ELECTRON TUBES

RCA Application Note

AN - 143
March 31. 1950

Use of Sharp-Cutoff Minature Pentode RCA-6CB6 in Television Receivers

This Note describes the high-frequency characteristics of miniature pentode RCA-6CB6 and its use in television rf tuners and video intermediate-frequency amplifiers. Input admittance data for the 6CB6 and design considerations for a video if amplifier system operating in the 40-megacycle region are given in detail.

Features of the 6CB6

The 6CB6 is, essentially, an improved 6AG5 with grid-plate transconductance increased 20 per cent, grid-plate capacitance decreased 30 per cent, and with the cathode and grid No.3 connected to separate base pins. The high transconductance and reduced grid-plate capacitance of the 6CB6 make it possible to obtain high gain at high frequencies, while the separate grid-No.3 connection makes possible the use of an unbypassed cathode resistor to reduce variations in input capacitance and input conductance with changes in bias. When this tube is used as an rf amplifier in a television tuner, for example, it offers advantages over other high-gain low-cost tubes because its lower grid-plate capacitance reduces oscillator radiation and its separate cathode and grid-No.3 connections make possible the use of an unbypassed cathode resistor to minimize the detuning effects encountered in sets employing automatic gain control.

Although there are several other rf pentodes having lower grid-plate capacitances than the 6CB6, the reduction in grid-plate capacitance of these types is accomplished by shielding the plate and is, therefore, accompanied by a large increase in output capacitance. Because the only capacitance in the tuned circuits of most television rf and if amplifiers is that of the tube electrodes and associated wiring, a large increase in output capacitance causes a decrease in plate-circuit impedance and a consequent loss in gain. The maximum grid-plate capacitance of the 6CB6 is 0.020 $\mu\mu f$; its output capacitance is only 1.9 $\mu\mu f$.

Input Admittance Considerations

Because tube loading is one of the major factors limiting the gain of a television rf stage, the input admittance data for the 6CB6 are of considerable design importance. Table I gives the short-circuit input admittance data for this tube at 100 megacycles.

Table I

Short-Circuit Input Admittance Data at 100 Megacycles for Type 6CB6

Operating Conditions:		
Plate Voltage	200	volts
Screen Voltage	150	volts
Control-Grid Voltage	-2.5	volts
Plate Current	9.2	ma
Screen Current	2.28	ma
Transconductance	6200	μmhos
Short-Circuit Input Capacitance:*		
Tube Operating	10.14	μμf
Tube Cutoff	8.6	μμf
Tube Cold	8.15	μμf
Capacitance Increase (cold to cutoff)	0.45	μμf
Capacitance Increase (cutoff to operating)	1.54	μμf
Short-Circuit Input Conductance:*		
Tube Operating	460	μmhos
Tube Cutoff	87	μmhos
Tube Cold	81	μmhos
Conductance Increase (cutoff to operating)	373	μmhos
Grid-to-Cathode Capacitance (measured at low frequency with tube cold)	0.0156	μμf

* Data for tube and socket, as measured on admittance meter; socket capacitance, 1 μμf; socket conductance, 2.55 μmhos.

The short-circuit input conductance at a transconductance of 6200 micromhos is given in Fig.1 for a frequency range of 20 to 100 megacycles. Fig.2 gives the input conductance at 100 megacycles for a transconductance range up to approximately 7000 micromhos. The approximate input conductance at any frequency and any value of transconductance may be determined from Fig.2 since, as shown in Fig.1, input conductance is proportional to the square of the frequency. The change in input capacitance, which is approximately the same throughout the present range of television frequencies, may be determined from Fig.3 for different values of transconductance.

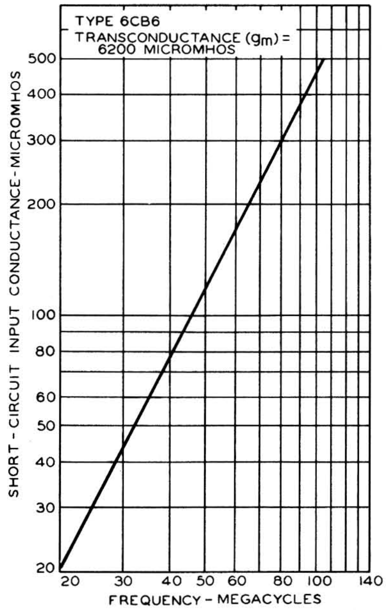


Fig. 1 - Change of Short-Circuit Input Conductance with Frequency.

