# VIDEO AMPLIFIERS

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***Part 9. An analysis of the design of wide-band video amplifiers. Special tubes and circuit design are necessary for high definition television reception.***

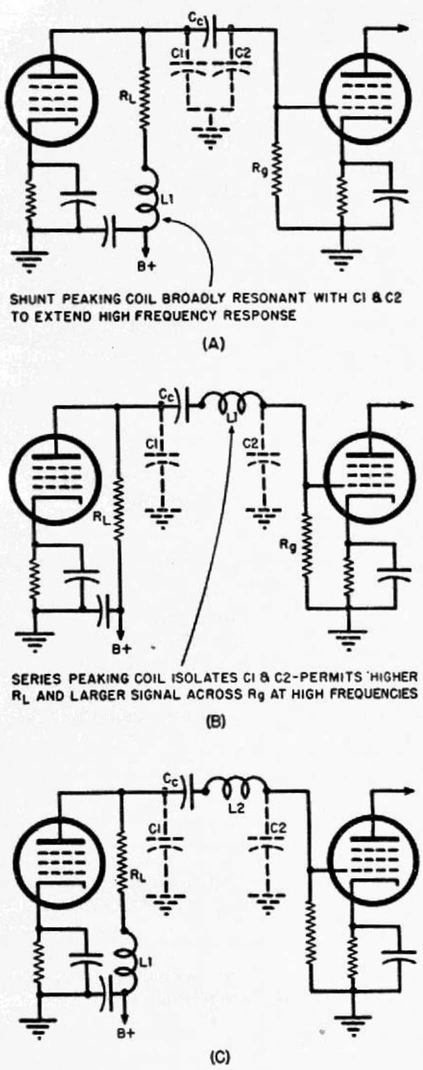


**Fig. 1. High frequency compensation. (A) Shunt peaking. (B) Series peaking. (C) Combination of shunt and series peaking.**

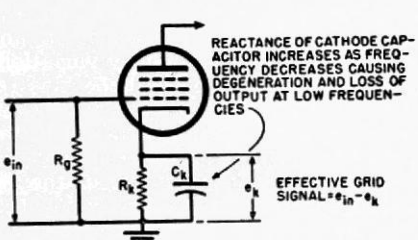


**Fig. 2. The effect of the cathode capacitor on the output gain at low frequencies.**

THE video amplifier is a resistance-coupled amplifier with necessary refinements to extend its frequency range. Video amplifiers used in critical television transmitter or test equipments have a linear response from almost zero cycles to as high as five or ten megacycles. The ordinary audio amplifier is lucky to have a linear response from one hundred cycles to six thousand cycles. A high-definition television receiver will have a linear response from 20 cycles to four megacycles; the smaller television receiver from 30 cycles to 2 or 2½ megacycles. A set with a large picture tube generally has a video amplifier with a broad response because the tube can more fully utilize the high-frequency components of the signal. In so doing, a sharp, well-defined picture appears on the fluorescent screen.

In the resistance-coupled amplifier and in the video amplifier, capacity limits both the high- and low-frequency characteristics. Low-frequency degeneration is caused by the increasing reactance of the series coupling capacitors and cathode by-pass capacitors; high-frequency degeneration, by the decreasing reactance of distributed shunt capacity (tube input and output capacities, wiring capacity, and parts capacity to ground). The video amplifier has the following features:

1. High mutual conductance tubes.
2. Tubes with low input and output capacities.
3. Low value plate load resistors.
4. Large value by-pass and coupling capacitors.
5. High-frequency compensating circuits.
6. Low-frequency compensating circuits.
7. An occasional direct-coupled stage (no interstage coupling capacitor).
8. Proper positioning of component parts to reduce distributed capacity.

The effects of capacity on the high- and low-frequency limits can best be demonstrated with simple mathematics. For example, the effects of shunt capacity on 1000 cycles and 1 megacycle can be clearly demonstrated by calculating the output voltage of a vacuum-tube circuit which has two milliamperes of alternating plate current. See Fig. 5. Output voltage, of course, is equal to the alternating component of plate current, times the load impedance. Consequently, in a plate circuit using a 100,000-ohm load resistor and having a total distributed capacity of 40 μμfd., the output voltage for a 1000-cycle, 2-ma., component of plate current is:

$$e_o = i_p \times Z_L$$

$$e_o = .002 \times \frac{R_L \times X_{ct}}{\sqrt{R_L^2 + X_{ct}^2}}$$

$$e_o = .002 \times \frac{10^5 \times 4 \times 10^6}{\sqrt{(10^5)^2 + (4 \times 10^6)^2}}$$

$$\therefore e_o = 200 \text{ volts approx.}$$

Output voltage for a 1-megacycle, 2-ma., component of plate current is:

$$e_o = i_p \times Z_L$$
$$= 8 \text{ volts approx.}$$

This represents a voltage differential of 192 volts, or the gain of the stage drops 96% at one megacycle in comparison with the gain at 1000 cycles. It is clear how little the shunt capacity affects the lower frequencies (output determined primarily by the

