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5881—A New Beam Power Tube

C. E. Atkins
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As published in Radio & Television News, September 1950.

POWER OUTPUT TUBES GET ROUGH TREATMENT. In the endeavor to obtain maximum output, amplifier designers frequently operate the tubes at, and sometimes beyond, established ratings. This has been especially true in the case of the 6L6 and its glass equivalents, the 6L6G(A). As a result, failures are sometimes too common, particularly in continuous-duty service. Some of these tubes stand up remarkably well, but different production runs of the same tube type often exhibit considerable variability in marginal operating environments where some special characteristic is being exploited or where it is necessary to rely upon the stability of a certain parameter under extreme conditions.

Power tube failures are usually due to gas. The presence of gas in the tube results in ion bombardment of the cathode so that its emissive capability is ultimately destroyed. Gas difficulties are cumulative inasmuch as a small gas content may result in grid current, lowering the operating bias and thus increasing the plate current. The greater plate current produces more gas ionization and hence more grid current, further decreasing the bias and initiating a run-away condition. Furthermore, the increased plate current results in greater heating of the tube electrodes which, in turn, may cause the release of additional quantities of gas.

While gas is frequently the final cause of cathode destruction, it may not be the initial culprit. All tubes can be made gassy if heated sufficiently. There are always at least minute traces of oxygen, nitrogen, carbon dioxide, and other gases in the tube elements and in the glass or metal envelope. The degree to which they are removed during manufacture is a relative sort of thing, depending upon the temperature and duration of bake-out and bombardment. If a tube approaches this temperature in service, it is likely to become gassy and, of course, the temperature of the electrodes and envelope depends upon the severity of the application. When a power tube is operated at its maximum rating, various kinds of spurious behavior may push the dissipation beyond what is considered safe and normal. Parasitic oscillations are by no means uncommon in power amplifiers, and there is reason to believe that tube design is a factor in their incidence. Grid emission will, of course, initiate the same lethal cycle described in the case of residual gas, In power tubes especially the grid is prone to emit electrons thermionically and, as in the case of gas, the resulting grid current changes the grid bias, often raising the plate current and overloading the tube. Of course, in the case of both gas current and grid emission current, there is a distortion of the grid signal which is also undesirable.

Cathode emission failure is not invariably due to gas ion bombardment. In many applications tubes are employed where standby operation is a feature of the service. In order that electron emission be immediately available, the heaters of this tubes are energized, while the plate and screen voltages are removed or, in many cases, a blocking voltage is applied to the control grid sufficient to shut off the plate current. Many tubes lose their cathode emission when operated for protracted periods under these conditions. This phenomenon has been called “sleeping sickness.” It is roughly analogous to the atrophy of body muscles or organs after long periods of idleness.

For a long time there has been a growing demand for a tube with dynamic characteristics like the 6L6 but of a design that would cope more vigorously with the problems encountered in a heavy-duty audio output tube. After considerable experimentation, the Tung-Sol design and development engineers have evolved a design which embodies many features which should qualify it as a successful candidate. This is experimental type DT281 (the RTMA commercial number is 5881), it has some intriguing features.

The tube is short and stocky to insure mechanical ruggedness. With shorter active electrodes, alignment is more readily maintained. This is especially important in a beam power tube where electrode configuration has the additional function of beam formation in order to produce the high density electron cloud in the screen-plate space for the suppression of secondary emission from the plate. The electrodes are carefully secured to arrowhead shaped top and bottom micas, on three edges of which mica side-snubbers have been pinned, By this means the walls of the envelope enlist in the support of the “mount” (tube jargon for the electrode assembly). The electrode leads are brought in through a glass disc-called a button stem instead of the flat vertical press stem employed with the 6L6G-GA. This radial arrangement with liberal spacing of the leads through the stem is insurance against breakdown due to electrolysis in the glass. Also, it is believed to render the tube less susceptible to certain kinds of parasitic oscillation.

Extra precautions have been taken to deal with gas. Of course, the tube is carefully baked, adroitly bombarded, and thoroughly pumped. The massive plate of carbonized nickel is three times thicker than commonly used. It is painted with zirconium, which aids in the adsorption of gas during the life of the tube. Stray gas molecules coming in contact with the zirconium surface, adhere to the metal and are prevented from entering the active inter-electrode space to interfere with the thermionic operation of the device. To clean up exhaust gases and effect the continual removal of gas from the tube by chemical means, a pure barium getter is used. Three getter flags are currently employed.

