voltage
E_{cc1}	#1 Grid supply voltage
E_{cc2}	#2 Grid supply voltage
E_f	Filament or heater terminal voltage
E_{ff}	Heater or filament supply voltage
E_{inv}	Peak (or crest) inverse voltage
E_{sig}	Signal voltage (input to control grid)
g_m	Grid-plate transconductance (mutual conductance)
I_b	Average or quiescent value of plate current
I_c	Average or quiescent value of grid current
I_{c1}	Average or quiescent value of #1 grid current
I_{c2}	Average or quiescent value of #2 grid current
I_f	Filament or heater current
I_L	Load current
I_s	Total electron emission (total cathode current)
ma.	Current in milliamperes
megohm	Resistance in millions of ohms
mw.	Milliwatts is power expressed in thousandths of watts
P_i	Power input
P_o	Power output
P_p	Anode dissipation
RMS	Root-Mean-Square
R_L	Load resistance
r_p	Plate resistance
s_c	Conversion tranconductance
t_k	Cathode heating time
μ	Amplification factor
μfd	Capacitance in microfarads
$\mu\mu$fd	Capacitance in micro-microfarads
μmhos	Conductance in micromhos

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 ELECTRON TUBE DIVISION NEWARK, NEW JERSEY, U.S.A.

SYMBOLS OF TUBE ELEMENTS

(AS EMPLOYED IN CONNECTION WITH BASE DIAGRAMS)

USE THIS COLUMN FOR ALL DATA SHEETS DATED PRIOR TO JUNE 15, 1944

G_a	Anode Grid
R	Ray Control Electrode
F	Filament
F_t	Filament Tap
G	Control Grid
H	Heater
H_t	Heater Tap
I_c	Internal Connection
K	Cathode
N_c	No Connection
P	Plate
D_p	Diode Plate
S	Metal Shell
S_i	Internal Shield
X_s	External Shield
T	Target
▮	Beam Plate
F_c	Filament Center (Electrical)
G_m	Modulator Grid
G_o	Oscillator Grid
G_s	Screen Grid
H_c	Heater Center (Electrical)
P_i	Input Plate
P_o	Oscillator Plate
P_r	Remote Cut-Off Plate
P_s	Sharp Cut-Off Plate
S_u	Suppressor Grid

USE THIS COLUMN FOR ALL DATA SHEETS DATED JUNE 15, 1944 AND LATER

A (A_1, A_2, etc.)	Anode
D (D_1, D_2, etc.)	Deflectors, Ray Control Electrode
F	Filament
F_t	Filament Tap
G (G_1, G_2, etc.)[A]	Grid
H	Heater
H_t	Heater Tap
I_c	Internal Connection (Not For External Use)
J	Jumper
K	Cathode
N_c	No Connection
P (P_1, P_2, etc.)	Plate, Diode Plate
S	Shell
S_i	Internal Shield
S_x	External Shield
T	Target
▮	Beam Plate

[A] GRID SUBSCRIPT NUMBERS ARE USED ONLY WHEN THERE IS MORE THAN ONE GRID IN THE TUBE. THEY SIGNIFY THE SEQUENCE FROM THE CATHODE. FOR EXAMPLE, G_3 INDICATES THE 3RD. GRID FROM THE CATHODE. WHEN THERE ARE TWIN ELEMENTS IN A TUBE, SUBSCRIPTS ARE USED ONLY IF THERE IS MORE THAN ONE GRID IN ANY GIVEN UNIT. FOR EXAMPLE, A TRIODE-PENTODE IS LABELLED G_2, G_3 FOR A PENTODE SECTION, WHEREAS THE TRIODE SECTION IS LABELLED G. IF THERE ARE 2 PENTODE SECTIONS, THERE ARE THEN TWO SETS OF SUBSCRIPTS.

ALL BASING DIAGRAMS ARE BOTTOM VIEWS. THEY ARE SYMBOLIC AND DO NOT NECESSARILY REPRESENT INTERNAL TUBE CONSTRUCTION.

