AUDIANA

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The Miller Effect

The Miller effect, a frequently mentioned electronic phenomenon, is of importance in audio work, but is seldom discussed thoroughly. It results in large values of input capacitance at the grid of a three-element tube, or of a pentode with added grid-plate capacitance, when the tube is used in the conventional plate-loaded amplifier circuit. This capacitance is in addition to the grid-cathode capacitance caused by the geometry of the tubes, and frequently limits the high-frequency response of amplifiers in which such tubes are used.

Figure 1(A) shows the circuit of a triode with the interelectrode capacitances contributed by the tube geometry indicated by dotted lines. The equivalent circuit for this tube is shown in *Fig.* 1(B). If an alternating current signal E_g is applied at the input terminals, alternating currents will flow through the capacitors C_{gp} and C_{gk}. These currents together will be I_g. The amount of current I_g that flows through these capacitors is determined by the voltage and frequency of the alternating current input in addition to the gain and plate resistance of the tube and its load impedance. Examining the circuit, we see that the output voltage of the tube is effectively in series with the input voltage and the capacitor C_{gp}. Therefore if we add the currents algebraically, the current due to the output voltage $-KE_g$ is seen to aid the current due to the input voltage E_g.

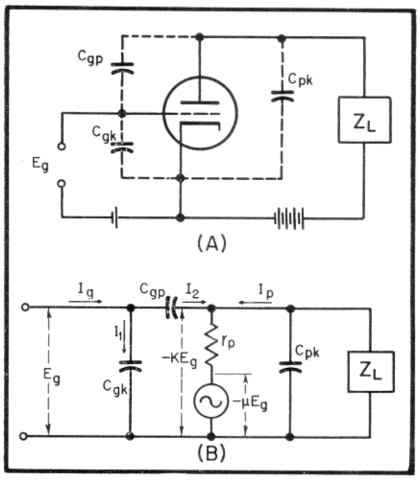


Fig. 1 (A). Typical tube circuit with inter-electrode capacitances indicated. (B). A.c. equivalent circuit at high frequencies.

To develop the full picture of what takes place it is best to use some simple mathematics and develop expressions for the gain of the amplifier stage and the input admittance $\left(\frac{1}{R+jX}\right)$ of the amplifier. With these figures we can determine quite closely the numerical value of the input capacitance of the stage.

From the equivalent circuit, we see that the output voltage is divided between the load Z_L and the plate resistance r_p and we may therefore write the expression for the output voltage

$$E_o = -\mu \frac{Z_L}{r_p + Z_L} E_g$$

and the gain, which is the ratio of input to output voltage across the load, is therefore

$$K = \frac{E_o}{E_g} = -\mu \frac{Z_L}{r_p + Z_L}$$

If the load is not a pure resistance it is possible to have a complex gain; that is, the output voltage can have a component that is more or less than the expected 180 deg. out of phase with the input voltage. When there is such a phase difference it will be indicated by ψ. In this case we shall have to express the gain as $K/\underline{\psi}$. Examining *Fig. 2* it can be seen that the output voltage will be $-KE_g$, and that the current through the capacitor C_{gp} is $\frac{KE_g}{Xc_{gp}}$ and that due to the input voltage E_g is $\frac{E_g}{Xc_{gp}}$, where X is the reactance of the capacitor and may be expressed as $\sqrt{-1}\,2\pi fC$ or $j\omega C$ or $\omega C/\underline{90°}$. We can now determine the currents I_g, I_1 and I_2 (disregarding the effect of C_{gp} on the gain of the tube, and any effects due to the a.c. plate current dividing between the load and C_{gp}. These are both valid assumptions for audio frequency work) as follows:

$$I_g = I_1 + I_2$$
$$I_1 = j\omega C_{gk} E_g$$
$$I_2 = j\omega C_{gp}\ (E_g + KE_g/\underline{\psi})$$

we may rewrite this last expression as

$$I_2 = j\omega C_{gp}\,[E_g + KE_g\ (\cos\psi + j\sin\psi)]$$

and get for the total current through the capacitive reactance

$$I_g = j\omega C_{gk} E_g + j\omega C_{gp} + [1 + K\ (\cos\psi + j\sin\psi)]E_g$$