To deal with grid emission, the grid electrodes are given special treatment. Thermionic emission, so essential in a cathode, can be dangerous and damaging when it emanates from other electrodes in a tube. All metals emit electrons thermionically if they become hot enough. The free electrons in a metal, which render it conductive and contribute to many of its metallic properties, are in a state of agitated, continual movement. They are prevented from jumping out of the metal at its surface by the action of electric forces at this boundary, which tend to keep the electrons inside the metal. When heat is imparted to the metal the electrons become increasingly agitated and may develop sufficient momentum to jump out of the metal in spite of the surface force tending to keep them inside. This surface force varies with the different metals, being low for some and high for others. The lower this force the more suitable the metal may be for use as a cathode to supply electrons thermionically. When thin layers of different metals are built up in a special laminated fashion, the surface forces are still further reduced. In the oxide coated cathodes now extensively used, some such arrangement is provided which results in relatively efficient electron emission.

Now the control grid is necessarily close to the cathode. There is never more than a few thousandths inch between the cathode surface and the grid wires. Accordingly, it is very easy for cathode material to condense on the grid wires after evaporation from the cathode. This may occur in the process of tube manufacture or later during the life of the tube. The sensitive cathode materials may form films on the grid wires, providing a fairly efficient source of thermionic electrons. The grid's proximity to the cathode makes it vulnerable in another respect. There is considerable heat energy in the cathodes of power tubes and this naturally has an elevating effect upon the grid temperature. Because of the temperature the grid can achieve, plus the likelihood of its surface being contaminated by cathode material, it is easy to see why grid emission is a common occurrence. Of course, the emitted current is minute, being on the order of a few microamperes instead of the milliamperes or even amperes emitted from the cathode. However, where there is a lot of resistance in the grid circuit this is all that is necessary to cause a lot of trouble.

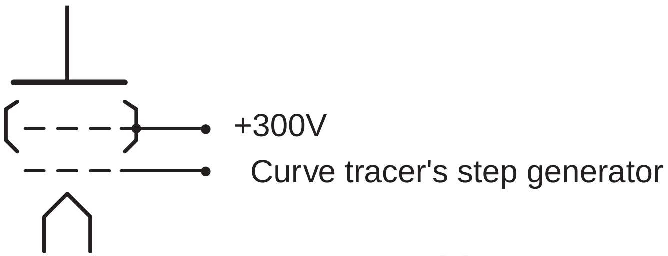
In the 5881, grid emission has been dealt a severe blow by the use of gold plated wire on this electrode. Cathode materials do not effectively contaminate gold-plated grid wires and hence the possibility of grid emission is greatly reduced when the grid surface is gold. Furthermore, gold itself is not an efficient electron emitter. Naturally the standard power tube practice of copper side-rods, carrying heat away from the grid to a "black body" radiating member in the ends is used here.

The screen grid, being farther from the cathode, is not as vulnerable as the control grid, although it is by no means immune to the same ills. Since it absorbs current, it develops heat on its own account, unlike the control grid which is heated by other electrodes in the tube. Small amounts of emission-current can often be tolerated, but there is always a limit. In the 5881 the screen grid is painted with a special carbon suspension which is quite porous and, of course, very black. Its color, as any physics student knows, increases the radiation of heat away from it so that it can run cooler. The porosity of the carbon coating is useful when the tube is used under circumstances where secondary emission from this electrode may be harmful. It is believed the secondary electrons are trapped in the porous labyrinth. Also, the porosity is necessary to facilitate de-gassing this electrode during the manufacturing process.[†]

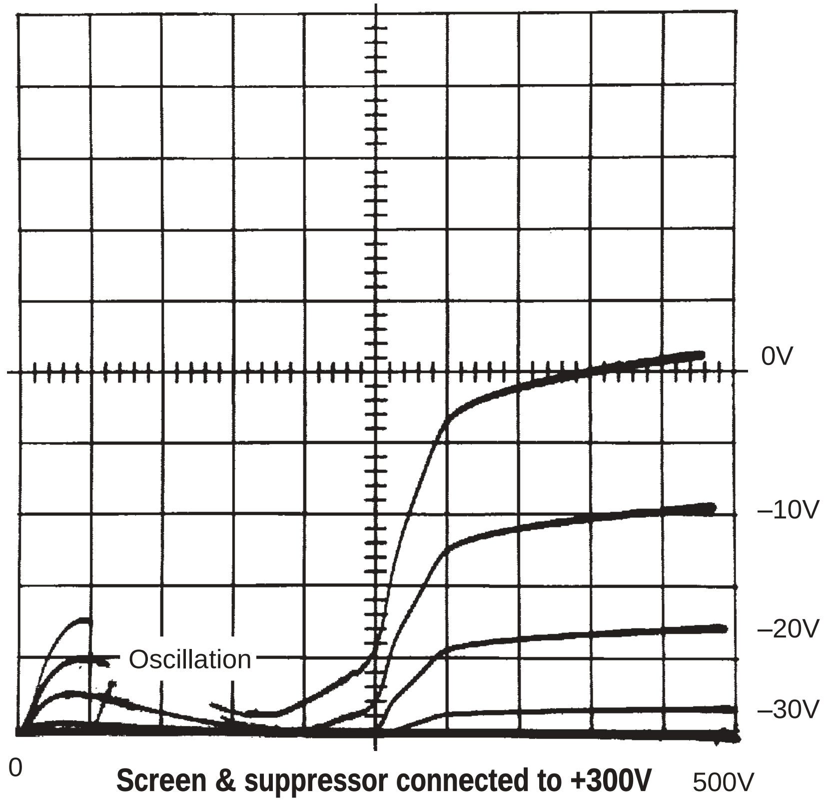
Cathode failure (or "sleeping sickness") during standby periods is combated by the use of a cathode sleeve of high purity, grade A, electrolytic nickel. It is generally more difficult to process cathodes with this type of sleeve, but exhaustive tests indicate a much greater stability than with the nickel alloy cathode sleeves commonly used in electron tubes,

