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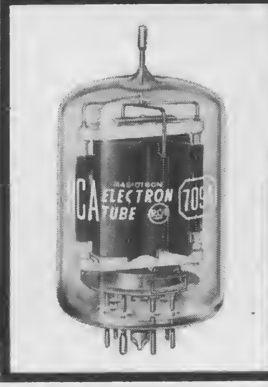

DETERMINATION OF TYPICAL OPERATING CONDITIONS

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.

Included 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_1 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_1 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_1 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: $PD = (I_{bms}/4)\ (E_b + 3\ e_{bmin})$.

(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 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_{c1} from the plate-characteristics curves as the control-grid voltage at which the plate voltage is E_b and the plate current is I_{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_{c2}: $I_{c2} = i'_{c2}/4$.

(13) Calculate DP: $DP = E'_g i'_{c1}/4$. (For AB_1 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_1 tube driving power is zero, determine the approximate driver-output requirements from published AB_2 typical operating conditions at approximately the same E'_g and operating frequency.

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

* * *

E_b	*DC plate voltage (with respect to cathode)*
e_{bmin}	*Minimum plate voltage necessary to produce the required peak current (from the characteristics curves)*
E_{c2}	*DC screen-grid voltage*
E_{c1}	*DC control-grid voltage*
e_{cm}	*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_{bms}	*Maximum signal, dc plate current*
I_{bo}	*Zero-signal, dc plate current*
i'_b	*Instantaneous peak plate current*
I_{c1}	*Maximum-signal, dc control-grid current*
I_{c2}	*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*
PD_o	*Plate dissipation at zero signal*
PI	*Plate power input at maximum signal*
PO	*Power output at maximum signal*
P_{ft}	*Feed-through power at maximum signal (cathode-drive operation)*
DP	*Driving power at maximum signal*
SI	*Screen-grid input at maximum signal*
R_p	*Effective rf plate-load resistance*

Example—The following example illustrates the calculation of typical operating conditions for class AB_1 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 ($E_{c2} = 350$ 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 0.085 ampere.

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

(4) $PD = (I_{bms}/4)\ (E_b + 3\ e_{bmin}) = (0.217/4)\ [2000 + 3\ (300)] = 157$ watts.

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

(6) $PI = E_b I_{bms} = (2000)\ (0.217) = 434$ watts.

Table I: Ratings and operating conditions for RCA tubes used as linear rf power amplifiers.

