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intermittent voice operation of power tubes

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The power capability of a transmitting tube is often the subject of long and heated discussions among amateurs (and even among equipment design and tube engineers). In the past, amazing things have been done to power tubes by daring amateurs who seemingly had an inexhaustible supply of replacement tubes at hand.[1] The tube manufacturer looks upon such goings-on with mixed emotions; he's proud his products can take such a beating, but he shudders at the gross overload he knows is taking place, and he has nightmares when he imagines that such tactics are being done by users who may be ignorant of the basic limitations of vacuum tubes. Sometimes that manufacturer may be his own worst enemy. When he speaks of the ruggedness, long life and reliability of his product, he may unintentionally be inviting some eager-beaver to prove the utter conservatism of his remarks.

Up to now, tube ratings have been based upon an absolute system providing "maximum" ratings and "typical" operating conditions for various classes of service, for use below a certain specified frequency. These ratings are designated as *Continuous Commercial Service* (CCS) and *Intermittent Commercial and Amateur Service* (ICAS). The CCS rating may be defined as, "that type of service in which long tube life and reliability of performance under continuous operating conditions are the prime consideration.[2]" The ICAS rating is defined to include the many applications where the "transmitter design factors of minimum size, light weight, and maximum power output are more important than long tube life." The term "intermittent" is used to identify operating conditions in which no operating or "on" period exceeds five minutes and every "on" period is followed by an "off" or standby period of at least the same or greater duration.

These ratings are of cold comfort to today's radio amateur. The first rating applies to high-reliability service (broadcast, military, etc.) wherein off-the-air time is critical or costly; and the second rating, by its very definition, excludes amateur operation in meaningful terms. Neither classification, moreover, applies to ssb or cw operation. Ssb and cw are more properly expressed in terms of peak-to-average power ratio rather than in terms of "on" and "off" periods.

Before new and meaningful ratings are proposed for today's operational modes, it would be prudent to look for a moment at transmitting tube ratings now in use and examine their validity. Contrary to often expressed belief, maximum ratings and typical operating conditions are not arbitrary figures dreamed up by the manufacturer to avoid answering legitimate questions posed by users. On the contrary, they are the result of careful analysis of tube geometry and of prolonged life tests run on typical production tubes with some guaranteed or expected life in mind. Properly understood, the maximum ratings and typical operating conditions can be employed by the tube user to decided advantage.

transmitting tube ratings

Maximum ratings (or absolute maximum ratings) are those limits within which all tubes of a given type should give satisfactory service and long useful life. Why they are necessary at all and how they are determined are discussed in this article.

The *data sheet* (often suspected of being written by the wise to impress the humble) informs the user of the capabilities and limitations of the tube, both of which are based upon the maximum temperature the elements of the tube can safely withstand for an expected life. Heat, then, is the enemy of unlimited tube life, but heat is the unfortunate consequence of making the tube work. Once the maximum tube capability is determined *a compromise of some kind must be made to establish useful life without exceeding the heat limitations, yet allowing some safety factor for "cockpit troubles."*

maximum plate dissipation

Plate dissipation is limited by the maximum safe temperature of the plate and plate-to-glass (or ceramic) seals of the tube. Generally speaking, the plate will withstand several times its maximum rated dissipation level for a short period of time. Other parts of the tube (glass envelopes, mainly) are greatly affected by the excessive heat radiated by the plate. High level of plate temperature may cause the grid, filament or envelope to become overheated. The grid structure may warp, the filament temperature may rise to an excessively high degree, or the tube envelope may be destroyed. These effects, however, are not instantaneous, and short periods of plate overload do not usually overheat the adjoining tube structure to a damaging extent. However, the user has no way of telling to what degree he can safely exceed the plate dissipation limit, or over what period of time this abuse can take place. The obvious conclusion is that the maximum plate dissipation rating should not be exceeded in continuous operation if long tube life is desired.

maximum plate voltage

The maximum plate voltage point is set at a value above which the internal or external insulators of the tube may arc over, or above which the envelope of a glass tube may be damaged from dielectric losses. Finally, a plate voltage ceiling tends to set a limit to the maximum rf charging current flowing in the plate and screen leads, or plate and grid leads in grounded-grid service. The charging current is a function of the rf plate voltage which, in turn, is a function of the dc plate voltage. Setting a limit on the dc voltage sets a limit on charging current without the difficult task of determining the current directly. This effect depends on frequency and is the reason for the upper frequency limit for maximum ratings.