The 5881 carries ratings similar to the 6L6, except that the allowable screen dissipation is 3.0 watts instead of 2.5 watts while the maximum plate dissipation is 23 watts instead of 19 watts for the 6L6. The tube has a low loss micanol base. Preliminary tests give results which augur well for the future of the type.

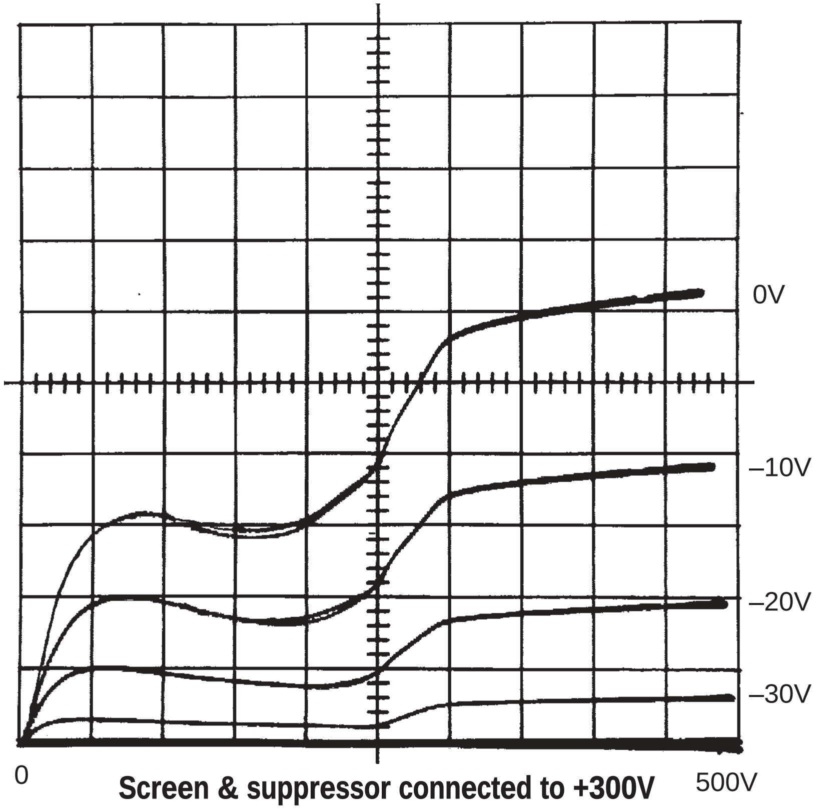
[†] See the comparative study of plate current variation as a function of secondary emission in tetrode-connected nickel- and graphite-anode 813 beam tetrodes conducted by PEARL, Inc., appended to this paper as Pg. 3.



Nickle plate 813



Graphite plate 813



A comparative study of the secondary emission within type 813 beam tetrodes having nickel and graphite anode anode structures appears above.

The beam forming structure in the 813 is connected to a pin on its base so that for conventional, tetrode operation it can be connected to ground or a negative potential.

In this case, the beam former was connected to the +300V screen supply so as to negate its suppression of secondary emission from the plate, particularly in the operational vicinity where the plate and screen voltages are approximately equal.

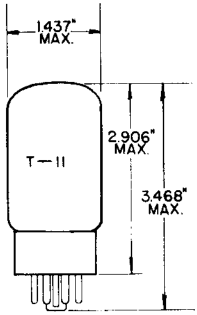
Evidence of plate secondary emission is provided by the severe to mild dips (nickel and graphite respectively) in the plate current curves in their +100 to 300-plate-volts regions.

Note that in the graphite case shown directly above, the plate current is much, much higher, indicating substantially lower secondary emission from the more open, “sponge-like” graphite surface. In contrast, the nickel plate structure can be usefully, if somewhat loosely, considered rather “mirror-like” in that “inbound” electrons—travelling at approximately 10% of C, the speed of light—effectively “bounce off” the plate.