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**Fig. 3. Loss of gain at low frequencies.**

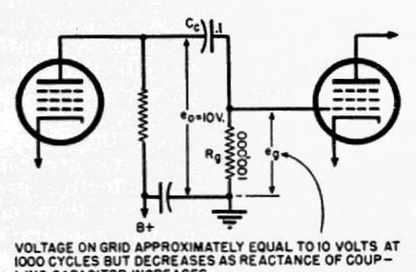



**Fig. 4. Low frequency compensation.**

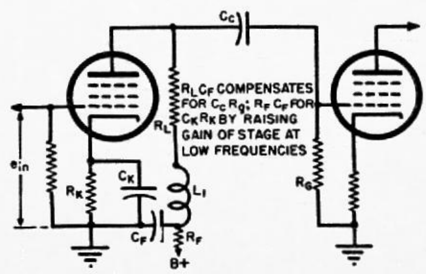
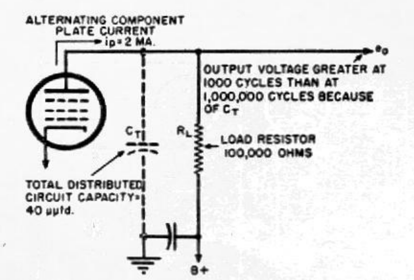
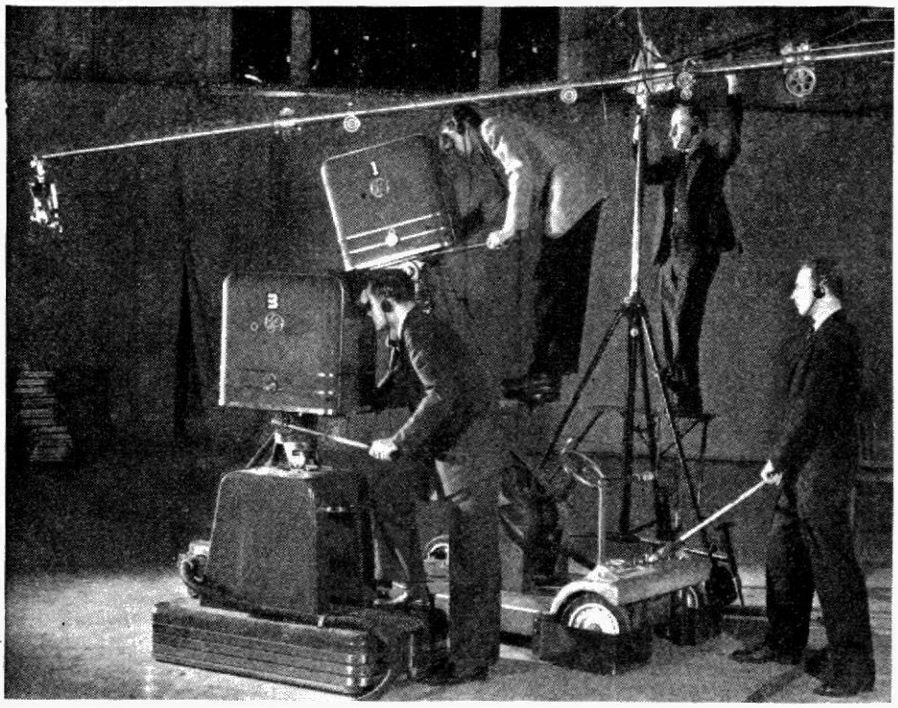



**Fig. 5. Loss of gain at high frequencies.**





Camera and boom at General Electric's television station WRGB at Schenectady, N. Y.

value of the resistor at these frequencies), but how dominant it becomes at the high frequencies.

