CHAPTER 31

FILTERING AND HUM

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SECTION 1 : INDUCTANCE-CAPACITANCE FILTERS

Consideration has already been given in Chapter 30 to the value of ripple voltage E_R in the output of condenser- and choke-input rectifier systems. This chapter takes into consideration the filter components required to reduce the value of ripple given by the graphs in Chapter 30, to the value that is allowable for the equipment under consideration. The latter value will be designated as E_{R1} for one additional filter section, as in Fig. 31.1A, or E_{R2} for two additional filter sections.

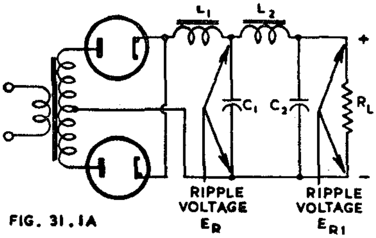

FIG. 31.1A

Fig. 31.1A. *Circuit diagram of full-wave choke-input rectifier system, followed by single section filter L_2C_2 to give reduced ripple voltage E_{R1}.*

It can easily be shown that for a given total value of LC, maximum filtering is obtained when all the filter sections are similar. Increasing the number of sections for a given total value of LC also increases the filtering, but there is little gained in breaking up the filter into more sections than that number which makes $X_L = 10X_c$. This is only appropriate if there is a definite limitation in the maximum value of LC. In general, better economy will be achieved by using not more than two sections, and increasing the value of C to give the required filtering.

The filter factor $\alpha = E_R/E_{Rn} = (\omega_R{}^2LC - 1)^n$

where n is the number of additional similar sections.

LC is the value of LC for one section (henrys and farads)

and $\omega_R = 2\pi f_R$

where f_R = ripple frequency.

This can be expressed as :—

$$LC = (\sqrt[n]{\alpha} + 1)/\omega_R{}^2 = 0.0254\,(\sqrt[n]{\alpha} + 1)/f_R{}^2.$$

The formula above assumes that $X_L \geqq 20X_c$, the usual practical case.

For quick reference, a graph has been prepared (Fig. 31.1B) for a single section filter to give the relationships between the values of E_R, E_{R1} and L_2C_2 based on the