While this is approximately correct, it is more accurate to say that most “inbounds” stimulate the emission of as many as several “secondaries” from the plate, thereby creating a region of negative charge that inhibits the flight of “inbounds” from the filament, this causing the reduction in plate current seen where the plate and screen voltages are nearly equal.

TUNG-SOL

BEAM PENTODE

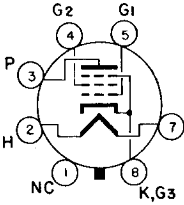


GLASS BULB
SHORT INTERMEDIATE SHELL
7 PIN OCTAL B7-47
OUTLINE 11-1

COATED UNIPOTENTIAL CATHODE

HEATER
6.3 VOLTS 900 MA.
AC OR DC

ANY MOUNTING POSITION



BOTTOM VIEW
BASING DIAGRAM
JEDEC 7AC

THE 5881 IS THE ELECTRICAL EQUIVALENT TO TYPES 6L6 AND 6L6G EXCEPT THAT THE PLATE AND SCREEN DISSIPATION RATINGS HAVE BEEN INCREASED APPROXIMATELY 20 PERCENT. IT EMBODIES A COMPLETE MECHANICAL REDESIGN WHICH RESULTS IN GREATER RESISTANCE TO SHOCK AND VIBRATION. THE USE OF TREATED GRIDS AND ANODE GREATLY INCREASES ITS OVERLOAD CAPABILITIES AND THEREBY PROVIDES DESIRABLE IMPROVEMENT IN CONTINUITY OF SERVICE. THE ADDITION OF A LOW-LOSS BARRIER TYPE BASE WILL PROVIDE OBVIOUS ADVANTAGES IN CERTAIN APPLICATIONS.

RATINGS

INTERPRETED ACCORDING TO DESIGN CENTER SYSTEM

MAXIMUM HEATER-CATHODE VOLTAGE	200	VOLTS
MAXIMUM PLATE VOLTAGE	400	VOLTS
MAXIMUM GRID #2 VOLTAGE	400	VOLTS
MAXIMUM PLATE VOLTAGE (TRIODE CONNECTION)	400	VOLTS
MAXIMUM PLATE DISSIPATION	23	WATTS
MAXIMUM GRID #2 DISSIPATION	3	WATTS
MAXIMUM PLATE DISSIPATION (TRIODE CONNECTION)	26	WATTS
MAXIMUM GRID RESISTANCE (FIXED BIAS)	0.1	MEGOHM
MAXIMUM GRID RESISTANCE (SELF BIAS)	0.5	MEGOHM

TYPICAL OPERATING CONDITIONS AND CHARACTERISTICS

CLASS A_1 AMPLIFIER - SINGLE TUBE

PLATE VOLTAGE	250	300	350	VOLTS
GRID #2 VOLTAGE	250	200	250	VOLTS
GRID #1 VOLTAGE	-14	-12.5	-18	VOLTS
PEAK AF SIGNAL VOLTAGE	14	12.5	18	VOLTS
TRANSCONDUCTANCE	6 100	5 300	5 200	µMHOS
PLATE RESISTANCE	30 000	35 000	48 000	OHMS
ZERO-SIGNAL PLATE CURRENT	75	48	53	MA.
ZERO-SIGNAL GRID #2 CURRENT	4.3	2.5	2.5	MA.
MAXIMUM SIGNAL PLATE CURRENT	80	55	65	MA.
MAXIMUM SIGNAL GRID #2 CURRENT	7.6	4.7	8.5	MA.
LOAD RESISTANCE	2 500	4 500	4 200	OHMS
POWER OUTPUT	6.7	6.5	11.3	WATTS
TOTAL HARMONIC DISTORTION	10	11	13	PERCENT

CONTINUED ON FOLLOWING PAGE

CONTINUED FROM PRECEDING PAGE

CLASS A_1 AMPLIFIER – SINGLE TUBE – TRIODE CONNECTION

GRID #2 CONNECTED TO PLATE

PLATE VOLTAGE	250	300	VOLTS
GRID VOLTAGE	−18	−20	VOLTS
PEAK AF SIGNAL VOLTAGE	18	20	VOLTS
ZERO-SIGNAL PLATE CURRENT	52	78	MA.
MAXIMUM SIGNAL PLATE CURRENT	58	85	MA.
AMPLIFICATION FACTOR	8	---	
TRANSCONDUCTANCE	5 250	---	µMHOS
LOAD RESISTANCE	4 000	4 000	OHMS
TOTAL HARMONIC DISTORTION	6	5.5	PERCENT
POWER OUTPUT	1.4	1.8	WATTS