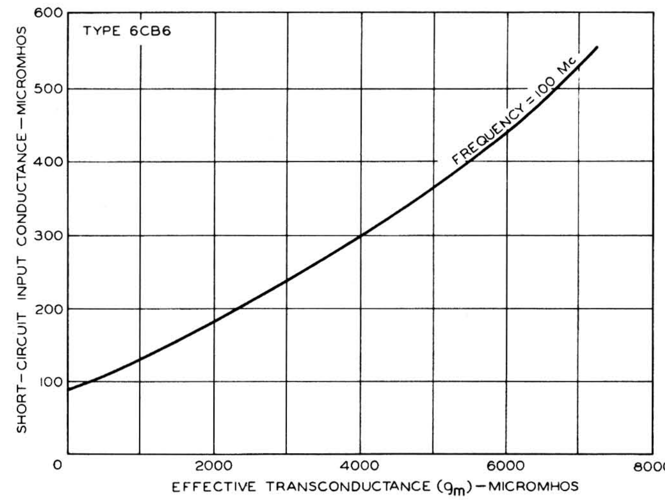


Fig. 2 - Change of Short-Circuit Input Conductance with Transconductance.

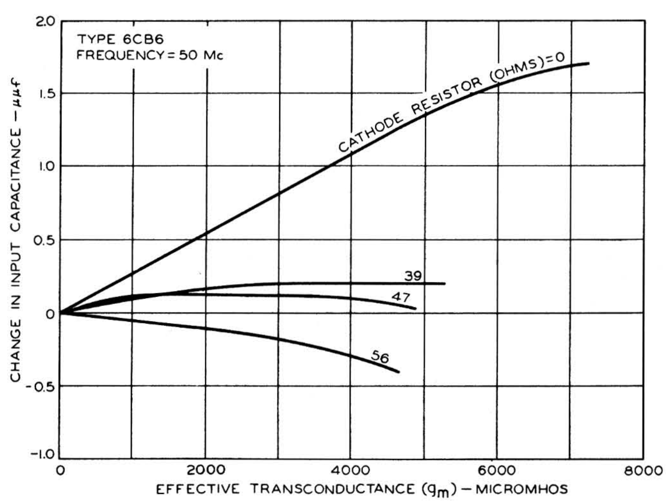


Fig. 3 - Change of Short-Circuit Input Capacitance with Transconductance for Various Values of Unbypassed Cathode Resistors.

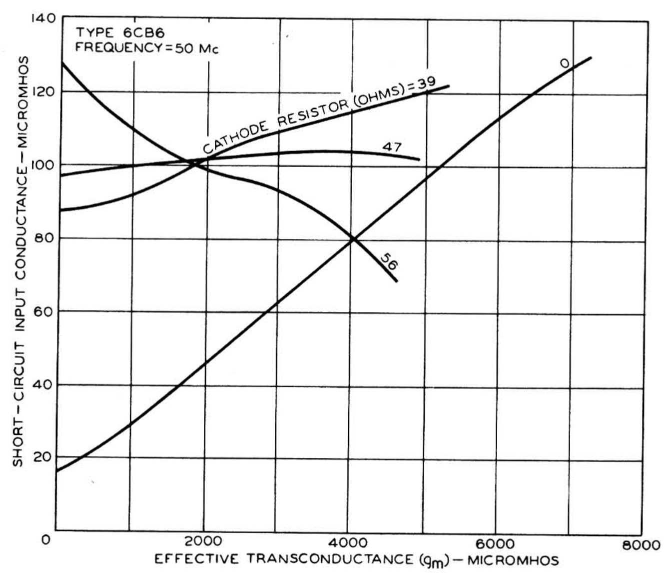


Fig. 4 - Change of Short-Circuit Input Conductance with Transconductance for Various Values of Unbypassed Cathode Resistors.