If the value of the plate resistor is reduced to 4000 ohms, the effect of the shunt capacity is minimized. Now, under the same conditions, the output for a 1000-cycle component is:

$$e_o = i_p \times Z_L$$

$$e_o = \frac{.002 \times 4000 \times 4 \times 10^6}{\sqrt{4000^2 + (4 \times 10^6)^2}}$$

$$= 8 \text{ volts approx}$$

The output for a one-megacycle component is:

$$e_o = i_p \times Z_L$$

$$= \frac{.002 \times 4000 \times 4 \times 10^3}{\sqrt{4000^2 + (4 \times 10^3)^2}}$$

$$= 5.65 \text{ volts approx.}$$

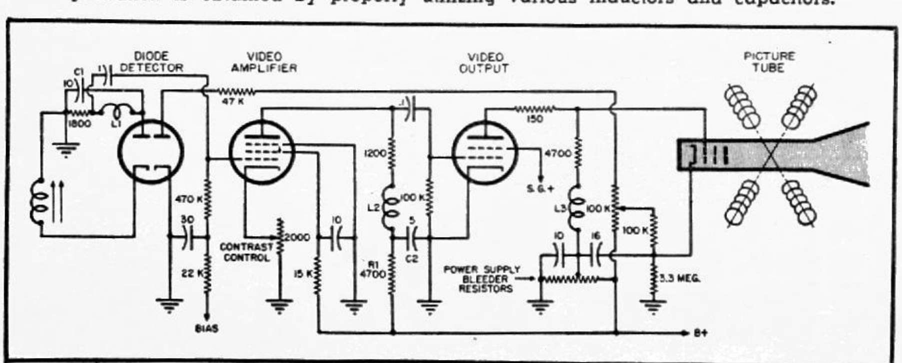
This represents a voltage differential of 2.4 volts, or 30.3% drop in output voltage at one megacycle. Although the response has been leveled off, the gain is much less. Therefore, a tube with a high mutual conductance (measure of how effective a tube is in converting a grid voltage variation to a plate current variation) is used to obtain the greatest possible variation in plate current. The greater the plate current variation, the greater will be the output voltage developed across the low plate resistor, which must be used, of necessity, to prevent high-frequency degeneration. Thus, response can be improved by keeping shunt capacity to a minimum and reducing the value of the load resistor. Gain can be increased by keeping shunt capacity to a minimum (permitting insertion of a higher load resistor), and by using a tube with a high mutual conductance.

A similar example can be used to demonstrate low-frequency degeneration by series coupling capacitors. See Fig. 3. In this circuit, the coupling capacitor has a value of .1 μfd. and the grid resistor a value of 100,000 ohms. Now, at 1000 cycles, the reactance of the coupling capacitor is approximately 1600 ohms, and there is only a tiny voltage drop across the capacitor of the series resistor-capacitor voltage divider, consisting of the coupling capacitor and grid resistor. Thus, if 10 volts appears in the output, $e_o$, of the preceding stage, this voltage, almost in its entirety, appears on the grid of the next tube. However, if the frequency of the 10-volt output signal is thirty c.p.s., the reactance of the coupling capacitor is approximately 53,000 ohms, which is more than one-half the resistance of the grid resistor. Consequently, a greater portion of the 10-volt output signal appears across the capacitor.

The low-frequency response can be improved in two ways; by increasing the value of the capacitor (increased capacity reduces reactance at all frequencies), or by increasing the value of the grid resistor so that a greater percentage of the total voltage applied to the series combination appears across the resistor even at low frequencies. These methods are subject to a number of limitations. For instance, the value of the grid resistor may not be increased beyond a certain safe value, set by the manufacturer, to prevent faulty operation caused by excessive gas currents. Another limitation is the fact that certain tubes in television circuits draw a limited amount of grid current. The excessively high grid resistor would develop too large a negative bias. Capacitor value can not be increased too much for the d.c. leakage increases, and the increased capacity to ground of the physically larger capacitor reduces the high-frequency response.

A second factor which causes low-frequency degeneration is the increasing reactance of the cathode by-pass capacitor as the frequency decreases. For example, if a 10μfd. by-pass capacitor shunts a 400-ohm cathode resistor, Fig. 2, the capacitor's reactance is 16 ohms at 1000 cycles, but, at 30 cycles, it jumps to 530 ohms. The cathode by-pass capacitor is actually a filter capacitor, as it levels off and fills in any audio frequency variations appearing across the cathode bias resistor. Now, to be an effective filter, the reactance of the capacitor at the prescribed frequency must not be greater than 1/5 the value of the resistor it shunts. In our example, this reactance is only 16 ohms at 1000 cycles and, consequently, it effectively filters any 1000-cycle variation attempting to appear across the cathode resistor. However, at 30 cycles, this reactance is even larger than the value of the cathode resistor, seriously reducing the effectiveness of the filter action. Thus, at 30 cycles, there is a considerable variation across the cathode resistor. Since the effective signal voltage appearing on the grid of the tube is measured from grid to cathode, this variation, $e_k$, across the cathode resistor, subtracts from the grid signal, $e_{in}$, reducing the effective grid signal to some value less than $e_{in}$. Consequently, less output appears in the plate circuit at 30 cycles than at 1000 cycles ($e_{in}$ equal at both frequencies) at which freq. $e_k$ is negligible.