CLASS A_1 PUSH-PULL AMPLIFIER

VALUES ARE FOR TWO TUBES

PLATE VOLTAGE	250	270	VOLTS
GRID #2 VOLTAGE	250	270	VOLTS
GRID #1 VOLTAGE	−16	−17.5	VOLTS
PEAK AF GRID TO GRID VOLTAGE	32	35	VOLTS
TRANSCONDUCTANCE (EACH TUBE)	5 500	5 700	µMHOS
PLATE RESISTANCE (EACH TUBE)	24 500	23 500	OHMS
ZERO-SIGNAL PLATE CURRENT	120	134	MA.
ZERO-SIGNAL GRID #2 CURRENT	10	11	MA.
MAXIMUM SIGNAL PLATE CURRENT	140	155	MA.
MAXIMUM SIGNAL GRID #2 CURRENT	16	17	MA.
LOAD RESISTANCE	5 000	5 000	OHMS
POWER OUTPUT	14.5	17.5	WATTS
TOTAL HARMONIC DISTORTION	2	2	PERCENT

CLASS AB_1 PUSH-PULL AMPLIFIER

VALUES ARE FOR TWO TUBES

PLATE VOLTAGE	360	360	VOLTS
GRID #2 VOLTAGE	270	270	VOLTS
GRID #1 VOLTAGE	−22.5	−22.5	VOLTS
PEAK AF GRID TO GRID VOLTAGE	45	45	VOLTS
ZERO-SIGNAL PLATE CURRENT	88	88	MA.
ZERO-SIGNAL GRID #2 CURRENT	5	5	MA.
MAXIMUM SIGNAL PLATE CURRENT	132	140	MA.
MAXIMUM SIGNAL GRID #2 CURRENT	15	11	MA.
LOAD RESISTANCE	6 600	3 800	OHMS
POWER OUTPUT	26.5	18	WATTS
TOTAL HARMONIC DISTORTION	2	2	PERCENT