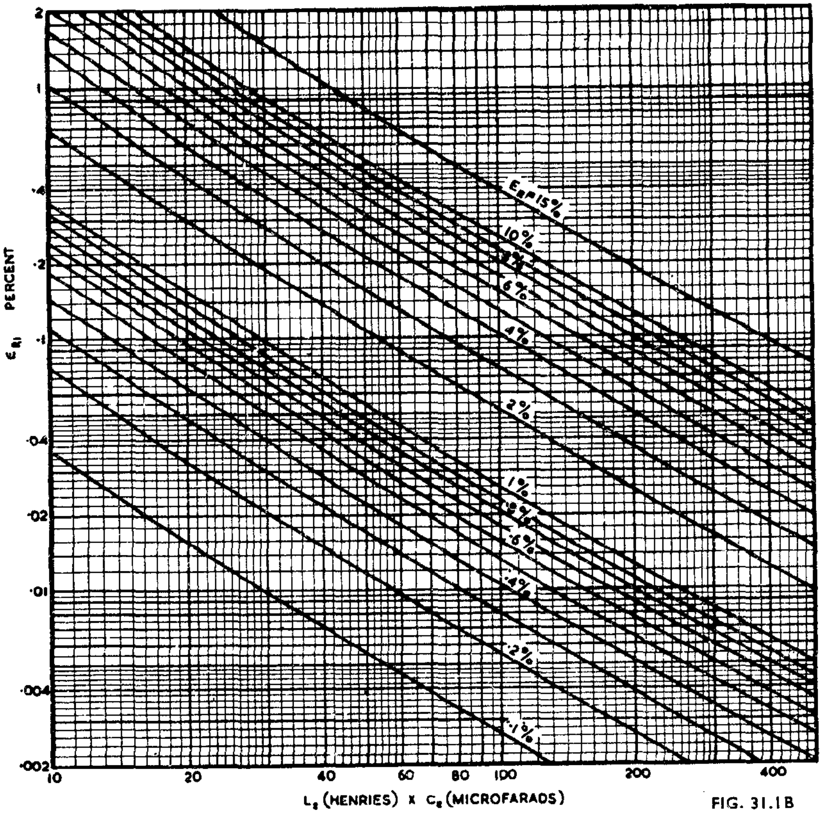

FIG. 31.1B

Fig. 31.1B. *Approximate relationships between ER, ER_1 and L_2C_2 for 50 c/s full-wave rectification (i.e.* 100 *c/s ripple frequency) and single section filter. For other ripple frequencies, the value of the LC scale should be multiplied by the appropriate factor as follows.*

40 *c/s ripple*—6.25 ; 50 *c/s ripple*—4 ; 60 *c/s ripple*—2.78 ; 80 *c/s ripple*—1.56 ; 120 *c/s ripple*—0.695.

approximate formula $\alpha = \omega_R{}^2LC$ which is sufficiently accurate for most applications. The values of L_2C_2 in Fig. 31.1B only hold for full-wave 50 c/s, but may be adapted to other conditions by multiplying by a factor (see title).

With either a condenser-input (Fig. 30.1F) or choke-input filter having a second filter section (Fig. 31.1A) it is important to avoid resonance between the choke L (or L_2) and condensers C_1 and C_2 in series. The inductance should be sufficiently large to avoid resonance, with a comfortable margin, over the whole frequency range of the amplifier and at least down to the ripple frequency (e.g. 100 c/s for 50 c/s mains and full wave rectification). This may be accomplished by ensuring that in Fig. 31.1A

$$L_2 \geqq \frac{C_1 + C_2}{C_1C_2} \cdot \frac{25\,000}{f^2} \text{ henrys}$$

where f = minimum rated frequency of amplifier in c/s,
and C_1 and C_2 are in microfarads.

When f = 100 c/s, $L_2 \geqq \dfrac{C_1 + C_2}{C_1C_2} \times 3.5.$

When $f = 50$ c/s, $L_2 \geqq \dfrac{C_1 + C_2}{C_1 C_2} \times 14.$

When $f = 25$ c/s, $L_2 \geqq \dfrac{C_1 + C_2}{C_1 C_2} \times 56.$

For example, when $C_1 = C_2 = 8\ \mu$F and $f = 25$ c/s, $L = 14$ henrys minimum.

SECTION 2 : RESISTANCE-CAPACITANCE FILTERS

In cases where filtering of a low-current supply is required, as in the case of the early stages of an audio-frequency amplifier or for certain applications in electronic instruments, resistance-capacitance filters can be used. The filter factor $\alpha = E_R/E_{R1} = \omega CR + 1$ and for ripple frequencies of 50, 60, 100 and 120 c/s this can be read directly from Fig. 31.2, for a single section filter.

See also Chapter 4 Sect. 8(ii) and (iii).

