Examination of Conditions which Give Rise to Hum Due to Heater-Grid Capacitance

This topic, which is apparently of general interest, has previously been treated in R.C.A. Application Note No. 88, reprinted in Radiotronics, No. 87.*

An examination is made below of the various conditions which may give rise to hum due to heater-grid capacitance. Derivations are included of formulae from which the magnitude of the hum voltage may be evaluated. These formulae are the same as those quoted in the Application Note, and it is shown that they are approximations only, but give results which are accurate enough for practical purposes.

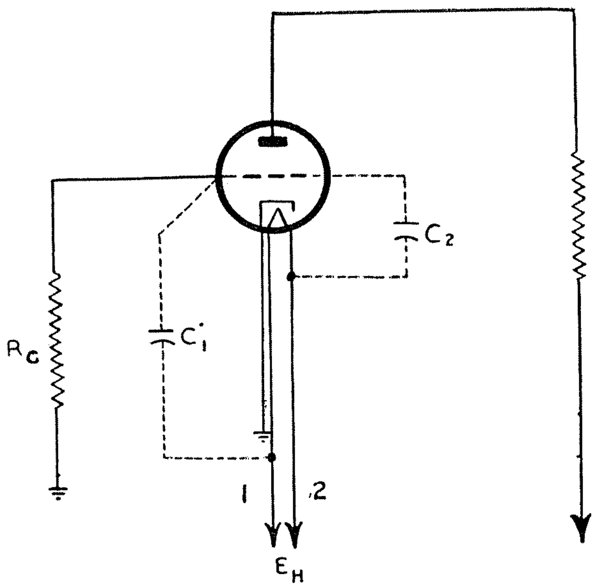

FIG. 1

Consider the circuit shown in figure 1 in which
E_h = heater voltage.
C_1 = capacitance between grid and heater lead 1,
C_2 = capacitance between grid and heater lead 2,
R_g = grid resistor.

Two cases may be treated as a first step—with heater lead 1 earthed, and then, as an alternative, with heater lead 2 earthed.

CASE 1—HEATER LEAD 1 EARTHED

The equivalent circuit for this condition is shown in figure 2.

Then $E_g = I_2R_g$ = hum voltage applied to grid.

Write $Z_1 = \dfrac{1}{j\omega C_1}$, $Z_2 = \dfrac{1}{j\omega C_2}$.

Mesh 1.

$$I_1 (Z_1 + Z_2) - I_2Z_1 - E_h = 0.$$

Mesh 2.

$$-I_1Z_1 + I_2 (R_g + Z_1) = 0.$$

* Now out of print.

Solving these two equations simultaneously by determinants to find I_2:

$$\frac{-I_2}{\begin{vmatrix} Z_1 + Z_2 & -E_h \\ -Z_1 & 0 \end{vmatrix}} = \frac{1}{\begin{vmatrix} Z_1 + Z_2 & -Z_1 \\ -Z_1 & R_g + Z_1 \end{vmatrix}}$$

$$\therefore I_2 = \frac{E_h.Z_1}{Z_1.R_g + Z_2 (R_g + Z_1)}$$

but since $E_g = I_2.R_g$,

$$\therefore E_g = I_2R_g = \frac{E_h.Z_1.R_g}{Z_1.R_g + Z_2 (R_g + Z_1)}$$

Now for most practical cases,

$$Z_2 = \frac{1}{j\omega C_1} \gg R_g$$

$$Z_1 = \frac{1}{j\omega C_2} \gg R_g$$

$$\therefore E_g = \frac{E_h.Z_1\, R_g}{Z_1.Z_2} \text{ approx.}$$

$$= \frac{E_h.R_g}{Z_2} \text{ approx.}$$

$$= jE_h.R_g.\omega\, C_2 \text{ approx.}$$

$$\text{and } |E_g| = |E_h| R_g\omega C_2 \text{ approx.} \quad \ldots\ldots\ldots\ldots \quad (1)$$

CASE 2—HEATER LEAD 2 EARTHED.

The equivalent circuit to be considered is shown in figure 3.

Again $E_g = I_2.R_g$ = hum voltage applied to grid

and $Z_1 = \dfrac{1}{j\omega C_1}$

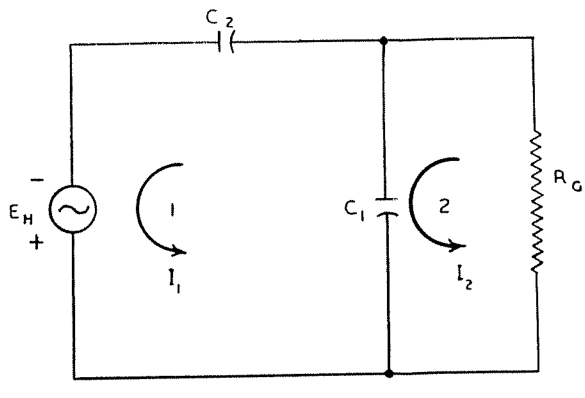

FIG.2

$$Z_2 = \frac{1}{j\omega C_2}$$

Mesh 1.

