HAM TIPS
RCA
A PUBLICATION OF THE RCA TUBE DIVISION
Vol. 14, No. 3 December, 1954

# Determination of Typical Operating Conditions for RCA Tubes Used as Linear RF Power Amplifiers

By A. P. Sweet*

During the past several years, there has been a tremendous increase in the use of single-sideband, suppressed-carrier transmission in amateur-radio radiotelephony. This type of transmission offers several advantages over the widely-used amplitude modulation methods. These advantages include reduced band-width and the elimination of heterodyne-interference problems. More useful power can be obtained with the same tubes and power supplies or, conversely, smaller tubes and power supplies can be used to deliver the same useful power.

With high-level amplitude modulation, a carrier and two groups of sideband frequencies are generated. The total power in the two sidebands at 100 per cent modulation is equal to one half of the carrier power. Thus, for every 100 watts of total transmitted power, 67 watts is in the carrier and 16.5 watts is in each sideband. Yet, one sideband contains all of the necessary intelligence for communication (provided certain receiver requirements are met).

### Half the Bandwidth

Single-sideband, suppressed-carrier transmission utilizes only one sideband. By the elimination of the other sideband, the bandwidth is cut in half. By suppression of the carrier, heterodyne interference is eliminated. Only 16.5 watts of power is required to convey the same intelligence. Conversely, if the original 100 watts of power is transmitted in a single sideband, six times the former useful power will be obtained.

The literature contains considerable information on various methods of generating single-sideband, suppressed-carrier signals. However, little information is available on the choice of tubes for amplifying these signals and the methods of calculating typical operating conditions for these tubes.

### Linear RF Amplifiers

Single-sideband signals must be amplified by linear rf amplifiers. These amplifiers are identical to af power amplifiers except that resonant tank circuits are used in the grid and plate circuits instead of audio-frequency transformers. Consequently, the tube manufacturer's ratings for af power amplifier and modulator service for class A, $AB_1$, $AB_2$, and class B and typical operating conditions will apply, provided the tube is also capable of operating at the higher frequencies involved. The same derating factors for plate voltage and input versus frequency shown by the manufacturer for class-C telegraphy ratings should be applied to single-sideband operation at the frequencies where they become applicable.

Because the tank circuits act as energy-storage systems, it is not necessary (as in case of audio work) to use two tubes in push-pull in class-AB or class-B, linear, rf amplifiers. However, if only one tube is used, the rf harmonics will be higher thereby making the TVI problems more severe.

Although the manufacturer's ratings are based on 100 per cent modulation with sine-wave signals, normal voice modulation reaches this condition only on the peaks of modulation. The ICAS ratings shown by RCA have

* *Power Tube Engineering, Lancaster, Pa.*

taken this factor into account. Consequently, no attempt should be made to operate above these maximum ratings. Such operation will result in shorter tube life and the possibility of early tube damage during transmitter adjustment or unexpected overloads such as microphone "howl."

Since only rf power amplifiers are being considered, class A operation will not be discussed further. Of the remaining classes, $AB_1$ operation with tetrodes or pentodes is the simplest since only the plate- and screen-voltage supplies require good regulation.

*Table I* includes the maximum ratings and typical operating conditions for several RCA tubes used as linear rf power amplifiers. If it is desired to operate at conditions other than those given, typical conditions can be calculated by means of the following procedure:

1. Make sure $E_b$ is within tube ratings.
2. Refer to the published curves. On the average plate characteristics curves, select a point on the zero grid-voltage curve near the "knee," and record $i'_b$,* and $e_{bmin}$; from the average screen-grid characteristics curves, determine $i'_{c2}$ for this point.
   ($E_{c2}$ equals the value shown for the curves used.)
3. Calculate $I_{bms}$: $I_{bms} = i'_b/3$.
4. Calculate PD:
   $$PD = \frac{I_{bms}}{4}(E_b + 3e_{bmin}).$$
5. Calculate SI: $SI = E_{c2}i'_{c2}/4$.
6. Calculate PI: $PI = E_bI_{bms}$.
7. Check the values found in steps 4, 5, and 6 to determine whether they are within tube ratings. Normally, they will be within ratings for $AB_1$ operation. If they are not, a lower value of $i'_b$ (either in the negative-grid region or at a lower screen voltage) must be selected and steps 2 through 7 repeated.
8. Calculate PO: $PO = PI - PD$.
9. Calculate $I_{bo}$: $I_{bo} = I_{bms} / 5$.
10. $E_{c1}$ can now be found on the plate characteristics curves as the grid voltage where the plate voltage is $E_b$ and the plate current is $I_{bo}$.
11. $E'_g = [E_{c1}] + e_{cm}$.
    This value of $E_g$ is the absolute value of $E_{c1}$ (the brackets mean ignore the sign) plus the algebraic value of $e_{cm}$ (include the sign). If the original point in step 2 was selected on the zero grid-voltage curve, then $e_{cm}$ is equal to zero and
    $$E'_g = [E_{c1}].$$
12. Calculate $I_{c2}$: $I_{c2} = i'_{c2}/4$.
13. Calculate DP: $DP = \frac{E'_g i'_{c2}}{2}$ (for $AB_1$ operation, $i'_{c1} = 0$ so DP is zero).