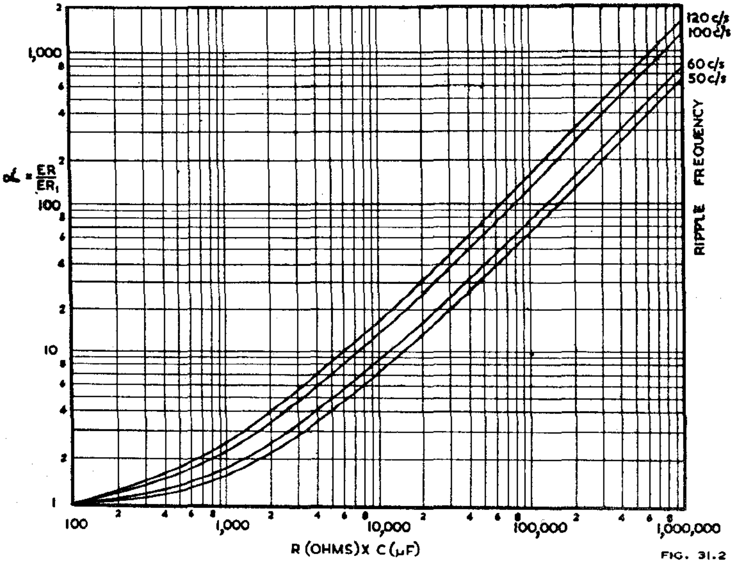

FIG. 31.2

Fig. 31.2. *Curve for determining the value of* $\alpha = E_R/E_{R1}$ *of a resistance-capacitance type single section filter for frequencies of* 50, 60, 100 *and* 120 *c/s. This curve is based on the formula,* $E_R/E_{R1} = \omega CR + 1$.

SECTION 3 : PARALLEL T FILTER NETWORKS

A useful filter network is that shown in Fig. 31.3(a). This can be transposed, for any one frequency, to its equivalent Π network as in (b) and, by correct choice of the values of circuit components, the attenuation can be made theoretically infinite at any one frequency (f_∞). Conditions for infinite attenuation are—

$1/C_1\omega = KR_2$

$2R_1 = K^2R_2$

$2/C_2\omega = R_2/K$ where K is a constant.

When the parallel T network is used for power supply filtering, the value of K to be used depends upon a number of considerations :—

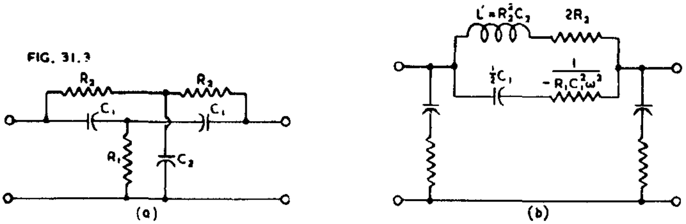

Fig. 31.3. *Resistance-capacitance parallel T network and its equivalent Π network.*

1. The d.c. resistance of the filter (i.e. $2R_2$) should be as low as possible.
2. The total capacitance should be as low as possible.
3. Standard value components may be used.

Table 1 : Showing the relationships between R_1, R_2, C_1 and C_2 for various K values.

K	Resistances	Capacitances	f_∞
1/2	$R_2 = 8R_1$	$C_2 = 0.5C_1$	$1/(\pi R_2C_1)$
$1/\sqrt{2}$	$R_2 = 4R_1$	$C_2 = C_1$	$1/(\sqrt{2}\pi R_2C_1)$
1	$R_2 = 2R_1$	$C_2 = 2C_1$	$1/(2\pi R_2C_1)$
$\sqrt{2}$	$R_2 = R_1$	$C_2 = 4C_1$	$1/(2\sqrt{2}\pi R_2C_1)$

Table 2 : Showing the total capacitance values required for various values of K with $f_\infty = 100$ c/s, $R_2 = 200$ ohms.

K	Capacitance in μF		
	C_1	C_2	$2C_1 + C_2$
1/2	15.9	7.95	39.75
$1/\sqrt{2}$	11.25	11.25	33.75
1	7.95	15.9	31.8
$\sqrt{2}$	5.625	22.5	33.75

