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## DETERMINATION OF TYPICAL OPERATING CONDITIONS

For RCA Tubes Used as Linear RF Power Amplifiers

Part I

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During the past few years, ham interest in single-sideband transmission has been on a continual upswing. As a result, numerous articles have been published on the theory and construction of linear triode and tetrode amplifiers. While these articles have discussed classes of tube operation and compared grid-drive to cathode-drive circuits, only a handful provided design information for adapting tube manufacturers' data to available components or to the amateur's specific requirements.

Micluded among the "selected few" was an article by A. P. Sweet, which appeared in the December, 1954, issue of HAM TIPS. It presented such information in the form of step-by-step calculations for use in converting published maximum ratings to typical operating conditions.

Now, six years later, having recognized the need to bring this design information up to date, HAM TIPS is pleased to offer here Part I of a two-part article prepared by W3FAL. This first part extends the calculations to include cathode-drive (grounded-grid) operation of tetrodes and triodes in class AB<sub>1</sub> service.

In the next issue, Part II will cover the procedure for calculating typical operating conditions for class B operation of triodes or triode-connected tetrodes in a cathode-drive circuit.

Sample calculations are based on published data and curves for the RCA-7094 power tetrode. Also included is a chart which lists maximum ratings and typical operating conditions for several widely used RCA power tubes.

## Class AB<sub>1</sub> Operation of Tetrodes (Grid-Drive Circuit)

When it is desirable to operate tubes at conditions other than those given in the published data, typical operating conditions can be calculated from the maximum ratings and characteristics curves. The calculations required for class AB<sub>1</sub> operation of a tetrode in grid-drive

service are given below. This procedure may be adapted to triode tube types by eliminating the terms  $E_{c2}$ ,  $I_{c2}$ ,  $i'_{c2}$ , and SI from the calculations.

(1) Make sure that  $E_b$  is within maximum ratings. ( $E_b$  is one of 21 symbols defined on page 2.)

(2) On the average plate-characteristics

curves, select a point near the "knee" of the curve for zero control-grid voltage; record  $i'_b$  and  $e_{bmin}$ . From the average screen-grid characteristics curves, determine  $i'_{c2}$  for this point; record  $E_{c2}$  for the curves used.

(3) Calculate  $I_{bms}$ :  $I_{bms} = i'_b/3$ .

(4) Calculate PD: PD =  $(I_{bms}/4)$  (E<sub>b</sub> + 3  $e_{bmsn}$ ).

(5) Calculate SI: SI =  $E_{c2}i'_{c2}/4$ .

(6) Calculate PI:  $PI = E_b I_{bms}$ .

(7) Check the values obtained in steps 3 through 6 to determine whether they are within tube ratings. If either  $I_{bms}$ , PI, or PD is out of ratings, select a point slightly lower than the original point on the knee of the curve for zero control-grid voltage and recalculate steps

E<sub>b</sub> DC plate voltage (with respect to cathode)

e<sub>bmin</sub> Minimum plate voltage necessary to produce the required peak current (from the characteristics curves)

E<sub>c2</sub> DC screen-grid voltage E<sub>c1</sub> DC control-grid voltage

e<sub>cm</sub> Maximum control-grid drive voltage needed to obtain the required peak plate current at a given minimum plate voltage

E'g Peak value of control-grid voltage

swing

I<sub>bms</sub> Maximum signal, dc plate current I<sub>bo</sub> Zero-signal, dc plate current

i'<sub>b</sub> Instantaneous peak plate current I<sub>c1</sub> Maximum-signal, dc control-grid current

I<sub>c2</sub> Maximum-signal, dc screen-grid current

i'c1 Instantaneous peak control-grid current

i'c2 Instantaneous peak screen-grid current

PD Plate dissipation at maximum signal

PDo Plate dissipation at zero signal

PI Plate power input at maximum signal

PO Power output at maximum signal Ptt Feed-through power at maximum signal (cathode-drive operation)

DP Driving power at maximum signal

SI Screen-grid input at maximum signal

R<sub>p</sub> Effective rf plate-load resistance

2 through 6. If only SI is out of ratings, select a point slightly higher on the knee. If SI and either  $I_{bms}$ , PI, or PD are out of ratings, select a lower value of  $i'_b$  (either in the negative-control-grid region or at a lower screen-grid voltage) and repeat steps 2 through 6.

(8) Calculate PO: PO = PI - PD.

(9) Calculate  $I_{bo}$ :  $I_{bo} = I_{bms}/5$ .