average dc plate current

The fundamental limit on plate current is the available supply of electrons emitted by the filament or cathode of the tube. The maximum plate-current figure is intended to set a value which may be easily realized throughout the expected life of the tube. If operating conditions are chosen which require that the maximum plate-current limitation to be exceeded at the start of tube life, it may become increasingly difficult to maintain the desired value of plate current as the tube ages. There is a definite relationship between the *maximum instantaneous value* of plate and grid current and the *average dc* (meter reading) *plate current* which differs for each class of tube operation. In linear-amplifier service, for example, most transmitting tubes are run class AB_1, AB_2 (loosely termed class B).* In these cases, the peak plate current is about three times the indicated (average)

*Most class-B linear amplifiers are operated in class AB_2. Class-B operation is defined as cutoff operation with an 180° operating angle of plate current flow. Class AB_2 operation signifies less-than-cutoff condition with more than 180° operating angle.

dc plate current. For long life, the cathode emission should be great enough to provide two or three times the required peak value of plate, plus grid, plus screen current.

The user can quickly determine the allowable average dc plate current in linear service for thoriated tungsten filament-type tubes by merely multiplying the filament watts by a factor of about 5.5. This is a rule-of-thumb number that – over the years – has proven to give a conservative balance between allowable plate current and good tube life. For the 3-500Z, therefore, the filament power is 5 (volts) x 14.5 (amperes) = 72.5 watts. Therefore, allowable maximum average dc plate current for linear amplifier service is 72.5 x 5.5 = 400 milliamperes.

In the case of an indirectly heated cathode the rule-of-thumb is different. Emission from an indirectly heated cathode depends upon the emissive material and the active cathode area, assuming cathode temperature is the proper value. The rule-of-thumb in this case for oxide cathodes is that maximum average dc plate current is approximately 125 milliamperes for each square centimeter of cathode area. For example, the 4X150A tetrode has an active cathode area a little over 2.0 square centimeters and the average dc plate current rating is 250 milliamperes.

long pulse service

In pulse service where the "on" time is small compared to the "off" time, many transmitting tubes can be run to much higher peak power limits than are permissible in continuous service. In continuous service, the maximum voltage and current limitations are set with a safety factor in mind to consider average power dissipated on the tube electrodes. In pulse service, when the tube "rests" for an appreciable time, it is possible to set new guidelines on peak electrode dissipation and maximum ratings, provided the *average* electrode dissipation and maximum temperature ratings are not exceeded.

In pulse service (less than 0.1 second) a thoriated tungsten power tube may have an anode instantaneous peak dissipation capability as high as 100 times the average power capability, and the available filament emission may be as high as 80 milliamperes per watt of filament power. In some cases, the filament voltage has been boosted above normal to obtain emission levels as high as 150 milliamperes per watt with the penalty of greatly reduced tube life.

In the case of the oxide-coated cathode, the peak pulse current is not as clearly defined or as easily generalized as in the case of the thoriated filament tube. A figure of 500 milliamperes peak plate current per watt of heater power is often used for very short pulse service (less than 3 microseconds), and other numbers are available giving pulse plate current in terms of active cathode area.

In *long* pulse service (more than 0.1 second), the rise in temperature of the electrodes rather than the average power during the pulse often becomes the basic tube limitation, and twe maximum capability of the power tube is progressively derated as the pulse length increases. For a radiation cooled tube, a pulse length of 2.5 seconds is often considered equivalent to a continuous duty operation. In the case of an oxide-coated cathode, life tests indicate that a peak-to-average dc plate current ratio of 2.0 for long pulse (0.5 second) is not unrealistic. This corresponds to a duty factor of 0.5.

voice and cw operation

A shadow world exists between continuous duty (CCS) operation, and ICAS operation on the one hand and pulse operation. Amateur voice and cw operations seem to fall into this shadow area. Cw operation may be compared to a form of pulse operation as it defines an "on" and "off" duty cycle wherein the two times are approximately equal. This would represent a duty cycle of fifty percent (0.5) and the pulse (cw) waveform would be nearly square.*

*Note quite true; waveshaping is necessary to some extent to reduce key clicks.