*

| | |
|---|---|
| $E_b$ | *Dc plate voltage.* |
| $e_{bmin}$ | *Minimum plate voltage for the required peak current (from the characteristics curves).* |
| $E_{c2}$ | *Dc screen voltage.* |
| $E_{c1}$ | *Dc control grid voltage.* |
| $e_{cm}$ | *Maximum grid-voltage drive to obtain the required peak plate current at a given minimum plate voltage.* |
| $E'_g$ | *Peak value of grid-voltage swing.* |
| $I_{bms}$ | *Maximum-signal, dc plate current.* |
| $I_{bo}$ | *Zero-signal, dc plate current.* |
| $i'_b$ | *Instantaneous peak plate current.* |
| $I_{c2}$ | *Maximum-signal, dc screen current.* |
| $i'_{c2}$ | *Instantaneous peak screen current.* |
| $i'_{c1}$ | *Instantaneous peak grid current.* |
| PD | *Plate dissipation at maximum signal.* |
| PI | *Plate power input at maximum signal.* |
| PO | *Power output at maximum signal.* |
| DP | *Driving power at maximum signal.* |
| SI | *Screen input at maximum signal.* |

## Class-$AB_2$ Tetrode or Class-B Triode Operation

Class-$AB_2$ tetrode and class-B triode operation provide more power than class-$AB_1$ operation, but have the disadvantage of placing stiffer requirements on the driver and grid-bias supply regulation.

Calculation of typical operating conditions other than those given in the tube data sheets is slightly more complicated for class-$AB_2$ and class-B operation than for class $AB_1$, but is still relatively simple with the procedure outlined below:*

1. Make sure $E_b$ is within tube ratings.
2. Assume a value of $I_{bms}$. A good starting point is at
   $$I_{bms} = \frac{3\text{ (rated PD)}}{E_b}.$$
   Check this value to see whether it is within ratings. If it is not, use the maximum rated value of $I_{bms}$.
3. Calculate $i'_b$: $i'_b = 3I_{bms}$.
4. From the plate characteristics curves, select a value of $e_{bmin}$ near the "knee" of the curves at which $i'_b$ can be obtained. Also record $E_{c2}$, $e_{cm}$, $i'_{c1}$ and $i'_{c2}$ for this point.
5. Calculate PD:

*Calculation for tetrodes is discussed; the triode case is the same except for the omission of the calculation of screen-input power.*

$$PD = \frac{I_{bms}}{4}(E_b + 3e_{bmin}).$$

6. Calculate SI: $SI = \frac{E_{c2} i_{c2}}{4}$

7. Calculate PI: $PI = E_b I_{bms}$.

Check the values found in steps 5, 6, and 7 to determine whether they are within the maximum ratings for the tube type. If the calculated values exceed the maximum ratings, choose a lower value of $I_{bms}$ and repeat steps 3 through 7.

If the plate dissipation and input are below the maximum ratings but the screen input is high, it may be possible to choose a higher value of $e_{bmin}$ in step 4 (and repeat steps 5, 6, and 7) to get all values within ratings. The reverse case can also be applied.

If all the values are well below maximum ratings, a higher value of $I_{bms}$ can be chosen in step 2, and steps 3 through 7 repeated to see whether the operation is still within ratings. If so, this latter set of operating conditions will provide slightly more power output.

When values that are slightly below the maximum ratings are obtained for plate dissipation, screen input, and plate input,, the corresponding value of $I_{bms}$ represents the maximum value which can be used at the original plate voltage selected. Lower values of $I_{bms}$, which give more conservative operation but less power output, can also be used.

Once the value of $I_{bms}$ is selected, the remainder of the calculation follows steps 8 through 13 shown for class $AB_1$ operation. The driving power (DP) calculated does not include the rf tube and circuit losses. Consequently, for adequate performance, at least ten times this value of power should be available from the driver.

The following example illustrates the calculation of "typical operation" conditions for the class-$AB_2$, CCS operation of the type 807 with an $E_b$ of 600 volts:

1. The maximum plate voltage rating is 600 v.
2. Determine $I_{bms}$:

$$I_{bms} = \frac{3\ (\text{rated PD})}{E_b} = \frac{3\ (25)}{600} = .125 \text{ amp.}$$

This value is above the maximum-signal, dc plate-current rating (from tube handbook or tube bulletin); therefore, the maximum rated value of 120 ma will be used as a first approximation.