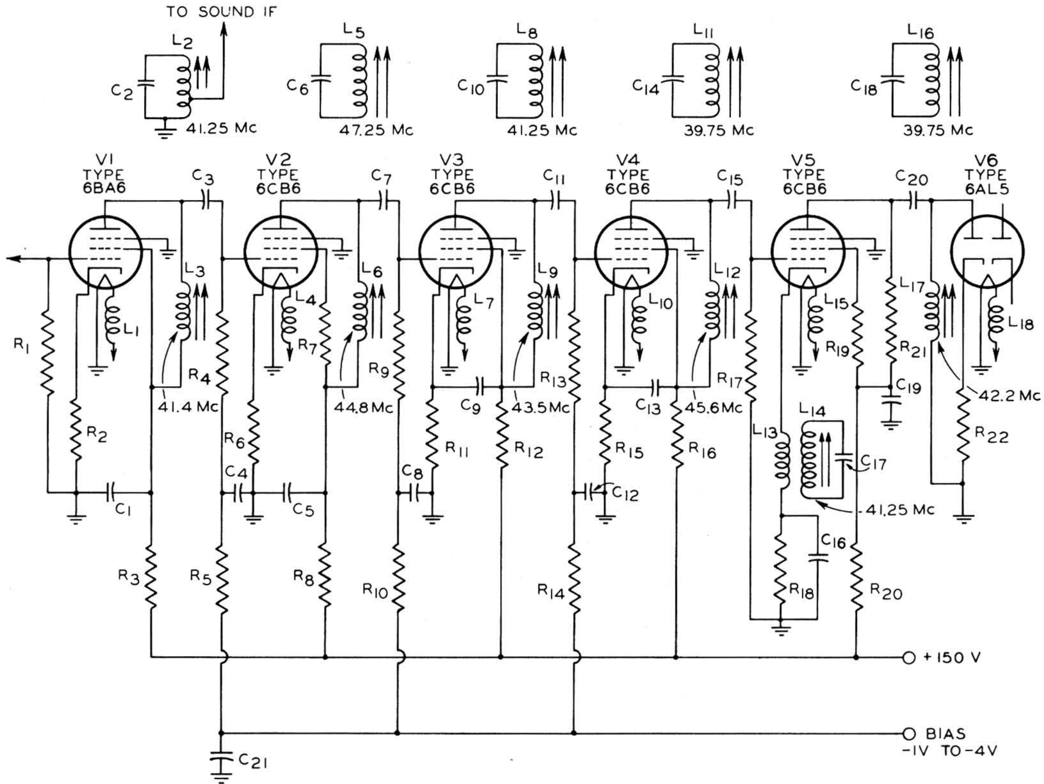
When the grid bias of any rf or if amplifier is varied in order to vary the gain, both the input capacitance and the input conductance of the tubes vary also, and the shape of the pass band is changed. In a television receiver employing automatic gain control (agc), the rf response as well as the if response will vary. The increase in input capacitance of the 6CB6 at 50 megacycles with the cathode at rf ground potential is approximately 1.5 μμf between the value of 8.6 μμf at cutoff and the value of 10.1 μμf at a transconductance of 6200 micromhos. The corresponding increase in input conductance is about 100 micromhos (from 87 micromhos at cutoff). In order to compensate for these changes in input capacitance and input conductance, an unbypassed cathode resistor can be used with the 6CB6 because of its separate grid-No.3 connection. Figs.3 and 4 were taken to determine the optimum value of cathode resistor and show that a 47-ohm cathode resistor is very nearly optimum. Although the data for Figs.3 and 4 were taken at 50 megacycles, the optimum cathode resistor will be about the same for all currently used television rf and if frequencies. Because a 47-ohm cathode resistor is too small in value to provide proper bias for the tube, it is necessary to supplement this bias either with fixed bias or with additional cathode bias supplied by a 130-ohm bypassed resistor.

Intermediate-Frequency Amplifier Design

The main requirements of a suitable television if amplifier tube are high transconductance for high gain and low grid-plate capacitance for low feedback. The combination of reduced grid-plate capacitance and high transconductance of the 6CB6 makes it possible to obtain a higher gain with this tube than with other similar types. This tube, therefore, is suitable not only for the 20-megacycle if band, but also for the RMA-recommended 40-megacycle band. The remainder of this Note considers some of the factors important to the design, construction, and operation of a stagger-tuned video if amplifier system operating with a picture if carrier frequency of 45.75 megacycles and a sound if carrier frequency of 41.25 megacycles.