Voice operation, on the other hand, is a different and more complex problem. The voice waveform is not a square pulse; it has a large peak-to-average power ratio with irregular waveform. Normal speech, unclipped, uncompressed or otherwise altered, seems to have a peak-to-average ratio of about 14 dB.[3] Various compression and clipping techniques can reduce this ratio to 3 to 5 dB before severe distortion becomes apparent.[4] Thus, heavily clipped or compressed speech waveforms tend to resemble the cw duty cycle as far as the peak-to-average power ratio is concerned.

It is prudent to expect, therefore, that the power capability of a tube can be safely increased for *Intermittent Voice and CW Service* (IVS service) over the CCS rating provided the maximum element temperature of the electrodes is not exceeded and the cathode (or filament) emission is sufficient to satisfy plate and grid current peaks. In addition, the tube in question should not have an intolerable level of intermodulation distortion when operated in linear service under these enhanced conditions.

This type of intermittent operation is done everyday with the popular sweep tubes used in ssb equipment designed for amateur service. Small soft-glass envelope tubes (i. e., the 6LQ6) are run up to 250 or 300 watts PEP input with no apparent harm *provided* the maximum level of plate dissipation is held within reason, even though the average, long-term dissipation rating in tv service is only 30 watts or so. The user is taking advantage of the intermittent nature of amateur voice operation and the high peak-to-average ratio of the human voice to get more watts per dollar of tube investment. Many amateurs have found, to their regret, an overworked sweep tube tends to overheat and shows extremely short life when a voice clipper/compressor unit is used to bring up the average power of the equipment, or if extended cw operation is used. A moment's reflection upon the heating process in the tube will show the reason for this problem. The tube is being pushed so far that any margin of safety has vanished. Unfortunately, no one has yet been able to miniaturize the watt!

Thus, there's a limit beyond which pushing the transmitting tube becomes uneconomical. It may be well to push an inexpensive sweep tube to 300 watts PEP input, since a tuning error, or other maladjustment won't bankrupt the unlucky user. The owner of a more expensive transmitting tube, however, may well have second thoughts before he blasts his pet power tube. Obviously, some middle ground is called for where the peak-to-average power ratio of ssb and cw operation can afford new and conservative tube ratings more in line with today's usage.

intermittent voice service

In single sideband service, the two plate current values of significance are the single-tone plate current and the two-tone plate current. The ratio of single-tone to two-tone plate current may vary from 1.1/1 to 1.57/1, depending upon the class of operation. Two-tone plate current is useful as the magnitude of intermodulation distortion products may be specified as the reduction in decibels of one product from one tone of a two-equal-tone signal. Precedence exists, therefore, for providing typical operating data for linear amplifier service specifying the dc plate current under two-tone conditions of average plate current and plate current at the peak of the modulation envelope. Such data for the 8122 is shown in **table 1**.[2]

Based upon such data, extensive life tests have been run at the Eimac Division of Varian to determine if more meaningful operating conditions could be specified for either ssb or cw operating modes. As far as amateur operation is concerned, the limiting mode is cw, where the duty factor is about 0.5. The duty factor for single sideband transmissions with unprocessed speech runs about 0.05 for a 13-dB peak-to-average signal and could rise as high as 0.5 for high levels of speech compression or clipping. A duty factor of 0.5 (peak-to-average ratio of 2.0) for Intermittent Voice Service rating would therefore cover both table 2. Preliminary operating data for 8873 family of ceramic/metal, zero-bias power triodes.