3. $i'_b = 3I_{bms} = 3\,(120) = 360$ ma.
4. From the 300-v $E_{c2}$ curves, *Fig. 1,* select $e_{bmin} = 90$ v, and read $e_{cm}$ ($= +12$ v). From *Figures 2* and *3,* read $i'_{c1} = 12$ ma, and $i'_{c2} = 35$ ma, respectively.

5. $PD = \frac{I_{bms}}{4}[E_b + 3(e_{bmin})]$

$$= \frac{120}{4}[600 + 3(90)] = 26 \text{ w.}$$

6. $SI = \frac{E_{c2} i_{c2}}{4} = \frac{300(.035)}{4} = 2.6$ w.

7. $PI = E_b I_{bms} = 600\,(.120) = 72$ w.

PD and PI are both above ratings, and a lower value of $e_{bmin}$ at the required current cannot be found on the curves. Therefore, a lower value of $I_{bms}$ must be chosen; try a value of 100 ma, and repeat steps 3 through 7:

3. $i'_b = 3\ (100) = 300$ ma.
4. From the 300-v $E_{c2}$ curves: $e_{bmin} = 70$ v, $e_{cm} = +7$ v, $i'_{c1} = 8$ ma, $i'_{c2} = 35$ ma.

5. $PD = \frac{.100}{4}[600 + 3(70)] = 20.3$ w.

6. $SI = \frac{300(.035)}{4} = 2.6$ w.

7. $PI = 600\ (.100) = 60$ w.

These values are within ratings; therefore, the remainder of the calculations can be completed:

8. $PO = PI - PD = 60 - 20.3 = 39.7$ w.

9. $I_{bo} = \frac{I_{bms}}{5} = \frac{100}{5} = 20$ ma.

10. $E_{c1}$ (from *Fig. 1*) $= -35$ v.

11. $E'_g = [E_{c1}] + e_{cm} = 35 + (+7) = 42$ v.

12. $I_{c2} = \frac{i'_{c2}}{4} = \frac{35}{4} = 8.7$ ma.

13. $DP = \frac{E'_g i'_{c2}}{2} = \frac{42(.008)}{2} = .17$ w.

These values compare reasonably well with the published values.

(*Continued on Page 5*)

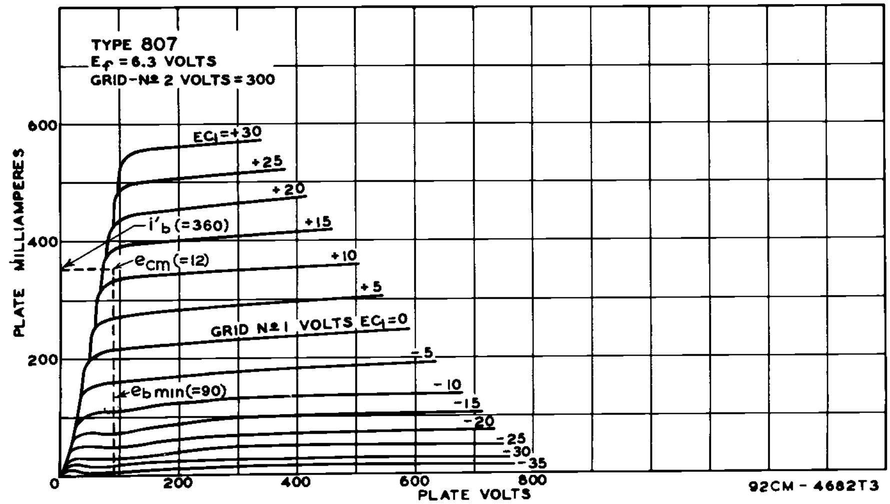


Fig. 1. Average plate characteristics for the type 807 tube (grid-No. 2 voltage = 300).

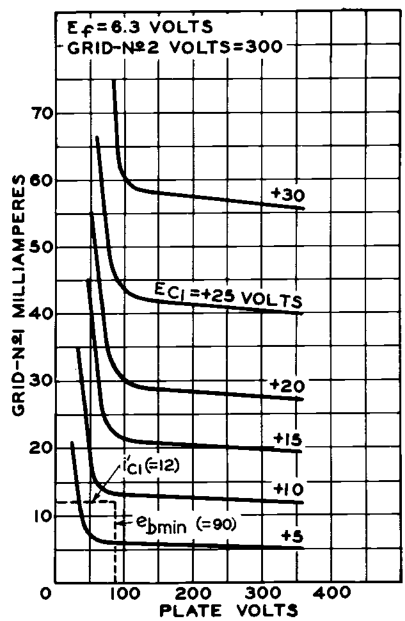


Fig. 2. Average control-grid characteristics for the type 807 tube grid-No. 2 voltage = 300).