Damping Resistor Considerations

In the design of a stagger-tuned if amplifier, the values of the damping resistors required to obtain the desired pass band are affected by the input conductance of the tubes used. At high frequencies, the tube input-conductance components due to transit-time effects, tube lead inductance, and feedback through the grid-plate capacitance from the plate circuit are effectively in parallel with the tuned grid circuit. The conductance components due to transit-time effects and tube lead inductances are positive in sign and vary with the square of the frequency. The input-conductance component due to feedback through the grid-plate capacitance, measured at the grid-circuit resonant frequency, may be either positive or negative. It is positive for a tube with the plate circuit tuned to a frequency lower than that of the grid circuit and negative for a tube with the plate circuit tuned to a frequency higher than that of the grid circuit. If the grid-plate capacitance is high, the input conductance will vary rapidly over the band and the grid and plate circuits will not be independently tunable. Because bandwidth depends to a considerable extent on input conductance,



C1: 5000 μμf, ceramic
C2: 22 μμf, ceramic
C3: 150 μμf, mica
C4: 5000 μμf, ceramic
C5: 470 μμf, mica
C6: 75 μμf, ceramic
C7: 150 μμf, mica
C8: 5000 μμf, ceramic
C9: 5000 μμf, ceramic
C10: 22 μμf, ceramic
C11: 150 μμf, mica
C12: 5000 μμf, ceramic
C13: 5000 μμf, ceramic
C14: 25 μμf, ceramic
C15: 150 μμf, mica
C16: 47 μμf, mica
C17: 100 μμf, ceramic
C18: 25 μμf, ceramic
C19: 5000 μμf, ceramic
C20: 150 μμf, mica
C21: 0.1 μf, paper
L1, L4, L7, L10, L15, L18: Heater chokes, 15 turns #22 enam. on 1/4" form
L2, L8, L11, L16: 7 turns #14 enam., 1/2" dia. 5/8" long concentric with and 5/8" from cold end of L3, L9, L12, L17, respectively
L3, L9, L17: 11 turns #30 enam. on 1/4" form
L6, L12: 10 turns #30 enam. on 1/4" form

All capacitors 500 volts.

L13: 2 turns #22 enam. on 1/4" form
L14: 4 turns #22 enam. on 1/4" form 3/8" long 1/4" from cold end of L13
L5: 3 turns #14 enam., 1/2" dia. 1/2" long concentric with and 5/8" from cold end of L6
R1: 1000 ohms
R2: 68 ohms
R3: 470 ohms
R4: 15000 ohms (12000 ohms at 42 Megacycles)
R5: 1000 ohms
R6: 47 ohms
R7: 10 ohms
R8: 470 ohms
R9: 3900 ohms
R10: 1000 ohms
R11: 47 ohms
R12: 470 ohms
R13: 2400 ohms
R14: 1000 ohms
R15: 47 ohms
R16: 470 ohms
R17: 82000 ohms (32000 ohms at 42 Megacycles)
R18: 180 ohms
R19: 10 ohms
R20: 470 ohms
R21: 6800 ohms
R22: 22000 ohms

All resistors 0.5 watt.

Fig. 5 - Schematic Diagram of 40-Megacycle 4-Stage Stagger-Tuned Video IF Amplifier System.

the short-circuit input-conductance curves given in Figs.1 and 2 can be used together with the formulas given in the Appendix to obtain an approximate value for the damping resistor. These curves, however, do not show the input-conductance component due to feedback through the grid-plate capacitance and, consequently, exact determination of the value of the damping resistors is a trial-and-error process with the calculated values serving as a guide.

Circuit Considerations

A circuit diagram of a 40-megacycle video if amplifier using 6CB6's is shown in Fig.5. The diagram includes the plate circuit of a converter stage and a 6AL5 video detector. Each stage is tuned by adjusting its inductance for resonance with the tube and circuit capacitance. Because tube capacitance will vary slightly from tube to tube, when tubes are changed retuning is necessary to obtain the same band-pass characteristics.