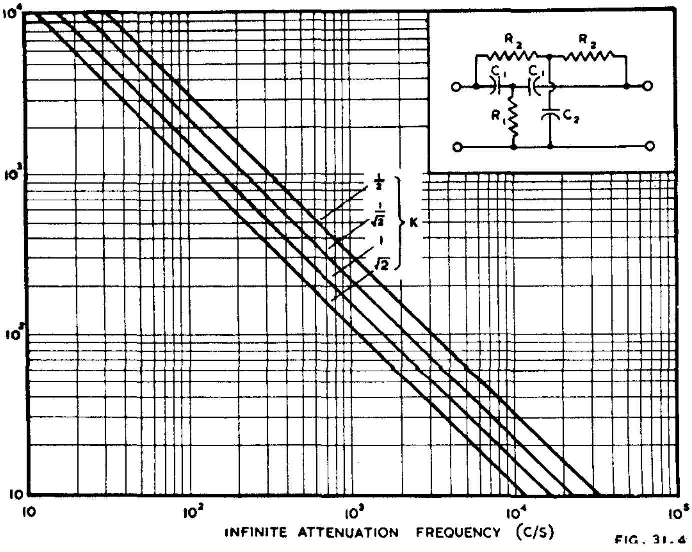

FIG. 31.4

Fig. 31.4. *Values of* R_2C_1 *required for various values of* K *to obtain infinite attenuation at frequency* f_∞.

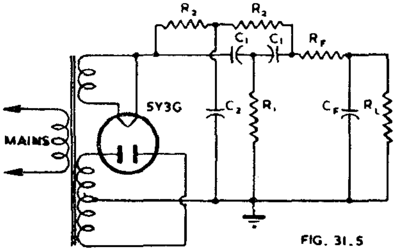

FIG. 31.5

Fig. 31.5. Typical complete filter circuit using a parallel T filter network.

By reference to Fig. 31.4, it will be seen that the minimum value of R_2C_1 will be required for $K = \sqrt{2}$. When $f_\infty = 100$ this gives a value of R_2C_1 not easily obtainable with standard values of components, and $K = 1$ will give more easily obtained values. Also when $K = 1$, the total capacitance required is a minimum. Where use is made of this filter, some attenuation must be provided for the ripple frequency harmonics, and this may be accomplished by means of a resistance-capacitance filter (see Sect. 2). A typical complete circuit is shown in Fig. 31.5.

For the theory of parallel T filter networks reference should be made to Chapter 4, Sect. 8(iii). See also Ref. 1.

SECTION 4 : HUM—GENERAL

(i) Hum due to conditions within the valves (ii) Hum due to circuit design and layout (iii) Hum levels in receivers and amplifiers.

Hum in the output of an a.c. operated receiver or amplifier may be due to many causes. These may be sub-divided into two main groups, hum due to conditions within the valves, and hum due to circuit design and layout.

(i) Hum due to conditions within the valves

This is caused by the use of a.c. for the heater supply and can give rise to hum in the output in several ways :

(1) capacitive coupling from the heater to any electrode
(2) heater-to-cathode conduction
(3) heater-to-cathode emission (or vice versa)
(4) modulation of the electron stream by the magnetic field of the filament
(5) conduction (i.e. leakage) from any electrode, with ripple voltage applied, to another electrode
(6) hum due to operating valve in magnetic field from external source.

Explaining these in more detail :—

(1) The amount of hum appearing at the plate of a valve due to capacitive coupling between the valve heater and an electrode, will depend upon the electrode to which this coupling takes place. The most serious case is that between heater and control grid as the voltage transferred will be subject to the full gain of the valve. In fairly high gain amplifiers it is advisable to use a potentiometer of 100 to 500 ohms resistance across the heater supply close to the valve socket ; the slider is earthed and its position adjusted for minimum hum output. In this way the hum voltages fed from each side of the heater to the control grid can be made equal and opposite.

In lower gain amplifiers a centre-tapped heater winding may be used or, more usually, a centre-tapped resistor across the heater supply. In the latter case the resistor may have a resistance of 50 + 50 ohms for 6.3 volt heaters. In some cases it is practicable to omit any form of tapping, and in these cases one of the heater terminals should be earthed. In the case of types in which the control grid or plate pin is adjacent to one heater pin, the latter should be earthed. Where the grid pin is separated from one heater pin only by one other pin, the latter should preferably be earthed directly, or else by-passed to earth by a large condenser. In other cases the heater terminal to be earthed should be chosen to provide minimum hum with regard to the position of un-earthed or unbypassed terminals.