			Maximum Ratings—Absolute Values								Typical Operation									
Tube Type	Class of Operation	Service	Plate Voltage (E_b)	Grid-No. 2 Voltage (E_{c2})	Max-Signal Plate Current (I_{bms})—ma	Max-Signal Plate Input (PI)—watts	Max-Signal Grid-No. 2 Input (SI)—watts	Max.-Signal Grid-No. 1 + Grid-No. 2 Current ($I_{c1}+I_{c2}$)—ma	Plate Dissipation (PD)—watts	Grid-No. 1 Resistance —ohms	Plate Voltage (E_b)	Grid-No. 2 Voltage (E_{c2})	Grid-No. 1 Voltage (E_{c1})	Peak Grid-No. 1 Voltage (E'_g)	Zero-Signal Plate Current (I_{bo})—ma	Max-Signal Plate Current (I_{bms})—ma	Max-Signal Grid-No. 2 Current (I_{c2})—ma	Max.-Signal Grid-No. 1 + Grid-No. 2 Current ($I_{c1}+I_{c2}$)—ma	Drive Power (DP) -watts	Max-Signal Power Output (PO)—watts
2E26	AB_1	CCS	400	200	75	30	2.5		10	30 K	400	200	-25	25	9	45	10			12
		ICAS	500	200	75	37.5	2.5		12.5	30 K	500	200	-25	25	9	45	10			15
	AB_2	CCS	400	200	75	30	2.5		10		400	125	-15	30	10	75	16		0.2	20
		ICAS	500	200	75	37.5	2.5		12.5		500	125	-15	30	11	75	16		0.2	25
4-65A	AB_1	CCS	3000	600	150		10		65	250 K	1000	500	-85	85	15	85	12			40
											1500	500	-85	85	15	90	7			70
											1750	500	-90	90	10	85	9			85
	AB_2	CCS	3000	600	150		10		65		1000	250	-30	105	30	150	22		2.5	85
											1500	250	-35	100	30	125	15		1.5	125
											1800	250	-35	90	25	110	13		1.0	135
4-125A	AB_1	CCS	3000	600	225		20		125	250 K	1500	600	-90	90	30	110	9			80
											2000	600	-94	94	25	120	3			115
											2500	600	-96	96	25	115	4			165
	AB_2	CCS	3000	400	225		20		125		1500	350	-41	141	44	200	17		5.0	175
											2000	350	-45	105	36	150	3		3.0	175
											2500	350	-43	139	47	130	3		2.5	200
4-250A	AB_1	CCS	4000	600	350		35		250		2000	500	-88	88	55	200	11			230
											2500	500	-90	90	60	215	7			310
											3000	500	-93	93	60	205	5			370
	AB_2	CCS	4000	600	350		35		250		2000	300	-48	100	60	255	13		5.5	325
											2500	300	-51	100	60	250	12		5.0	420
											3000	300	-53	100	62	236	16		4.5	520
807 1625	AB_1										500	300	-32	32	22	70	8			23
		CCS	600	300	120	60	3.5		25	100 K	600	300	-34	34	18	70	8			28
		ICAS	750	300	120	90	3.5		30	100 K	750	300	-35	35	15	70	8			35
	AB_2										500	300	-30	43	30	120	10		0.2	38
		CCS	600	300	120	60	3.5		25		600	300	-32	40	24	100	9		0.1	40
		ICAS	750	300	120	90	3.5		30		750	300	-35	48	15	120	10		0.2	60
811A	B										750		0	100	16	175			10	90
		CCS	1250		175	165			45		1250		0	78	25	130			4	120
											1000		0	93	22	175			7.5	125
		ICAS	1500		175	235			65		1250		0	88	27	175			6	155
813	AB_1										2000	750	-90	80	25	130	20			165
		CCS	2250	1100	180	360	22		100		2250	750	-95	85	25	125	26			190
		ICAS	2500	1100	225	450	22		125		2500	750	-95	90	25	145	27			245
829B Natural Cooling	AB_1										500	200	-20	40	20	100	20			35
		CCS	750	225	250	100	7		30	100 K	600	200	-18	36	40	100	18			44
		ICAS	750	225	250	120	7		40	100 K	750	200	-21	42	20	100	20			55
	AB_2										500	200	-18	50	30	180	26		0.6	60
		CCS	750	225	250	100	7		30		600	200	-20	50	26	155	22		0.4	65
		ICAS	750	225	250	120	7		40		750	200	-19	50	32	160	25		0.5	85
832A	AB_1										500	180	-30	60	14	70	7			22
		CCS	750	250	90	36	5		15	100 K	600	150	-30	60	12	60	7			23
		ICAS	750	250	115	50	5		20	100 K	750	150	-32	64	12	60	7			30
833A	B	ICAS	3300		500	1300			350		3300		-80	190	60	300			20	710
6146 6159	AB_1										400	190	-40	40	32	114	13			27
		CCS	600	250	125	60	3		20	100 K	500	185	-40	40	29	108	13			35
											600	180	-45	45	13	100	12			40
											600	200	-50	50	14	115	14			47
		ICAS	750	250	135	85	3		25	100 K	750	195	-50	50	12	110	13			60
	AB_2										400	175	-41	48	17	116	9		0.2	31
		CCS	600	250	125	60	3		20		500	175	-44	51	14	121	9		0.3	41
											600	165	-44	49	11	104	9		0.2	45
											600	190	-48	55	14	135	10		0.3	55
		ICAS	750	250	135	85	3		25		750	165	-46	54	11	120	10		0.4	65
6524	AB_2										400	200	-23	72	25	145	10		0.1	39
		CCS	500	300	150	70	3		20	30 K	500	200	-26	70	20	116	10		0.1	40
											500	200	-25	76	25	145	10		0.1	50
		ICAS	600	300	150	85	3		20	30 K	600	200	-26	76	21	135	13		0.1	57
7094	AB_1	CCS	1500	400	350	300	20		100	30 K	1500	400	-65	60	30	200	35		4	185
		ICAS	2000	400	350	400	20		125	30 K	2000	400	-65	60	30	200	35		4	250
	B*	CCS	1500		350	300		200	100		1350	0	0	50	30	200		140	15	160
		ICAS	2000		350	400		200	125		1750	0	0	50	44	200		140	15	210
7580	AB_1	CCS	2000	500	350●		12		250	25 K	2000	400	-77	77	70	225	35		1	400●●

*Triode-connected cathode-drive operation

● During short periods of circuit adjustment under "single-tone" conditions, the average plate current may be as high as 350 ma.