If the screen grid of an rf amplifier tube is at rf ground, the effective grid-plate capacitance of the tube will be much higher than the value measured at low frequencies and regeneration may be encountered. At frequencies of 30 megacycles and higher, however, it becomes quite difficult to ground the screen grid effectively because of the inductance of the screen-grid and bypass-capacitor leads. In many cases, therefore, it may be necessary to adjust the lead inductances so that they are in series resonance with the bypass capacitor in order to ground the screen grid effectively. In the amplifier circuit shown in Fig.5, effective grounding could have been accomplished by selecting a suitable value of screen bypass capacitor and, depending upon its physical construction, by adjusting its lead lengths for series resonance. This method of preventing regeneration, however, was not needed in this amplifier because a 10-ohm unbypassed resistor is used in series with the screen grid in the high-impedance stages (V2 and V5) and the screen grid is bypassed to the cathode in the low-impedance stages (V1, V3, and V4).

In Fig.5, two values are given in the parts list for the damping resistor in the grid circuits of V2 and V5. The first value is the dc resistance as given by the manufacturer's color code. The second value is the high-frequency resistance as measured on a Q meter at 42 megacycles. Allen-Bradley half-watt resistors were used, but it is not known whether the relation found between the dc resistance and the high-frequency resistance of Allen-Bradley resistors would be consistent for all resistors of the same value. The high-frequency resistance of resistors made by other manufacturers will, of course, also show variations from the dc resistance value. The effect of the damping resistors, therefore, requires close individual checking when a stagger-tuned amplifier for frequencies in order of 40 megacycles and higher is constructed.

Overall Video Gain

The overall video gain of the amplifier circuit given in Fig.5 is measured in the following manner. A 43.5-megacycle unmodulated signal is applied to the control grid of the first if stage, an RMS-reading vacuum-tube voltmeter is connected to the plate of the video detector (across L5), and a dc voltmeter is connected across the video detector load (R22). The ac voltage at the detector plate and the dc voltage across the detector load are measured. Then, the meter across L5 is removed and the output of the signal generator reduced until the original dc voltage across the detector load is obtained. The overall gain is calculated by dividing the voltage measured across L5 by the output voltage of the signal generator. The overall gain at a fixed bias of one volt was 14280: an average stage gain of almost 11. Approximately the same gain can be obtained with the 6CB6 in amplifiers operating at lower intermediate frequencies including the 21.25-to-25.75-megacycle band.

Amplitude Characteristics

When an unmodulated signal is impressed on the grid of the first if stage, a dc voltage is developed across the video detector load. In Fig.6, the dc voltage obtained with different values of fixed grid bias is plotted against input signal strength to show the amplitude characteristics. These characteristics are very nearly straight lines. A straight-line amplitude characteristic is desirable in order to obtain undistorted video signals from the if amplifier.

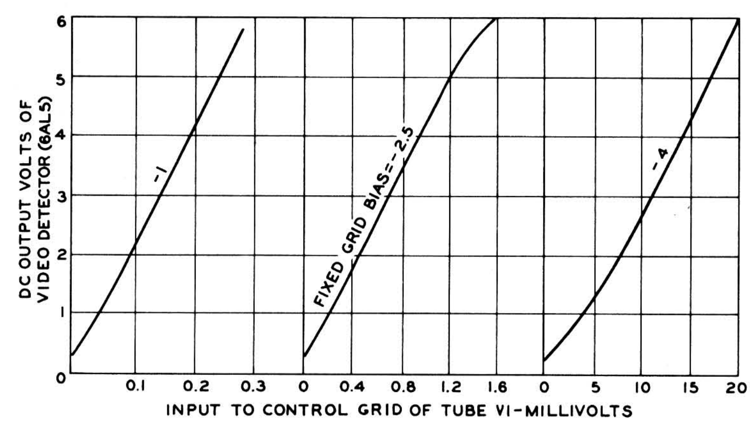


Fig. 6 - Amplitude Characteristic of Video IF Amplifier of Fig. 5.

Rejection Considerations

It is much more difficult to obtain sufficient rejection of the associated sound and adjacent-channel frequencies in a 40-megacycle system than in a 20-megacycle system. Because the ratio of mean frequency to bandwidth is almost twice as great for the 40-megacycle system as for the 20-megacycle system, the absorption traps for the higher-frequency system must have twice the Q required for the lower-frequency in order to have the same degree of rejection. In practice, it is almost impossible to obtain such high Q and still maintain a convenient physical coil size. The unloaded Q of the traps used with the amplifier described in this note was approximately 300. Even with such high-Q traps, it was found necessary to use two traps at 41.25 and 39.75 megacycles and to accept less than the desired rejection.