Cathode: Oxide coated, unipotential	
Warm-up time	60 sec
Heater voltage	6.3 V
Heater current	3.2 A
Direct interelectrode capacitances, grounded-grid connection	
Input	19.5 pF
Output	7.00 pF
Feedback	0.04 pF
Maximum frequency ratings	450 MHz
Operating temperature, maximum, ceramic seals and anode core	250° C
Base	11-pin Special (JEDEC E11-81)
Radio-frequency linear amplifier, cathode driven, class AB_2	
Absolute maximum ratings, to 450 MHz	
Plate voltage	2200 Vdc
Plate current, continuous	250 mA
Plate dissipation	see note 1
Grid dissipation	5 W
Typical operation, Intermittent Voice Service[2] frequencies to 30 MHz	
Peak envelope or modulation crest conditions	
Peak voltage	2000 Vdc
Cathode voltage[3]	8.2 Vdc
Zero-signal plate current	22 mA
Single-tone IVS plate current	500 mA
Two-tone plate current (approximate)	312 mA
Average plate current	250 mA
Single-tone grid current	30 mA
Two-tone grid current	12 mA
Peak rf grid-cathode voltage	67 V
Peak driving power	26 W
Peak power input	1000 W
Single-tone IVS useful output power	587 W
Resonant load impedance	2140 ohms
Intermodulation distortion products:	
3rd Order	-35 dB
5th Order	-36 dB

notes. 1. 8873 is conduction cooled, and plate dissipation depends upon heat-sink cooling. 8874 plate dissipation is 400 watts, and tube has an axial-flow, forced-air cooled anode. 8875 plate dissipation is 300 watts, and tube has a transverse-flow, forced-air cooled anode.
2. Intermittent voice and cw ratings are based upon the maximum voltage and current ratings given for a signal having a peak-to-average power ratio of 2.0 or more. During short periods of adjustment (less than 30 seconds), the average plate current may be as high as the IVS value.
3. Cathode bias is obtained from a zener diode.

the cw and ssb speech-with-processing situations.

The derivation of a different rating from an existing rating may only take place after extensive life tests have been completed to make sure that tube life is not being shortened and that maximum temperature and dissipation limits are not

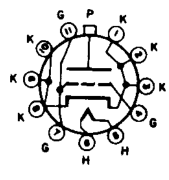

fig. 2. Tube base diagram for the 8873, 8874, 8875 family of zero-bias triodes. Multiple cathode leads keep cathode inductance to a minimum.

being exceeded. Any tube may be limited by grid or screen dissipation level and some may be limited by a plate voltage ceiling, or by available cathode emission. *Each tube type is an individual case, and to jump to conclusions or to interpret data from one type to another is risky and unfounded to say the least.* In all cases the total average current load on the oxide cathode will remain about the same for the new rating as for the average situation.

The *Intermittent Voice and CW (IVS)* rating may be defined as:

> That maximum voltage and current rating given for a signal having a maximum peak to average power ratio of 2.0 or more. During short periods of adjustment (less than 30 seconds), the average plate current may be as high as the IVS value.

In all cases, the IVS rating and "short period of adjustment" are limited by the maximum allowable temperature of the tube anode and seals.

using the ivs rating

The IVS rating is especially attractive to amateur operators as it outlines typical operating parameters for cw and ssb. How are the new ratings used? The following is an example of how an amateur operator can safely and properly tune up for an IVS operating condition with the aid of an inexpensive oscilloscope.

The oscilloscope is necessary for ssb adjustment at first since meter response to a voice waveform may vary from meter to meter and is, in any case, highly irregular and difficult to interpret.

1. The first step to achieve an IVS condition for either ssb or cw is to tune and load the linear amplifier with carrier (single tone) to an IVS rated value of dc plate current (as read on the plate meter), observing maximum "on" time. The amplifier is now ready for IVS CW operation. This could be called the "long-dash" tuning method. An electronic key is handy for this operation.

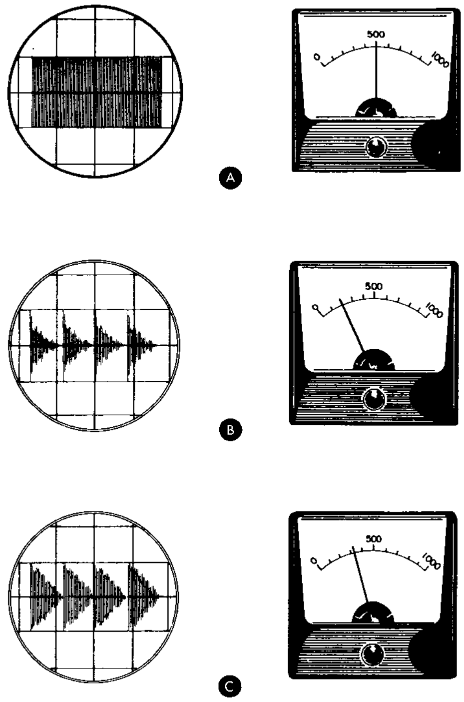

fig. 1. Typical meter readings for IVS operation.