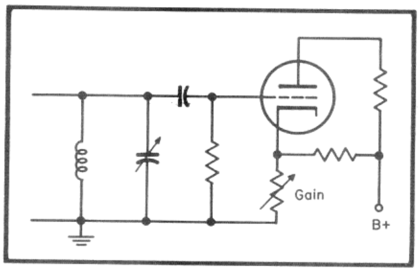


Fig. 2. Reactance control circuit based on the practical application of the Miller Effect.

The input admittance Y_g, $\left(\frac{1}{R+jX}\right)$ is then

$$Y_g = \frac{I_g}{E_g} = j\omega C_{gk} + j\omega C_{gp}\ [1 + K \times (\cos\psi + j\sin\psi)]$$

In those cases where the amplifier gain is not complex due to reactive elements in the load $\sin\psi = 0$ and we will have the equation reduced to

$$Y_g = j\omega\ [C_{gk} + C_{gp}\ (1+K)]$$

The input then appears to be loaded with a capacitance

$$C_i = C_{gk} + C_{gp}\ (1+K)$$

This is the common case that exists when the output load resistance is large compared to the capacitive reactance in the output circuit.

It is easily seen that at some frequency the input admittance will be low enough to by-pass sufficient input voltage to affect the gain. Beyond this point the gain will drop with frequency increase at the rate of about 6 db per oc-

e. The point at which the gain is vn 3 db is the frequency at which the acitive reactance is equal to the input stance (or where the admittance is al to the conductance).

mples

The two examples worked out in the culations of *Fig.* 3 show the effect the high-frequency gain caused by ow-mu triode as exemplified by the , and by one section of the high-mu de 12AX7.

The reduction in gain at high frencies because of the effective capacice has been termed the "Miller Ef-," having been described in a paper J. M. Miller of the Bureau of Stand-s in 1919. However the term should ude all effects involving the effective l-cathode capacitance such as the iller Effect" reactance control cir-s, one of which is discussed below, the Miller integrator much used in ar and computer circuits.

relectrode Capacitance

ince the effective grid-cathode ca-itance is a function of the grid-plate acitance, the Miller Effect caused by todes is negligible, the grid-plate acitance of most pentodes being of order of .005 $\mu\mu$f. This low value of acitance is due to the shielding effect he screen grid.

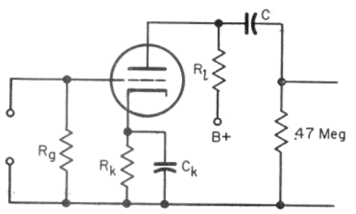
The grid-plate capacitance of minia-triodes is on the order of 1.6 $\mu\mu$f le that for metal and octal base tri-s varies from 2 to 4 $\mu\mu$f.

t must also be noted that if there sufficient phase shifts due to Miller ect and reactive load elements in a nber of audio stages around which e is negative feedback, there may be some frequency at which the various phase shifts will give an overall phase shift around the loop of 360 deg. (or zero). At this frequency, energy is being fed back in phase and it is possible to get sustained oscillations. This situation is likely to occur if there are more than three high-gain stages cascaded with feedback around all three.

Miller Reactance Control Circuit

Since the effective input capacitance may be greatly increased by changing the gain of the stage, it is possible to control the capacitance by controlling some circuit condition which in turn controls gain. Also, if the geometric tube capacitances do not give enough range of control, additional capacitance may be added between grid and plate, externally. This circuit has several limitations when used as a reactance tube, the principal one being that the signal amplitude in the circuit across which the tube is used cannot exceed the permissible grid swing for the operating voltages used. *Figure* 2 shows the Miller arrangement used to tune an *LC* circuit. To obtain greater range of control it is also possible to use pentodes or the 6L7 mixer tube. In each case the gain may be controlled by varying the d.c. potential on the appropriate element. This control voltage may be derived from a potentiometer or from a comparison circuit in automatic tracking systems.