For the least effect on the desired portion of the response curve and the smallest "after-response" due to the rejection traps, each trap, in addition to having high Q, should be coupled to a circuit which is relatively **close** to it in frequency.

Band-pass Data

The band-pass characteristics of the amplifier are obtained by applying the if signal to the grid of the 6BA6 mixer stage and varying the input-signal voltage to obtain a constant dc voltage across the video detector load throughout the pass band. Band-pass characteristics of the system are shown in Figs.7 and 8. Fig.7 is the response before rejection traps were added. These curves show a slight change in response with increasing grid bias, but the change is not enough to have any discernible effect on picture quality. Fig.8 shows the response after the addition of rejection traps. Obviously, the rejection at the frequency of the adjacent picture carrier and associated sound carrier is poor and the "after-responses" are quite pronounced. If sufficient space is available, additional rejection and smaller "after-responses" may be obtained by increasing the wire size and coil diameter of the rejection traps, thereby increasing their Q. Further improvement could be obtained by coupling to the converter stage or to the video detector stage with a double-tuned circuit and increasing the selectivity at the edge of the pass band. If a reduction in bandwidth is not too objectionable the overall bandwidth may be reduced, making it easier to trap out the undesired frequencies. Finally, if cost is not a major factor, the tuned circuits may be made of band-pass circuits such as overcoupled double-tuned circuits or m-derived networks.

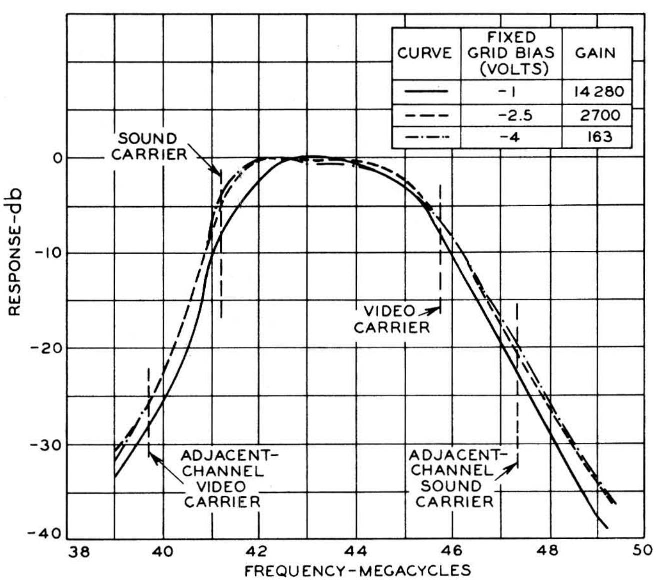


Fig.7 - Frequency Response of Video IF Amplifier Before Addition of Rejection Traps.

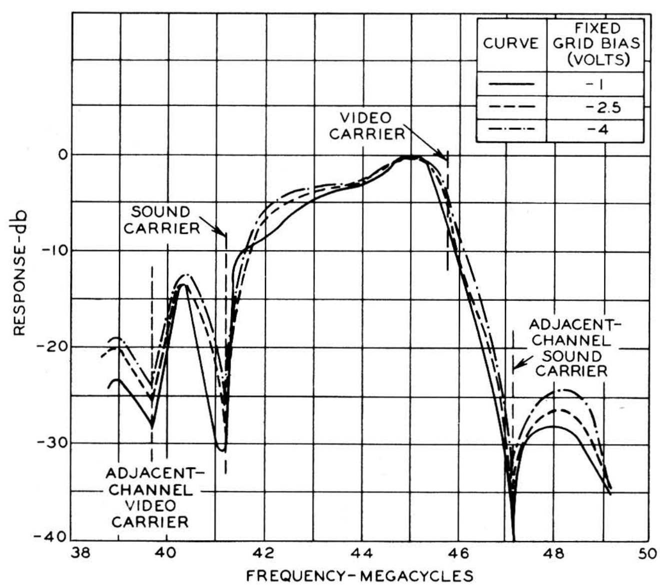


Fig.8 - Frequency Response of Video IF Amplifier After Addition of Rejection Traps.