PLATE 1453
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RATING SYSTEMS FOR ELECTRON DEVICES

[A]THE CONDITIONS UNDER WHICH AN ELECTRON TUBE MAY BE OPERATED ARE LIMITED BY THE FUNDAMENTAL CAPABILITIES OF THE TUBE ITSELF. PHYSICAL LIMITATIONS EXIST, FOR EXAMPLE, IN THE PERMISSIBLE TEMPERATURES AT WHICH THE VARIOUS ELECTRODES MAY BE OPERATED, IN THE AMOUNT OF CURRENT WHICH CAN BE EMITTED BY THE CATHODE, AND IN THE VOLTAGE GRADIENTS WHICH MAY BE PERMITTED BETWEEN THE VARIOUS TUBE ELEMENTS.

MAXIMUM TUBE RATINGS HAVE BEEN ESTABLISHED TO DEFINE THESE VARIOUS PHYSICAL LIMITATIONS OF THE TUBE IN TERMS OF READILY MEASURABLE QUANTITIES. THE NUMERICAL QUANTITIES PRESENTED AS MAXIMUM RATINGS INDICATE THE LIMITING OPERATING VALUES REQUIRED TO ASSURE SATISFACTORY TUBE LIFE AND PERFORMANCE.

BEFORE THE VALUE OF ANY RATING CAN BECOME MEANINGFUL, THE RATING SYSTEM ON WHICH THE RATING IS BASED MUST BE SPECIFIED. THE SYSTEM MUST DEFINE THE INTERPRETATION REQUIRED OF THE NUMERICAL VALUES AND INDICATE THE PROCEDURE NECESSARY TO DETERMINE WHETHER OR NOT A TUBE IS OPERATING WITHIN ITS RATING.

DEFINITION OF RATING SYSTEMS

DESIGN-CENTER RATING SYSTEM

[B]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 VOLT PLUS OR MINUS 10% IS ACCEPTED USA PRACTICE.

ABSOLUTE-MAXIMUM RATING SYSTEM

[C]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.

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TUNG-SOL

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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-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.

DISCUSSION

THE DESIGN-CENTER SYSTEM ASSIGNS THE ENTIRE RESPONSIBILITY FOR DEVICE USAGE TO THE DEVICE MANUFACTURER; HE MUST ACCEPT FULL RESPONSIBILITY FOR THE EFFECTS OF VARIATIONS IN DEVICE CHARACTERISTICS, AND VARIATIONS IN ANY POSSIBLE CIRCUIT OPERATING CONDITIONS. THE ABSOLUTE-MAXIMUM SYSTEM ASSIGNS THIS ENTIRE RESPONSIBILITY TO THE CIRCUIT DESIGNER. THE DESIGN-MAXIMUM SYSTEM EFFECTS A MORE LOGICAL DIVISION OF THESE BASIC RESPONSIBILITIES. IT ASSIGNS THE EFFECT OF VARIATIONS IN DEVICE CHARACTERISTICS TO THE DEVICE MANUFACTURER AND THE EFFECTS OF VARIATIONS IN THE CIRCUIT OPERATING CONDITIONS TO THE EQUIPMENT MANUFACTURER.

FOR AN EQUIPMENT DESIGNER TO DETERMINE WHETHER HE IS OPERATING WITHIN RATING UNDER ANY OF THE ABOVE SYSTEMS HE MUST ACCOMPLISH THE FOLLOWING:

DESIGN-CENTER SYSTEM

1. SELECT OR OTHERWISE OBTAIN A BOGEY DEVICE.
2. OPERATE EQUIPMENT USING BOGEY DEVICE AT STATED NORMAL SUPPLY VOLTAGE.
3. SELECT ALL COMPONENTS ASSOCIATED WITH DEVICE FOR AVERAGE VALUES, AND SET ALL CONTROLS FOR NORMAL SETTINGS.
4. MEASURE ALL DEVICE CURRENTS, VOLTAGE, DISSIPATIONS, ETC., AND COMPARE WITH RATINGS. IF NO RATING IS EXCEEDED THE DEVICE IS BEING OPERATED WITHIN RATING WHERE THE EQUIPMENT IS NOT SUBJECTED TO SUPPLY VOLTAGE VARIATIONS IN EXCESS OF STANDARD ACCEPTED PRACTICE.