The discussion of Miller Effect which has been presented is intended to indicate a simple method for determining the effect of the grid-plate capacitance on the operation of audio amplifiers, and a method of utilizing the large effective grid-cathode capacitance caused by this effect.



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C_{gp} = 3.8 $\mu\mu$f
C_{gk} = 4.2 $\mu\mu$f
K = 15

$$Y_g = j\omega\left[4.2 + 3.8(1+15)\right]\cdot 10^{-12} = j\omega\, 65\cdot 10^{-12}, \text{ or}$$

$$Z_g = \frac{1}{2\pi f\, 65\cdot 10^{-12}}$$

½ 12AX7

C_{gp} = 1.7 $\mu\mu$f
C_{gk} = 1.6 $\mu\mu$f
K = 73

$$Y_g = j\omega\left[1.6 + 1.7(1+73)\right] 10^{-12} = j\omega\, 128\cdot 10^{-12}, \text{ or}$$

$$Z_g = \frac{1}{2\pi f\, 128\cdot 10^{-12}}$$

If R_g is 0.1 Meg, the 3db point is at the point where $Z_g = R_g$ = 0.1 Meg

f_{3db} = 24,500 cps and the effective input capacitance is 65 $\mu\mu$f

f_{3db} = 12,400 cps and the effective input capacitance is 128 $\mu\mu$f

. 3. Method of calculation employed to determine the effective capacitance lected into the grid circuit of a vacuum tube. These calculations are included to compare the Miller Effect of low- and high-mu triodes.

Employment Register

POSITIONS OPEN and AVAILABLE PERSONNEL may be listed here at no charge to industry or to members of the Society. For insertion in this column, brief announcements should be in the hands of the Secretary, Audio Engineering Society, Box F, Oceanside, N. Y., before the fifth of the month preceding the date of issue.

- **Radio Engineer Wanted:** by prominent Chicago electronic mfgr. to design and supervise mfg. of full line of com'l ampls. Must have engineering degree or equivalent, and minimum of 2 yrs. design exp. in commercial P.A. systems. Give details including age, education, experience, reference, availability and salary expected. Box 601.
- **Electrical Design Engineer Wanted:** By large, modern, Eastern manufacturing firm for experimental development work in industrial electronics. Applicant must have degree in electrical engineering with communications or electronic option or equivalent in 10–15 years practical experience. Give details, including age, education, experience, references, availability, and salary expected. Box 401.
- **Audio, TV Field Engineer.** 10 yrs practical experience in maintenance of professional audio, TV, and radar equipment; design and maintenance custom home music systems. Member AES; Assoc AIEE. Good tech. educ. bkgnd; exc. references; exp. customer relations; extremely conscientious. Presently mgr. TV service lab and field service technician, electronic organs. Desire field work hi-fi audio or TV. Prefer Washington, D. C. area; consider other. Box 701.
- **Audio Engineer.** BS in radio from NYU, 26, married. Well versed all phases comm'l disc and tape recd'g. Presently employed large NYC studio, but not happy. A "future position" more desirable than a "present job." 9 yrs audio exp; available immediately, NYC metropolitan area. Box 501.
- **Audio and Electrical Engineer:** MS in physics; MS in EE. 10 yrs research, development, and design experience with magnetic and disc sound recording, acoustic measurements, and transducers. Also experienced in magnetic recording systems for computer applications. In present position for 10 years, but desire change to smaller company or consulting firm. Box 402.
- **Audio Engineer.** BEE from CCNY, 25, married. Superior knowledge of music; some informal experience with magnetic recording. Desire position in audio. Salary and location secondary. Box 301.