●● Peak envelope power

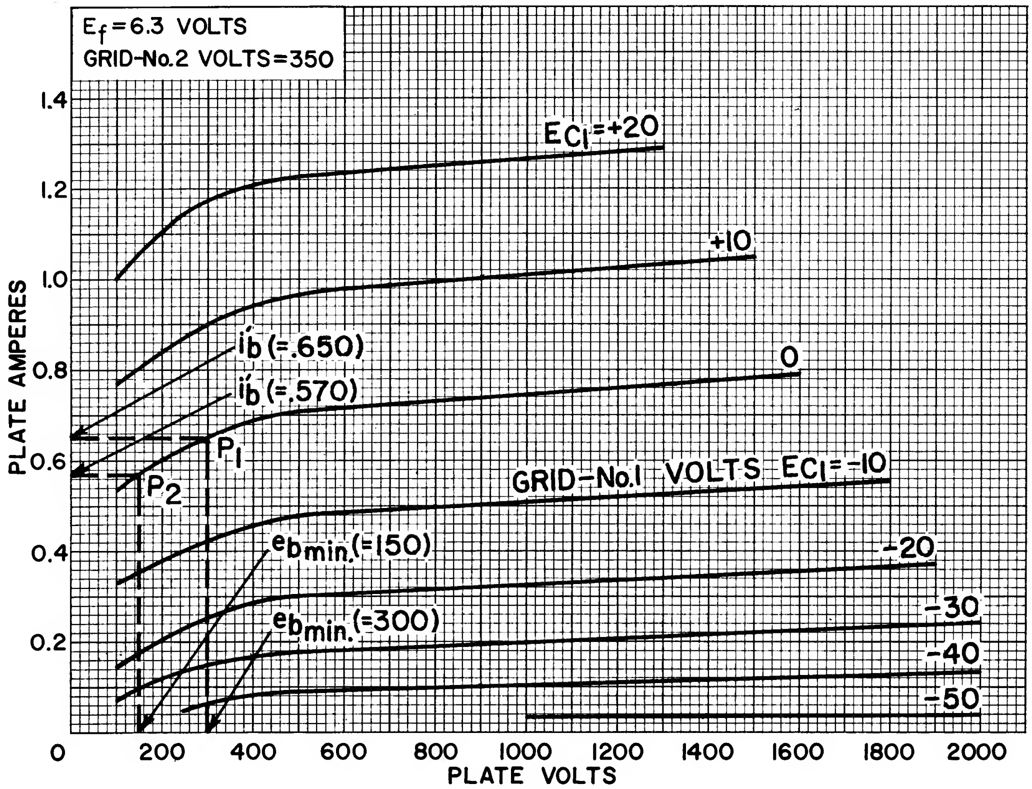

Figure 1: Typical plate characteristics of type 7094.

(7) Because both PD and PI are above the maximum ratings for the 7094, a lower value of i'_b 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-

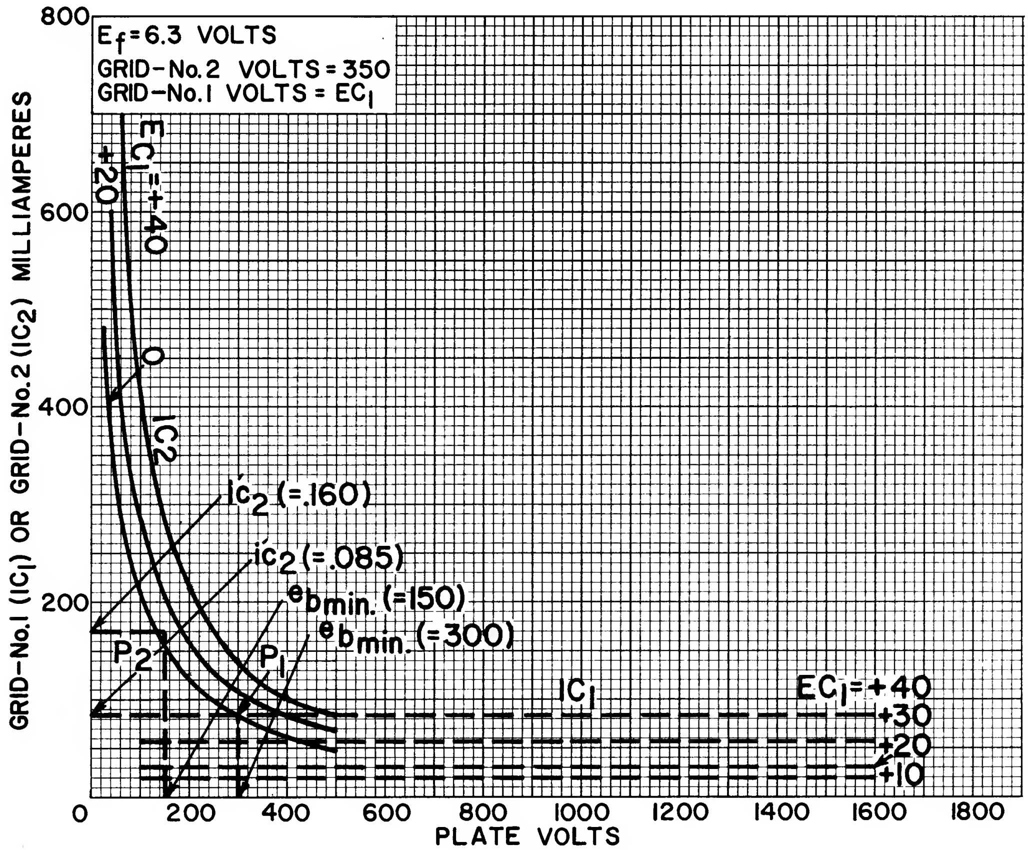

Figure 2: Typical characteristics for type 7094.

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) $I_{bo} = I_{bms}/5 = 0.190/5 = 0.038$ ampere.

(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) $DP = E'_g i'_{c1}/2 = (60)\ (0)/2 = 0$.

A suitable value of driving power can be determined from Table I. For the 7094 in ICAS AB_1 service, a typical value of 4 watts is listed.

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

From your local RCA distributor, headquarters for RCA receiving and power tubes.

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Harvey Slovik, Editor

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