Fig. 6. Schematic diagram of G.E. model 90 video amplifier. Frequency compensation is obtained by properly utilizing various inductors and capacitors.



A high-frequency compensating circuit, Fig. 1, inserted in the plate circuit of a video amplifier, can be used to sustain stage gain at the same level that it is over the middle range of frequencies, in spite of the decreasing reactance of distributed shunt capacity. The presence of the inductor in the plate circuit, Fig. 1A, forms a low $Q$ resonant circuit with the total distributed capacity and effectively equalizes the stage gain up to the desired top frequency for which the amplifier is designed. Another way of looking at the same so-called "shunt-peaking coil" system is that the increasing reactance of the inductor $L_1$, as frequency rises, balances the effects of the decreasing reactance of the total distributed capacity $C_t$ $(=C_1+C_2)$, maintaining, through a broadly resonant condition, the plate impedance essentially constant. Series peaking and combination series-shunt peaking, which perform similar tasks, are shown in Figs. 1B and 1C.

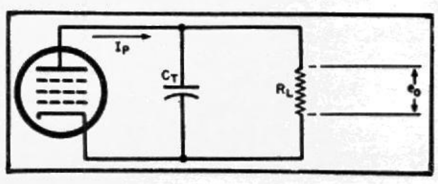
With series peaking, a greater gain is obtainable because, in calculating the value of the load resistor, only the plate circuit distributed capacity must be considered, the series inductor $L_1$ effectively isolating the plate circuit distributed capacity $C_1$ and the grid circuit distributed capacity $C_2$. Consequently, a higher value load resistor can be used without impairing high-frequency response, because the reactance of the distributed capacity does not become appreciable as quickly. The increase in load resistance causes an increase in stage gain. Furthermore, the inductor $L_1$ and grid circuit distributed capacity $C_2$ form a broadly resonant series circuit at the high-frequency limits, developing an appreciable voltage across $C_2$ and $R_g$, and therefore, on the grid of the tube.

In Fig. 1C, combination series-shunt peaking is used, effectively combining the advantages of both series and shunt peaking. A still larger value of load resistor can be used, increasing stage gain a bit more.

### How to Improve Low-Frequency Response

With low-frequency compensation, the actual gain of the stage is increased at lower frequencies to compensate for the loss of signal across a grid-coupling capacitor, or low-frequency degeneration caused by insufficient cathode filtering. A typical low-frequency compensated stage is shown in Fig. 4. Capacitor $C_f$ has an increasing reactance as the frequency decreases and, in combination with load resistor $R_L$, causes the plate impedance and stage gain to be greater

**Fig. 7. Equivalent output circuit at high frequencies. $C_t$ is the deciding factor.**



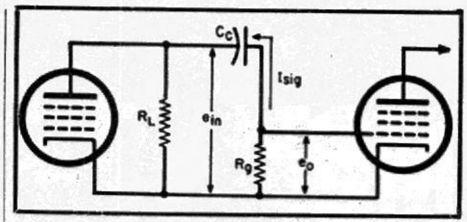



Fig. 8. Equivalent output circuit at low frequencies. $C_c$ is the deciding factor.

at lower frequencies. Thus, the loss in signal across $C_c$ at low frequencies is compensated for by a greater plate voltage signal, keeping an essentially constant signal across the grid resistor $R_g$ with a decrease in frequency. Likewise, the combination of $R_f$ and $C_f$ perform the same task with respect to cathode degeneration by raising the plate impedance of the stage in proportion to the loss of signal through degeneration at low frequencies.

### G.E. Model 90 Video Amplifier

The first frequency compensation encountered in the model 90 video amplifier (Fig. 6) is the diode peaking coil, $L_1$, which, in conjunction with the i.f. by-pass capacitor $C_1$, plus distributed capacities, forms a broadly tuned resonant circuit to keep the diode response essentially linear up to the high-frequency limit. Shunt peaking, inductors $L_2$ and $L_3$, is used in the plate circuits of the video amplifier and video output stage. Capacitor $C_2$ and resistor $R_1$ form a low-frequency compensating combination in the plate circuit of the video amplifier. Low-frequency response is held up by the large coupling capacitors; high-frequency response, by the low-value plate resistors. Since there are no cathode bias resistor-capacitor combinations to cause degeneration in the video amplifier, no correction on this count is necessary.