A. With single tone (carrier), the linear amplifier is loaded to maximum IVS plate current (500 mA in this example). Oscilloscope shows carrier pattern. Pattern height is noted as 2 units. Observe short tuneup time.

B. Carrier is removed and voice modulation applied and gradually increased until voice peaks reach carrier height of 2 units as noted in pattern A. Plate meter kicks up to about 200 mA on voice peaks. No speech processing used.

C. Adding speech processing (clipping or compression). Note that plate meter now kicks up under voice peaks to about 325 mA, but that voice peaks on oscilloscope rise no higher than the single-tone limit of 2 units. However, area under the peaks is greatly enhanced, indicating greater average-to-peak ratio of voice signal. If oscilloscope peaks are greater than 2 units height, with or without voice processing, amplifier is being overdriven, with accompanying splatter and distortion.

2. For ssb observe the rf output pattern on the oscilloscope and note the amplitude for reference.

3. Remove the carrier. Insert audio and slowly increase audio gain so that the instantaneous rf peaks observed on the oscilloscope reach the same maxi-

table 1. Type 8122, linear rf power amplifier service (AB_1). Typical CCS operation at 30 MHz with two-tone modulation.

Plate voltage	2000 Vdc
Grid no. 2 voltage	400 Vdc
Grid no. 1 voltage	-35 Vdc
Zero-signal plate current	100 mA
Plate current	
Peak of envelope	335 mA
Average	250 mA
Grid no. 2 current	
Peak of envelope	10 mA
Average	7 mA
Average grid no. 1 current	0.05 mA
Effective rf load resistance	3050 ohms

mum level as obtained in *step 2* under carrier insertion. The amplifier is now working at the correct IVS level of peak input.

4. Observe the average current peaks on the plate meter for future reference.

In summary, the amplifier is tuned up to IVS condition with single-tone excitation to set the peak signal level. The single tone is removed, and audio is applied so the instantaneous signal peaks reach the same peak level as before, but the peak-to-average level of the intelligence may vary widely, depending upon voice characteristics, degree of speech processing, etc. This is summed up in **fig. 1**.

ivs ratings for the 8873 family of triodes

The new 8873 family of zero-bias triodes is the first to carry the new IVS rating. These ratings are based upon the original design concept of the tube, plus extended life tests where electrode temperatures, cathode emission and power output were carefully monitored. For example, the continuous plate current rating is 250 milliamperes. The cathode area of the 8873 is over 2 square centimeters; this corresponds quite closely to the 125 milliamperes per square centimeter rule-of-thumb stated earlier for an oxide-coated cathode. The life tests showed that a peak dc plate current rating of 500 milliamperes is reasonable at a duty cycle of 0.5 (peak-to-average power ratio of 2.0), corresponding to the IVS philosophy (**table 2**). The various input levels at a given plate voltage may now be established. At 2000 volts, for example, the average plate input is 2000 (volts) x 250 (milliamperes) = 500 watts. This corresponds to key-down service, such as RTTY. The two-tone rating (as in a short two-tone test) is 2000 (volts) x 312 (milliamperes) = 624 watts, average power. The IVS rating for ssb voice or cw is 2000 (volts) x 500 (milliamperes) = 1000 watts peak envelope power. In the case of voice and cw, the average current "load" on the cathode is the same.

Thus, today's power tube may be rated in two different and useful ways. Commonly, it bears the continuous duty (CCS) rating, and occasionally it bears the semi-obsolete ICAS rating. It is hoped that the new IVS rating will find favor in the future as it permits greater operating economy to be achieved in the use of all power-grid tubes.

what about . . .

The immediate question arises, "If this is so, what about the IVS ratings for the 3-500Z or the 8122 or the 4X150A, or whatever?" The present answer to this query is that *each tube type must be examined on its merits* and the outer limits established for any new rating, whether it be pulse, ICAS, or IVS. This is a continual process with most tube manufacturers, and more relevant date of this type will probably be forthcoming over the months.

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