Valves with the grid connection brought out to a top cap have less capacitance coupling between heater and grid circuits, but there may be appreciable electromagnetic coupling into the loop formed by the cathode-to-grid path and the return path through the valve. For this reason it is sometimes found that a double-ended valve gives more hum in a low level amplifier than a well designed single-ended stage.

When single-ended valves are used, the all-glass (e.g. miniature) construction gives less capacitance coupling from heater to grid or plate than an equivalent single-ended valve with a " pinch " (stem press) construction.

Reduction of the grid resistor value will also reduce the hum due to capacitive coupling, as the grid resistor and the heater-to-grid capacitance form a potential divider which determines the proportion of the heater voltage fed to the grid, unless there is a large grid coupling condenser and a low impedance to earth from the other side of it.

Diode-heater capacitance can also cause high hum levels in diode-triodes and diode-pentodes as the diode is effectively coupled to the control grid. For this reason it is recommended that the diode used for signal detection should, in the case of double-diode valves, be the diode further from the heater pins on the valve base.

(2) Conduction from heater to cathode will cause a current to flow from the heater to the cathode, thence through the impedance between cathode and earth. The resultant hum may be minimized by reducing the effective voltage applied to the circuit, and by reducing the impedance between cathode and earth. The voltage may be reduced by a potentiometer connected across the heater supply, with the slider earthed and its position adjusted for minimum hum output—as for hum due to capacitive coupling. The impedance between cathode and earth may be reduced by the use of a large capacitance by-pass condenser across the cathode bias resistor, or may be made zero by earthing the cathode and obtaining negative bias from some hum-free source.

See also Ref. 7.

(3) Emission from heater to cathode is caused by impurities in the heater insulation material or from the deposit, during valve manufacture, of cathode material on to the heater. To overcome this fault the heater should be biased positively with respect to the cathode. As the voltage required may be of the order of 50 volts, the minimum required to give satisfactory hum reduction should be used to avoid exceeding the maximum permissible heater-cathode voltage.

Cathode-to-heater emission can also take place and cause hum, although it is not common. The cure for this is the biasing of the heater negatively with respect to cathode.

In the general case hum may be due to two or more causes, and minimum hum may be obtained in any particular case by connecting the moving arm of the potentiometer to a point of positive (or sometimes negative) voltage of the order of 5 to 50 volts and by experimentally obtaining optimum adjustment of both potentiometer and voltage.

(4) Modulation of the electron stream by the magnetic field will depend on the type of heater and the electrode construction. If the centre-point of the heater circuit is earthed, the double helix gives noticeably less hum than the folded heater, but when one side of the heater is earthed the reverse may occur, depending on the electrode arrangement—see Ref. 6, Fig. 47.

Heater-induced hum in a-f amplifiers—summary*

The amplifier designer has to make allowance for the total hum, effective at the grid of the valve, due to the use of a.c. supply to the heater. There are very few valve types for which information is available in this regard—see Chapter 18 Sect. 2(v) for hum data on types 12AY7 and 5879. Tables have been published (Ref. 10) giving values of the 60 c/s component of the hum voltage of a fairly wide range of types with

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*Contributed by the Editor.

cathode by-passed and unbypassed, grid resistor zero and 0.5 megohm, and with different heater earthing arrangements but this does not give any indication of the total hum and is likely to be misleading since the ratio of total hum to 60 c/s component varies widely from type to type.

By the choice of a suitable valve type (e.g. 5879, triode operation) it is possible to achieve a median hum voltage effective on the grid of less than 4 microvolts under optimum conditions, with only a small percentage exceeding 10 microvolts, with grid resistor 0.1 megohm. On the other hand, with other types of valves and with other than optimum conditions, the hum may exceed 500 microvolts.

See also Chapter 12, Sect. 10(vi) and Chapter 18, Sect. 2(iii).

Refs. 5, 6, 7, 9, 10.

(ii) Hum due to circuit design and layout

The most common of hum troubles due to circuit design is caused by insufficient smoothing in the power supply. Where hum is introduced in the early stages of an amplifier, a simple *RC* filter can often be used (see Sect. 2). *RC* filters can also be used to supplement conventional filtering when lack of filtering in r-f and converter stages causes modulation hum.