(10) Determine  $E_{\rm c1}$  from the plate-characteristics curves as the control-grid voltage at which the plate voltage is  $E_{\rm b}$  and the plate current is  $I_{\rm bo}$ .

(11) Calculate  $E'_g$ :  $E'_g = |E_{c1}| + e_{cm}$ . This value of  $E'_g$  is equal to the absolute value of  $E_{c1}$  (the straight lines around this term indicate that its plus or minus sign may be ignored) plus the algebraic value of  $e_{cm}$  (include the sign). If the point selected in step 2 was on the curve for zero control-grid voltage, then  $e_{cm}$  is equal to zero and  $E'_g = |E_{c1}|$ .

(12) Calculate  $I_{e2}$ :  $I_{e2} = i'_{e2}/4$ .

(13) Calculate DP: DP=  $E'_{g}i'_{c1}/4$ . (For AB<sub>1</sub> operation,  $i'_{c1}$  equals zero; therefore, DP is also zero.) This value of DP does not include rf tube and circuit losses. The power available from the driver, therefore, should be at least 10 times this value in grid-drive operation. Because AB<sub>1</sub> tube driving power is zero, determine the approximate driver-output requirements from published AB<sub>2</sub> typical operating conditions at approximately the same  $E'_{g}$  and operating frequency.

(14) Calculate  $R_p$ :  $R_p = E_b/1.7 I_{bms}$ .

**Example**—The following example illustrates the calculation of typical operating conditions for class AB<sub>1</sub> tetrode operation of the RCA-7094 in a grid-drive circuit:

(1) The maximum plate voltage rating is

2000 volts.

(2) From the plate-characteristics curves shown in Figure 1 ( $E_{c2}=350 \text{ volts}$ ), select a point PI on the knee of the curve for zero control-grid voltage. At this point,  $i'_b$  is 0.650 ampere and  $e_{bmin}$  is 300 volts. At the corresponding point on the grid-characteristics curves shown in Figure 2,  $i'_{c2}$  is equal to 0.035 ampere.

(3)  $I_{bms} = i'_b/3 = 0.217$  ampere.

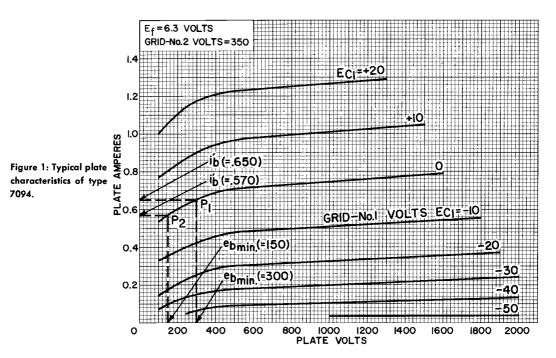
(4) PD =  $(I_{bms}/4)$  (E<sub>b</sub> + 3 e<sub>bmin</sub>) = (0.217/4) [2000 + 3 (300)] = 157 watts.

(5) SI =  $E_{c2}i'_{c2}/4 = (350) (0.085)/4 = 7.4$  watts.

(6) PI =  $E_bI_{bms}$  = (2000) (0.217) = 434 watts.