CONTINUED ON FOLLOWING PAGE

CONTINUED FROM PRECEDING PAGE

CLASS AB_1 PUSH-PULL AMPLIFIER – TRIODE CONNECTION

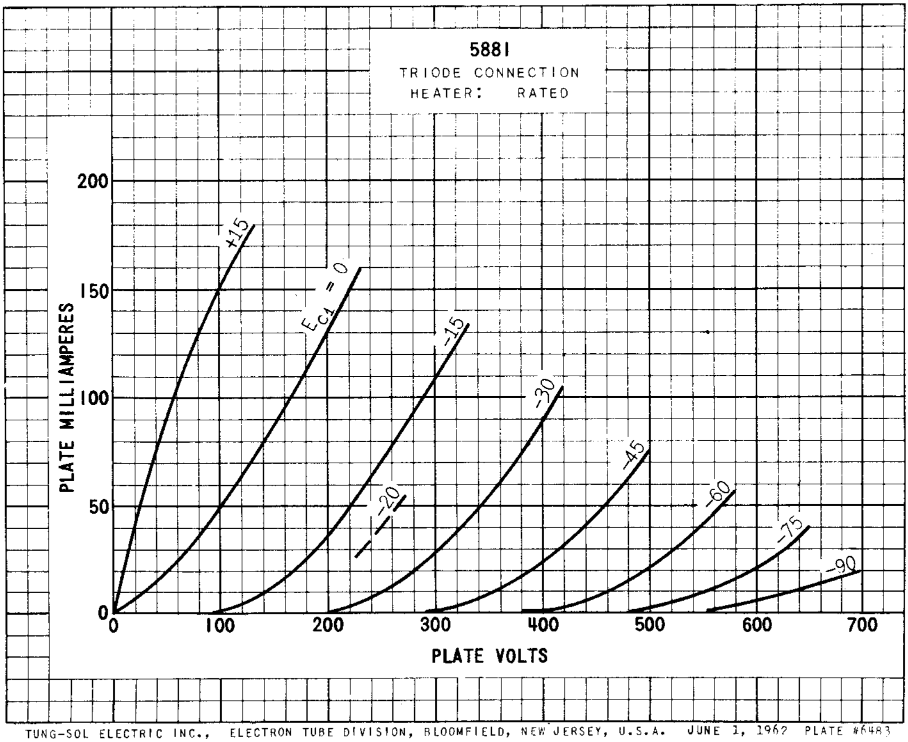
GRID #2 CONNECTED TO PLATE
VALUES ARE FOR TWO TUBES

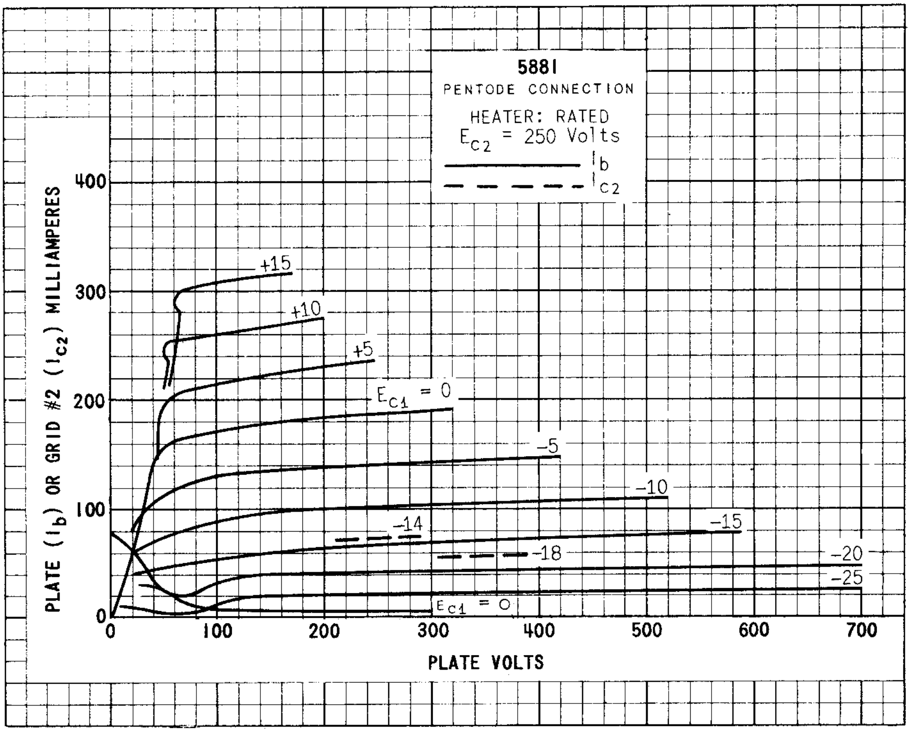
HEATER VOLTAGE	6.3	VOLTS
HEATER CURRENT	0.9	AMP.
PLATE VOLTAGE	400	VOLTS
GRID VOLTAGE	−45	VOLTS
PEAK AF GRID TO GRID VOLTAGE	90	VOLTS
ZERO-SIGNAL PLATE CURRENT	65	MA.
MAXIMUM SIGNAL PLATE CURRENT	130	MA.
LOAD RESISTANCE	4 000	OHMS
TOTAL HARMONIC DISTORTION	4.4	PERCENT
POWER OUTPUT	13.3	WATTS