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ABSOLUTE-MAXIMUM SYSTEM

1. ESTABLISH THE WORST PROBABLE OPERATING CONDITIONS FOR THE ITEM (VOLTAGE, CURRENT, DISSIPATION, ETC.,) TO BE RATED. THIS MEANS COMBINING EXTREMES OF SUPPLY VOLTAGE, LIMIT COMPONENTS, EXTREMES OF CONTROL SETTINGS, SIGNAL, AND ENVIRONMENT, AND LIMIT DEVICES IN SUCH A WAY AS TO PRODUCE THE WORST PROBABLE VALUE.
2. UNDER THE ABOVE CONDITIONS MEASURE THE ITEM CONSIDERED AND IF THIS IS WITHIN RATING, THE RATING IS BEING MET.
3. REPEAT THE ABOVE FOR EACH ITEM BEING CONSIDERED.

DESIGN-MAXIMUM SYSTEM

1. ESTABLISH THE WORST PROBABLE OPERATING CONDITIONS FOR THE ITEM TO BE RATED. THIS MEANS COMBINING EXTREMES OF SUPPLY VOLTAGE, LIMIT COMPONENTS, EXTREMES OF CONTROL SETTINGS, SIGNAL, AND ENVIRONMENT SO AS TO PRODUCE THE WORST PROBABLE CONDITIONS.
2. UNDER THE ABOVE CONDITIONS, USING A BOGEY DEVICE MEASURE THE ITEM CONSIDERED AND IF THIS IS WITHIN RATING, THE RATING IS BEING MET.
3. REPEAT THE ABOVE FOR EACH ITEM BEING CONSIDERED.

TO UNDERSTAND THE ABOVE ONE NEED TO UNDERSTAND THE FOLLOWING DEFINITION:

A. 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.

B. WORST PROBABLE CONDITIONS:

THE WORST PROBABLE CONDITION IS DIFFERENTIATED FROM THE WORST POSSIBLE CONDITIONS IN THAT SOME EQUIPMENT CAN BE ADJUSTED TO OPERATE SO AS TO BE UNUSABLE. THE PROBABILITY OF OPERATING EQUIPMENT UNDER SUCH CONDITIONS FOR ANY LENGTHY PERIOD OF TIME IS SMALL AND HENCE SHOULD NOT BE CONSIDERED AS WITHIN THE WORST PROBABLE CONDITION, BUT THE WORST POSSIBLE CONDITION.

FOR EXAMPLE A TELEVISION SET, CAN BE MISADJUSTED SO AS TO PRODUCE NO PICTURE AND AT THIS TIME EXTREMES OF VOLTAGE OR DISSIPATION MAY BE REACHED, WHICH COULD BE CALLED A WORST POSSIBLE CONDITION. THIS CAN BE CONTRASTED TO A CONDITION WHEREIN THE SET IS MISADJUSTED BUT A USABLE PICTURE IS STILL OBTAINED. SUCH A CONDITION WOULD BE CALLED THE WORST PROBABLE CONDITION.

THE ABOVE DEFINITIONS WERE TAKEN FROM A PUBLICATION (J5-C3) OF THE JOINT ELECTRON TUBE ENGINEERING COUNCIL. THIS PUBLICATION, INCLUDES A MORE EXTENSIVE WRITE UP FOR THOSE WISHING TO FURTHER STUDY THE SUBJECT OF MEANING AND APPLICATION OF THE RATING SYSTEM.

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TUNG-SOL

At least two occasions arise which make it desirable to obtain limit tubes for one or more characteristics. One is where one is trying to determine the ability of a circuit to operate with limit tubes; the other is when one wants to determine whether tubes are being operated within absolute-maximum ratings in a circuit.

However limit tubes are difficult to obtain even for one characteristic. And very often such tubes are unstable or have other characteristics out of limits. Therefore we believe an alternate procedure is much to be preferred. This consists of obtaining a number of tubes having known values for the characteristics of importance: preferably the range on these values should be fairly wide. Then a graph can be plotted which will show the correlation between the performance in the circuit in question and the known characteristics. Extrapolation of this graph will then lead to information on the performance of the circuit when limit tubes are installed in it.

An alternate method has three advantages over the limit tube method. First, it is easier to obtain tubes with the required known characteristics. Second, these tubes are generally more stable and may well be used many times for the purpose. Third, since it is not necessary that the tubes have limit characteristics, all characteristics on the tubes can be measured and used to determine the effect of any characteristic on circuit performance.