$$I_1 (Z_1 + Z_2) - I_2 Z_1 + E_h = 0$$

Mesh 2

$$-I_1 Z_1 + I_2 (R_g + Z_1) - E_h = 0$$

Solving these two equations for I_2,

$$\frac{-I_2}{\begin{vmatrix} Z_1 + Z_2 & E_h \\ -Z_1 & -E_h \end{vmatrix}} = \frac{1}{\begin{vmatrix} Z_1 + Z_2 & -Z_1 \\ -Z_1 & R_g + Z_1 \end{vmatrix}}$$

$$\therefore I_2 = \frac{E_h (Z_1 + Z_2 - Z_1)}{Z_1.R_g + Z_2 (R_g + Z_1)}$$

$$= \frac{E_h.Z_2}{Z_1.R_g + Z_2 (R_g + Z_1)}$$

$$E_g = I_2 R_g = \frac{E_h.Z_2.R_g}{Z_1.R_g + Z_2 (R_g + Z_1)}$$

as before,

$$Z_1 \gg R_g$$

and $Z_2 \gg R_g$

$$\therefore E_g = \frac{E_h.Z_2.R_g}{Z_1.Z_2} \text{ approx.}$$

$$= \frac{E_h.R_g}{Z_1} \text{ approx.}$$

$$= jE_h.R_g \, \omega \, C_1 \text{ approx.}$$

and $|E_g| = |E_h| \, R_g \, \omega \, C_1$ approx. .. .. (2)

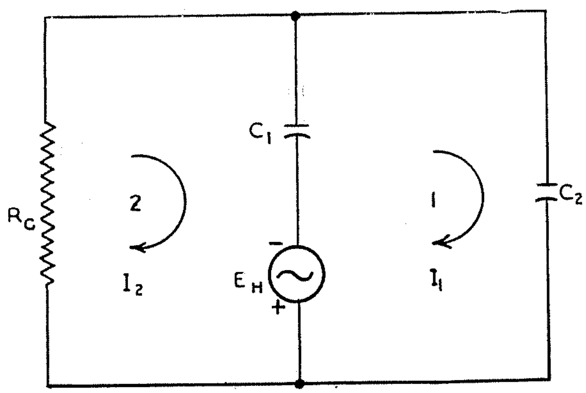

FIG. 3

From the results above, it becomes clear that earthing either lead 1 or lead 2 can give rise to different hum voltages on the grid of the valve being considered. Usually the values of C_1 and C_2 are nearly equal, so that it is often not very important which heater lead is earthed. It should be borne in mind, however, that a difference does exist and under certain circumstances it is possible to reduce hum due to these causes by interchanging the position of the heater-earth lead.

To obtain an idea of the order of the hum which may be present due to these effects take the solution for Case 1—Equation 1:

$$|E_g| = |E_h| R_g \, \omega \, C_2 \text{ approx.}$$

For a typical amplifier valve

$|E_h| = 6.3\text{V}$.
$R_g = 1$ megohm
$\omega = 2\pi f$
$= 2\pi \times 50$
$C_2 = 1 \ \mu\mu\text{F}$.

Then $|E_g| = 6.3 \times 1 \times 10^6 \times 2\pi \times 50 \times 1 \times 10^{-12} = 1.98$ millivolts approx.

So that it is seen that this effect may be serious if a high gain amplifier is employed, particularly if care is not taken to keep to a minimum the stray capacitances shunting C_1 and C_2.

In many applications the hum may be excessive with either of these connections, and it is preferable to use the arrangement shown in figure 4. This utilizes a simple bridge arrangement for reducing to zero the hum voltage E_g due to E_h, across R_g.

The condition for balance in the circuit of figure 4 is:—

$$\frac{R_1}{R_2} = \frac{C_2}{C_1}$$

R_1 and R_2 may be set by using a variable resistance and adjusting for balance. Usually in practice C_2 and C_1 are very nearly equal, and it is sufficient to use an ordinary centre-tapped resistance, a suitable value being of the order of 50 ohms total.

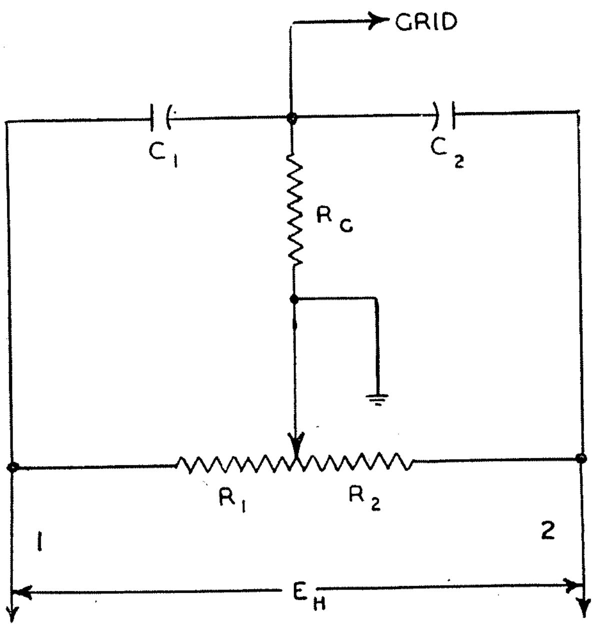

FIG. 4