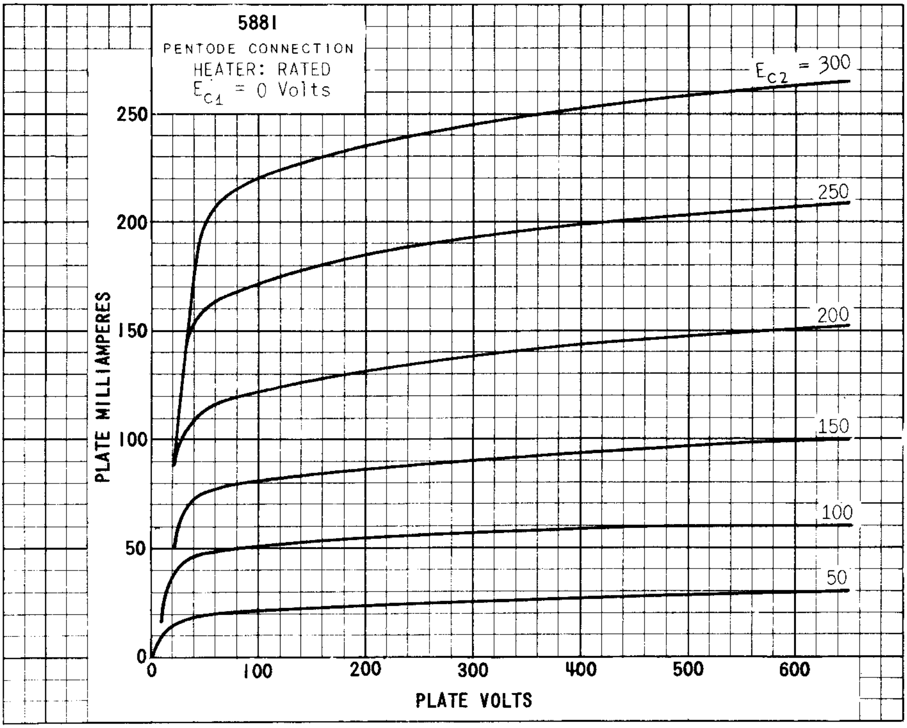
CLASS AB_2 PUSH-PULL AMPLIFIER

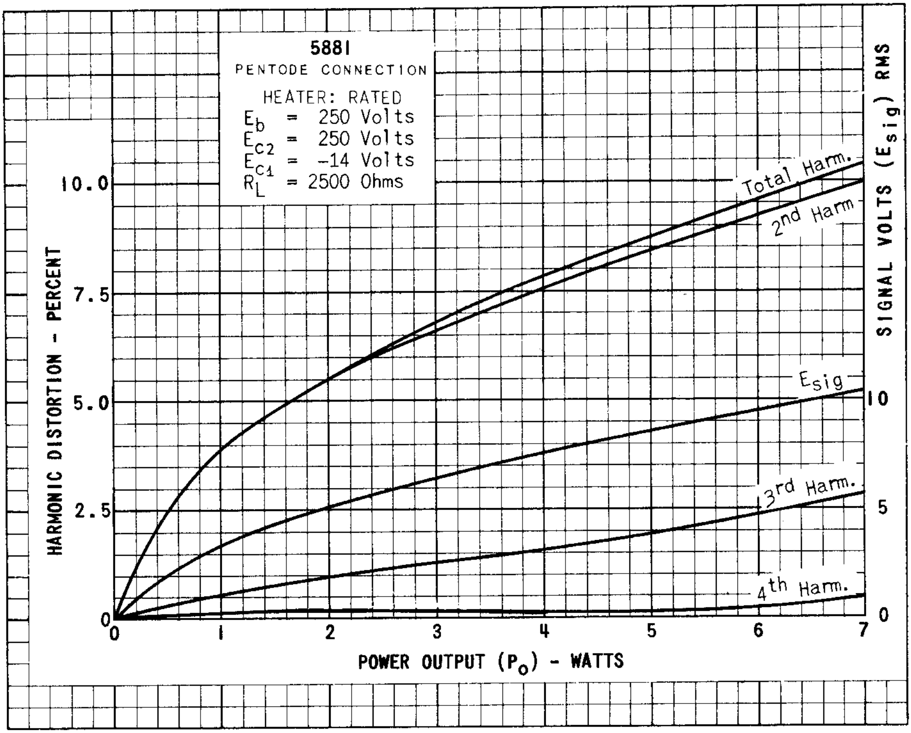
VALUES ARE FOR TWO TUBES

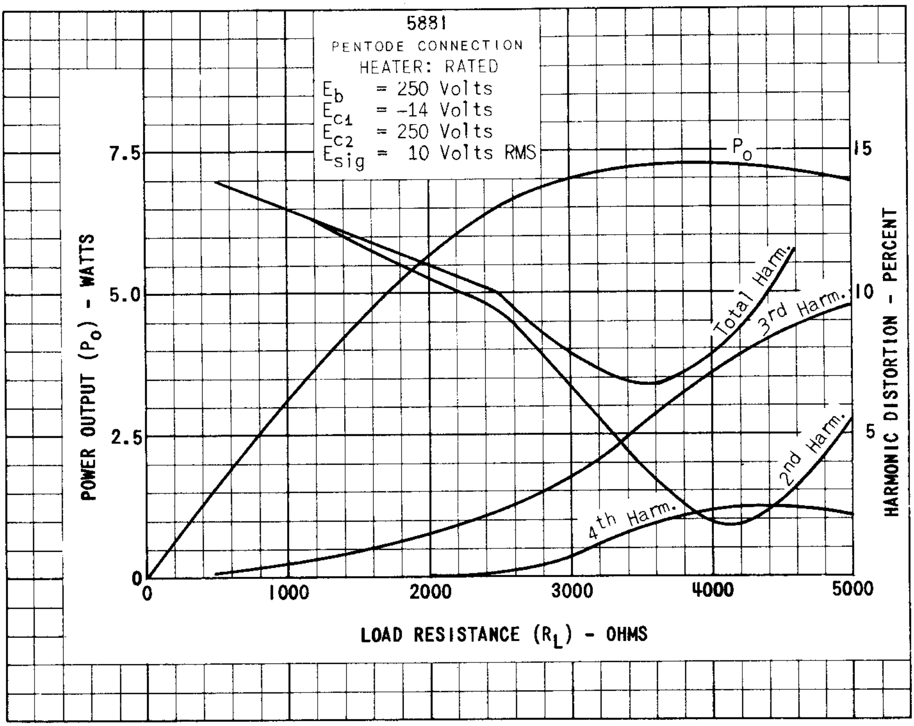
HEATER VOLTAGE	6.3	6.3	VOLTS
HEATER CURRENT	0.9	0.9	AMP.
PLATE VOLTAGE	360	360	VOLTS
GRID #2 VOLTAGE	225	270	VOLTS
GRID #1 VOLTAGE	−18	−22.5	VOLTS
PEAK AF GRID TO GRID VOLTAGE	52	72	VOLTS
ZERO-SIGNAL PLATE CURRENT	78	88	MA.
ZERO-SIGNAL GRID #2 CURRENT	3.5	5	MA.
MAXIMUM SIGNAL PLATE CURRENT	142	205	MA.
MAXIMUM SIGNAL GRID #2 CURRENT	11	16	MA.
LOAD RESISTANCE	6 000	3 800	OHMS
POWER OUTPUT	31	47	WATTS
TOTAL HARMONIC DISTORTION	2	2	PERCENT