RCA HAM TIPS

	Maximum Ratings—Absolute Values											Typical Operation									
Tube	Class of			Grid-No. 2	Max-Signal Plate	Max-Signa Plate	I Max-Signa Grid-No.	MaxSignal Plate Dis-	Grid-No. 1	Plate	Grid-No. 2	Grid-No. 1	Peak Grid-No. 1			Max-Signal Grid-No. 2	MaxSignal	Drive Power	Max-Signal Power		
Туре	Operation	Service	Voltage (E <sub>b</sub> )	Voltage (E <sub>c2</sub> )	Current (I <sub>bms</sub> )— <i>ma</i>	Inout	input (SI)—watts	Grid-No. $1 + \text{Grid-No. 2}$ sipation Current ( $I_{\text{Cl}} + I_{\text{C2}}$ ) — ma (PD) — wath	Recistance	Voltage (E <sub>b</sub> )	Voltage (E <sub>c2</sub> )	Voltage (E <sub>c1</sub> )	Voltage (E'g)	Current (1 <sub>bo</sub> )—ma	Current	Current	Grid-No. 1 + Grid-No. 2 Current (lc1+lc2) — ma	(DP)	Output		
2E26	AB <sub>1</sub>	CCS ICAS	400 500	200 200	75 75	30 37.5	2.5 2.5	10 12.5	30 K 30 K	400 500	200 200	-25 -25	25	9	45	10	current (1c1 + 1c2) — ind	-waiis	12		
		CCS	400 500	200 200	75 75	30	2.5	10	30 K	400	125 125	-15	25 30	10	45 75	10 16		0.2 0.2	20 25		
4-65A	AB <sub>2</sub>					37.5	2.5	12.5		1000	500		30 85	11 15	75 85	16 12		0.2	25 40		
	ABı	ccs	3000	600	150		10	65	250 K	1500 1750	500 500	-85 -90	85 85 90	15 15 10	90 85	7 9			70 85		
	AB <sub>2</sub>	ccs	3000	600	150		10	65		1000 1500	250 250	-30	105 100	30 30	150 125	22 15		2.5 1.5	85 125		
										1800	250	-35 -35	90	25	110	13		1.0	135		
4-125A	AB <sub>1</sub>	ccs	3000	600	225		20	125	250 K	1500 2000	600 600	90 94	90 94 96	30 25 25	110 120	9 3			80 115		
						<del></del>	0			2500 1500	600 350	-96 -41 -45	141		200	<del></del>		5.0	165 175		
	AB <sub>2</sub>	ccs	3000	400	225		20	125		2000 2500	350 350	-45 -43	105 139	44 36 47	150 130	3 3		5.0 3.0 2.5	175 200		
4-250 <b>A</b>	AB <sub>1</sub>	ccs	4000	600	350		35	250		2000 2500	500 500	-88 -90	88 90	55	200 215	11			230 310		
		_								3000 2000	500 300		93	60 60	205	5	_		370		
	AB <sub>2</sub>	ccs	4000	600	350		35	250		2500 3000	300 300 300	-48 -51 -53	100 100 100	60 60 62	250 250 236	13 12		5.5 5.0 4.5	325 420		
807 1625		000	600	200	100		2.5		100 1/	500	300	-32 -34	32 34	22 18	70	<u>16</u> 		4.5	520 23 28		
	AB <sub>1</sub>	CCS ICAS	600 750	300 300	120 120	60 90	3.5 3.5		100 K 100 K	600 750	300 300	35	34 35	18 15	70 70	8 8			28 35		
	AB <sub>2</sub>	ccs	600	300	120	60	3.5	25		500 600	300	-30 -32	43	30	120 100	10 9		0.2	38 40		
		ICAS	750	300	120	90	3.5	30		750	300	-35	48	15	120	10		0.2	60		
811A	В	ccs	1250		175	165		45		750 1250		0 0	100 78	16 25	175 130			10 4	90 120		
		ICAS	1500		175	235		65		1000 1250		0 0	93 88	25 22 27	175 175			7.5 6	120 125 155		
813	AB <sub>1</sub>	CCS ICAS	2250	1100	180	360	22 22	100 125		2000 2250 2500	750 750	-90 -95	80 85	25 25	130 125	20 26			165 190		
013	ADI	ICAS	2500	1100	225	450	22	125		2500 500	750 200	-95 -20	90	25 25 20	145 100	27			245 35		
829B Natural Cooling	AB <sub>1</sub>	CCS	750 750	225 225	250 250	100 120	7	30 <b>40</b>	100 K 100 K	600 750	200 200	-18 -21	36 42	40 20	100 100	18 20			44 55		
					-		7		100 11	500 600	200 200	-18 -20	50 50		180	26		0.6	60 65		
	AB <sub>2</sub>	CCS ICAS	750 750	225 225	250 250	100 120	7	30 40		750	200	-19	50	30 26 32	155 160	22 25		0.4 0.5	85		
832A	AB <sub>1</sub>	ccs	750	250 250	90	36	5 .	15	100 K	500 600	180 150	-30 -30	60 60	14 12	70 60	7 7			22 23		
833A	В	ICAS ICAS	750 3300	250	115 500	1300	5	20 350	100 K	750 3300	150	-32 -80	190	60	300	7	<del>-</del>	20	30 710		
6146 6159		ccs	600	250	125	60	3	20	100 K	400 500	190 185	-40 -40	40 40	32	114 108	13 13			27 35		
	AB <sub>1</sub>			200	120	00	Ü	20	100 10	600 600	180 200	45 50	45 50	29 13 14	100 115	12 14			40 47		
		ICAS	750	250	135	85	3		100 K	750 400	195 175	-50	50	12	110	13			60		
	AB <sub>2</sub>	ccs	600	250	125	60	3	20		500	175	-41 -44	48 51	17 14 11	116 121	9		0.2 0.3 0.2 0.3	31 41 45 55 65		
		ICAS	750	250	135	85	3	25		600 600 750	165 190 165	-44 -48	49 55	14	104 135	10		0.2	45 55		
6524								25		400	200	-46 -23 -26	54 72	25 20	120 145	10		0.4	39		
	AB <sub>2</sub>	ccs	500	300	150	70	3	20	30 K	500 500	200 200	26 25 26	70 76	25	116 145	10 10		$0.1 \\ 0.1$	40 50 57		
	A.P.	ICAS CCS	60 <b>0</b> 1500	300 400	150 350	85 300	<u>3</u>	20 100	30 K 30 K	600 1500	200 400	-26 -65	76 60	30	200	13 35	· · · · · ·	0.1			
7094	AB <sub>1</sub>	ICAS	2000 1500	400	350 350	400 300	20	125	30 K	2000 1350	400	-65 -65	60 50	30	200	35	140	4	185 250		
	B*	ICAS	2000		350	400	- 10	200 125		1750	0	0	50	44	200		140 140	15 15	160 210		
7580	AB <sub>1</sub>	ccs	2000	500	350 ●	<del>-,</del>	12	250	25 K	2000	400	77	77	70	225	35		1	400 ● ●		