APPENDIX

The following formulas* apply to the calculation of the resonant frequencies and the values of grid damping resistor for stagger-tuned circuits when the system dissipation factor (δ), which is the ratio of bandwidth (Δf) to geometric mean frequency (f_o) as defined below, is less than 0.3.

$$\delta = \frac{\Delta f}{f_o} = \text{ratio of bandwidth to geometric mean frequency.}$$

$$\Delta f = f_2 - f_1 \qquad f_o = \sqrt{f_1 f_2}$$

where f_1 = lower frequency edge of pass-band in cycles per second (0.707 response);
and, f_2 = upper frequency edge of pass-band in cycles per second (0.707 response).

With the values f_o and δ of the amplifier determined and with the desired number of stagger-tuned stages assumed (either four of five), subsitution of these values in the formulas below furnishes the required resonant frequency and dissipation factor for each stage.

It will be noted that two sets of formulas are given for a four-stage amplifier, one set for an amplifier consisting of two pairs of identically tuned stages (staggered pairs), and one set for an amplifier consisting of four individually tuned stages (staggered quadruple). Design problems for an amplifier using staggered pairs are simplified because only two frequencies are required and because the dissipation factors for all stages are the same. An amplifier employing a staggered quadruple, however, will have slightly higher gain and a flatter response curve.

Formulas for Four-Stage Stagger-Tuned System (Staggered Pairs)

Stage	Resonant Frequency	Dissipation Factor
A	$f_o + 0.35\Delta f$	$0.71\,\delta$
B	$f_o - 0.35\Delta f$	$0.71\,\delta$
C	$f_o + 0.35\Delta f$	$0.71\,\delta$
D	$f_o - 0.35\Delta f$	$0.71\,\delta$

* G.E. Valley and H. Wallman, VACUUM TUBE AMPLIFIERS (1st ed.; New York: McGraw-Hill Book Co. Inc., 1948), p. 186.

Formulas for Four-Stage Stagger-Tuned System
(Staggered Quadruple)

Stage	Resonant Frequency	Dissipation Factor
A	$f_o + 0.46\Delta f$	0.5δ
B	$f_o - 0.46\Delta f$	0.5δ
C	$f_o + 0.92\Delta f$	0.19δ
D	$f_o - 0.92\Delta f$	0.19δ

Formulas for Five-Stage Stagger-Tuned System
(Staggered Quintuple)

Stage	Resonant Frequency	Dissipation Factor
A	$f_o + 0.48\Delta f$	0.31δ
B	$f_o - 0.48\Delta f$	0.31δ
C	$f_o + 0.29\Delta f$	0.81δ
D	$f_o - 0.29\Delta f$	0.81δ
E	f_o	δ

The damping resistor (theoretical value) for each stage is determined from the dissipation factor and the resonant frequency of the stage by means of the following equation.

$$R = \frac{1}{2\pi f_r C d}$$

where R = theoretical value of damping resistance in ohms and includes the equivalent shunt resistance of the tuned circuit (measured or estimated) and the input conductance of the tube (from Fig.1).
f_r = resonant frequency of the stage in cycles per second.
d = dissipation factor of the stage.
C = total capacitance across circuit in farads (including tube and wiring capacitance).

The average stage gain (m) at resonance is

$$m = \frac{g_m}{2\pi C\Delta f}$$

where g_m = grid-plate transconductance in mhos

The overall gain (M) of the stagger-tuned system is $M = m^n$

where n = number of stagger-tuned stages.

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JUNE 15, 1950

ERRATA NOTICE

for

Application Note AN-143 "Use of Sharp-Cutoff Miniature Pentode RCA-6CB6 in Television Receivers"

Page 2. Last item in tabulation, "Grid-to-Cathode Capacitance," should read "Grid-to-Plate Capacitance."

Page 6. First sentence of second paragraph under **Circuit Considerations** should read, "If the screen grid of an rf amplifier tube is **not** at rf ground, the effective grid-plate capacitance of the tube will be much higher than the value measured at low frequencies and regeneration may be encountered."

Page 7. In lines 2, 5, and 8, L5 should be L17.

Page 10. In Formulas for Four-Stage Stagger-Tuned System, Stages C and D should read

C	$f_o + 0.19\,\Delta f$	$0.92\,\delta$
D	$f_o - 0.19\,\Delta f$	$0.92\,\delta$