5881
PENTODE CONNECTION
HEATER: RATED
E_{c2} = 250 Volts
I_b
I_{c2}
PLATE (I_b) OR GRID #2 (I_{c2}) MILLIAMPERES
0
100
200
300
400
PLATE VOLTS
0
100
200
300
400
500
600
700
+15
+10
+5
E_{c1} = 0
−5
−10
−15
−14
−18
−20
−25
E_{c1} = 0

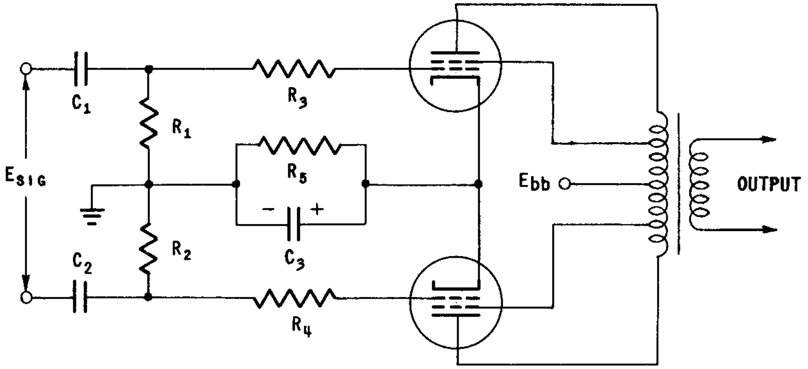

5881
PENTODE CONNECTION
HEATER: RATED
E_{c1} = 0 Volts
PLATE MILLIAMPERES
0
50
100
150
200
250
PLATE VOLTS
0
100
200
300
400
500
600
E_{c2} = 300
250
200
150
100
50


5881
PENTODE CONNECTION
HEATER: RATED
E_b = 250 Volts
E_{c2} = 250 Volts
E_{c1} = -14 Volts
R_L = 2500 Ohms
Total Harm.
2nd Harm.
E_{sig}
3rd Harm.
4th Harm.
HARMONIC DISTORTION - PERCENT
0
2.5
5.0
7.5
10.0
SIGNAL VOLTS (E_{sig}) RMS
0
5
10
POWER OUTPUT (P_o) - WATTS
0
1
2
3
4
5
6
7


5881
PENTODE CONNECTION
HEATER: RATED
E_b = 250 Volts
E_{c1} = -14 Volts
E_{c2} = 250 Volts
E_{sig} = 10 Volts RMS
P_o
Total Harm.
3rd Harm.
2nd Harm.
4th Harm.
POWER OUTPUT (P_o) - WATTS
0
2.5
5.0
7.5
HARMONIC DISTORTION - PERCENT
5
10
15
LOAD RESISTANCE (R_L) - OHMS
0
1000
2000
3000
4000
5000

TUNG-SOL

ULTRA-LINEAR OUTPUT STAGE



R_1, R_2 = 100 K. 1/2W
R_3, R_4 = 1 K. 1/2W
R_5 = 400 OHMS 10W

E_b = 450V.
E_{SIG} = 80V. PEAK TO PEAK
C_1, C_2 = 0.2 µf 600V
C_3 = 100 µf 50V

DIST. = 2.5%
P_o = 20W
R_1 = 6K

IN THE ULTRA-LINEAR CIRCUIT THE SCREEN VOLTAGES ARE DERIVED FROM TAPS ON THE PLATE WINDINGS OF THE OUTPUT TRANSFORMER, THE TAPS ARE LOCATED SO AS TO APPLY 43% OF THE PLATE SIGNAL VOLTAGE TO THE SCREEN GRID.

THE PLATE FAMILY FOR THIS CONNECTION IS SHOWN BELOW. THESE CURVES WERE OBTAINED BY STATICALLY VARYING THE PLATE VOLTAGE IN INCREMENTS ABOUT THE QUIESCENT POINT (400 VOLTS PLATE AND SCREEN SUPPLY) AND SIMULTANEOUSLY CHANGING THE SCREEN VOLTAGE BY 43% OF THE INCREMENT. IN THE GRAPH BOTH PLATE AND SCREEN VOLTAGES HAVE BEEN PLOTTED ALONG THE ABSCISSA.