(7) Because both PD and PI are above the maximum ratings for the 7094, a lower value of i'<sub>b</sub> must be used. Select a point P2 below the original point on the knee of the curve for

zero control-grid voltage and recalculate steps 2 through 6.

At the new point,  $i'_b$  is 0.570 ampere and  $e_{bmin}$  is 150 volts. At this point on the grid-

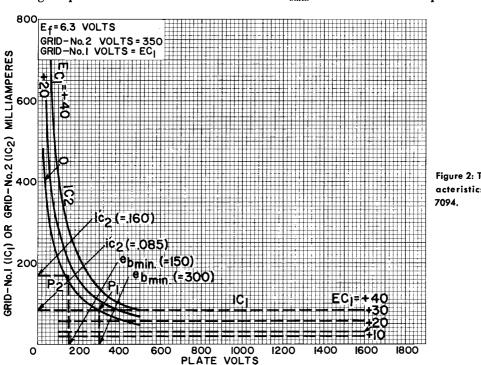


Figure 2: Typical characteristics for type

characteristics curves, i'c2 is 0.160 ampere.

 $I_{bms} = 0.570/3 = 0.190$  ampere.

PD = (0.190/4) [2000 + 3 (150)] = 116 watts.

SI = (350) (0.160)/4 = 14 watts. PI = (2000) (0.190) = 380 watts.

All values in steps 3 through 6 are now within maximum ratings, and the calculations may be continued.

(8) PO = PI - PD = 380 - 116 = 264

watts.

(9)  $I_{bo} = I_{bms}/5 = 0.190/5 = 0.038$  am-

pere.

(10)  $E_{c1}$  can now be determined from the plate-characteristics curves as the control-grid voltage at which the plate voltage is 2000 volts and the plate current is 0.038 ampere;  $E_{c1} = -50$  volts.

(11)  $E'_g = |E_{c1}| + e_{cm} = 50 + 0 = 50$ 

volts.

(12)  $I_{c2} = i'_{c2}/4 = 0.160/4 = 0.040$  ampere.

(13) DP =  $E'_{e}i'_{cl}/2 = (60) (0)/2 = 0$ .

A suitable value of driving power can be

determined from Table I. For the 7094 in ICAS AB<sub>1</sub> service, a typical value of 4 watts is listed.

(14)  $R_p = E_b/1.7 I_{bms} = 2000/ (1.7 \times 0.190) = 6200 \text{ ohms.}$ 

Table I shows the maximum ratings and typical operating conditions for several popular RCA tubes in linear rf amplifier service for single-sideband, suppressed-carrier service.

It should be remembered that the typical operating conditions shown by the manufacturer (or calculated by the preceding methods) are only approximate. Minor adjustments are usually made in actual operation by slight variation of the control-grid bias or screen-grid voltage. In linear rf amplifier circuits for single-sideband, suppressed-carrier transmission, it is particularly important to check the actual operating conditions when the transmitter is first set up to assure that linear operation within the maximum tube ratings is being obtained.

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