### Phase Distortion

Phase distortion in the audio amplifier is not noticeable unless it is severe; the same amount of distortion in a video amplifier seriously impairs its picture sharpness. The reason it is so noticeable is because the beam moves at such a high velocity across the screen that if one frequency component of a signal is delayed a number of microseconds with respect to another, the beam has already sped on an appreciable distance. Thus, if two different frequency components of a signal were originally transmitted with their peak amplitudes occurring at the same instant, phase distortion (referred to as non-linear phase delay) would cause one signal to reach peak amplitude before the other on the grid of the picture tube. Therefore, peak amplitude of one frequency component would be displaced with respect to the other on the picture-tube screen, causing the picture to blur.

Phase distortion can also alter the waveform of a rectangular pulse, for the pulse is composed of a fundamen-

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tal frequency and a series of harmonics. Now, if phase distortion is present, the higher harmonic components may lead or lag the fundamental and lower harmonics, which rounds off or distorts the pulse, causing delay in triggering or instability. Fortunately, if a linear frequency response is maintained stage by stage, the phase distortion or non-linear time delay is not serious; however, in systems in which there is lumped frequency compensation, there can be serious phase distortion which must be corrected by a phase network or some form of phase compensation in each stage.

In a parallel resistor-capacitor combination, a prescribed length of time is required for the voltage to build up across the combination after the plate current variation has passed through it. The actual delay time is proportional to the decreasing reactance-resistance ratio. When the reactance decreases, with an increase in frequency, to a value approaching the value of the resistance, the delay time or lagging angle increases. If the resistance is very small in comparison to the reactance of the distributed capacity (Fig. 7) over the middle range of frequencies, there is no appreciable lag, plate current variations and output voltage $e_o$ being essentially in phase. However, at the high frequencies, where the reactance of the distributed capacity approaches the value of the resistor, the time delay is constant for all frequencies (equal angles of lag); there is no phase distortion. This example is comparable to the usual 180-degree phase shift in a vacuum tube. However, if some frequencies, in this case the high frequencies, are delayed with respect to other frequencies as far as phase angle is concerned, it means that they are also delayed with respect to each other as far as time is concerned. Thus, it will take a higher frequency longer to build up across the combination than a lower frequency, producing phase distortion.

Likewise, the interstage coupling capacitor introduces phase distortion because it causes the lower frequencies, as they appear across the grid resistor, to lead the middle range frequencies. At frequencies where the reactance of the coupling capacitor is negligible in comparison with the grid resistance, the grid voltage is essentially in phase (no phase lag) with the signal current flowing through the series coupling-capacitor and grid-resistor combination. However, at low frequencies where the reactance of the coupling capacitor has increased to a value approaching the value of the grid resistor, the signal current begins to lead the voltage $e_{in}$ applied to the series combination. Since the voltage across the grid resistor is in phase with this current, it effectively leads similar voltages of the middle range of frequencies, which also appear across the grid resistor and which, supposedly, are to reach peak amplitude at the same instant.

Next month's installment treats the video amplifier in detail, demonstrating how it fits into the over-all theory of operation. It explains, among other things, signal polarity, necessity for direct coupling, d.c. reinsertion, contrast control, picture-tube bias, etc. In preparation for this article, the reader should review installments 2, 3, and 4, to refresh and reinforce his knowledge of the general over-all operation of the television system.

*(To be continued)*

## Spot Radio News
*(Continued from page 16)*

***Personals***

**Arie Vernes** has been appointed executive vice president and general manager of *Philips Export Corporation.* He will also continue his post as Secretary of the organization. . . . **William E. Snodgrass,** formerly executive v. p. of the *Dictograph Products Company* has joined *Western Electric* as general manager of the hearing aid division. . . . **Haraden Pratt** has been elected Chairman of the Radio Technical Planning Board, succeeding **Dr. W. R. G. Baker.** Mr. Pratt is vice president and chief engineer of *American Cable and Radio Corporation,* an *I. T. & T.* subsidiary. . . . In preparation for a postwar expansion of the phonograph record business, *RCA Victor* has announced the return of **Eli Oberstein,** to the Popular Artists Relations and Repertoire post he left in 1939. . . . **Lloyd L. Spencer,** vice president in charge

**One of the first to announce a television receiver out of the luxury class, the Viewtone Co of New York City, recently demonstrated its new set which they claim is designed for low cost mass production. The set retailing for about $100 is a small table-model. It uses a 7-inch viewing tube which affords sharp, clear-cut images and surprisingly comfortable viewing with a minimum of eye-strain.**