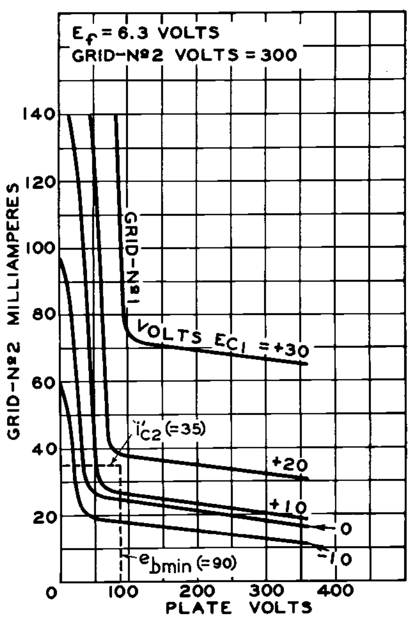


Fig. 3. Average screen-grid characteristics for the type 807 tube grid-No. 2 voltage = 300).

(*Continued from Page 3*)

*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 transmission.

It should be remembered that the typical operating conditions shown by the manufacturer (or calculated by the preceding methods) are approximate only. Minor adjustments are usually made in actual operation by varying the grid bias or screen voltage slightly. 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.

## 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 ($E_b$) | Screen Voltage ($E_{c2}$) | Max-Signal Plate Current ($I_{bms}$)-ma | Max-Signal Plate Input (PI)-watts | Max-Signal Screen Input (SI)-watts | Plate Dissipation (PD)-watts | Grid Resistance -ohms | Plate Voltage ($E_b$) | Screen Voltage ($E_{c2}$) | Grid Voltage ($E_{c1}$) | Peak Grid Voltage ($E'_g$) | Zero-Signal Plate Current ($I_{bo}$)-ma | Max-Signal Plate Current ($I_{bms}$)-ma | Max-Signal Screen Current ($I_{c2}$)-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 |
| | $AB_2$ | CCS | 600 | 300 | 120 | 60 | 3.5 | 25 | | 500 | 300 | -30 | 43 | 30 | 120 | 10 | 0.2 | 38 |
| | | | | | | | | | | 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 | CCS | 1250 | | 175 | 165 | | 45 | | 750 | | 0 | 100 | 16 | 175 | | 10 | 90 |
| | | | | | | | | | | 1250 | | 0 | 78 | 25 | 130 | | 4 | 120 |
| | | ICAS | 1500 | | 175 | 235 | | 65 | | 1000 | | 0 | 93 | 22 | 175 | | 7.5 | 125 |
| | | | | | | | | | | 1250 | | 0 | 88 | 27 | 175 | | 6 | 155 |
| 813 | $AB_1$ | CCS | 2250 | 1100 | 180 | 360 | 22 | 100 | | 2000 | 750 | -90 | 80 | 25 | 130 | 20 | | 165 |
| | | | | | | | | | | 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 |
| | $AB_2$ | CCS | 750 | 225 | 250 | 100 | 7 | 30 | | 500 | 200 | -18 | 50 | 30 | 180 | 26 | 0.6 | 60 |
| | | | | | | | | | | 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 | $AB_1$ | CCS | 600 | 250 | 125 | 60 | 3 | 20 | 100 K | 400 | 190 | -40 | 40 | 32 | 114 | 13 | | 27 |
| | | | | | | | | | | 500 | 185 | -40 | 40 | 29 | 108 | 13 | | 35 |
| | | | | | | | | | | 600 | 180 | -45 | 45 | 13 | 100 | 12 | | 40 |
| | | ICAS | 750 | 250 | 135 | 85 | 3 | 25 | 100 K | 600 | 200 | -50 | 50 | 14 | 115 | 14 | | 47 |
| | | | | | | | | | | 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 | $AB_2$ | CCS | 500 | 300 | 150 | 70 | 3 | 20 | 30 K | 400 | 200 | -23 | 72 | 25 | 145 | 10 | 0.1 | 39 |
| | | | | | | | | | | 500 | 200 | -26 | 70 | 20 | 116 | 10 | 0.1 | 40 |
| | | ICAS | 600 | 300 | 150 | 85 | 3 | 20 | 30 K | 500 | 200 | -25 | 76 | 25 | 145 | 10 | 0.1 | 50 |
| | | | | | | | | | | 600 | 200 | -26 | 76 | 21 | 135 | 13 | 0.1 | 57 |

TMK®

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

**RCA HAM TIPS** is published by the RCA Tube Division, Harrison, N. J. It is available free of charge from RCA Distributors

•

Joseph Pastor, Jr., W2KCN
Editor



FORM 3547 REQUESTED