Modulation hum can also be caused by capacitive coupling between primary and secondary windings of the mains transformer. The cure is the addition of an earthed electrostatic screen between the windings, or in some cases filters can be fitted in the mains leads as in a.c./d.c. receivers. Every care should be taken to eliminate r-f pickup from all sources other than the aerial, and receivers should be earthed directly rather than connected to the mains conduit which may have a high resistance earth connection. Capacitive coupling between the mains lead and aerial can also cause a mains frequency modulated carrier to be passed through the receiver.

In a.c./d.c. receivers care must be taken in the series connection of heaters. Usual practice is to place the a-f valve heater right at the earthy end, with the converter (which is particularly susceptible to modulation hum) next to it. In a.c./d.c. audio frequency amplifiers the earliest stages should be at the earthy end.

Electrostatic pick up of hum voltages by high impedance circuits from nearby leads carrying alternating currents may be avoided by the fitting of electrostatic shields or, where the capacitance of screened lead is permissible (as in the case of filament wiring) the use of screened a.c. leads is recommended. The use of twisted filament leads tends to cancel out the magnetic field around the leads.

The magnetic fields surrounding power transformers can give rise to induced currents in filter chokes and in a steel chassis. For this reason the use of a separate chassis in the case of high gain amplifiers is to be preferred. Alternatively the chassis may be made of non-magnetic metal. The placing of the power transformer laminations vertically usually gives rise to less hum than when they are placed in the same plane as the chassis, particularly when the chassis is of a magnetic material. Thorough screening of intervalve transformers (and more particularly microphone input transformers) from the magnetic field of the power transformer is also necessary, and high permeability shields or astatic type windings may be necessary in extreme cases to reduce hum to the required level. By orientating transformers and chokes with respect to each other a position of minimum coupling can be found which may avoid the necessity for taking more elaborate measures. If the position of minimum coupling is at all critical, it is recommended that an individual adjustment be made for each amplifier. The filter choke and transformer fields must also be kept away from high gain valves to prevent modulation of the electron stream.

The reason for high hum-level output in a receiver or amplifier can often be determined by the pitch of the note. If it is due to poor filtering, the 50 or 60 c/s in the case of half-wave rectification or the 100 or 120 c/s note with full-wave rectification will predominate. If the hum is induced from the power transformer the note will be 50 or 60 c/s while with capacitive hum pick up the note will be rough owing to the accentuation of the harmonics of the supply frequency.

When tracing hum it may be found that the reduction of hum in one part of the circuit may increase the overall hum level as, when the hum is due to more than one cause, a certain amount of cancellation may be taking place.

See also Chapter 18, Sect. 2(iii) on pre-amplifiers.

Hum caused by heater-cathode leakage with an unbypassed cathode resistor is dealt with in Chapter 7, Sect. 2(ix)B.

The effect of the output valve on hum originating in the plate supply *voltage**

(See Chapter 7, Sect. 2(ix) for the effect of feedback).

Case (1)—Triode with transformer-coupled output

The hum output voltage across the primary of the output transformer is

$E_{h0} = E_h R_L/(R_L + r_p)$
where E_h = hum voltage in plate supply
R_L = load resistance reflected on to primary of output transformer
and r_p = plate resistance of valve.
If $R_L = 2r_p$ (as is typical)
then $E_{h0} = 0.67\ E_h$.

Case (2)—Triode with parallel-feed (series inductor)

This is an excellent circuit for low hum provided that the choke L_1 has a reactance at the hum frequency at least several times the impedance of r_p and R_L in parallel.

See Chapter 7, Sect. 2 equation (55).

$E_{h0} = \cos\ \theta .\ E_h$
where $\theta = \tan^{-1} L_1/R$
and $R = r_p R_L/(r_p + R_L)$.

Case (3)—Pentode with transformer-coupled output

See Chapter 7, Sect. 2, equation (53).

$E_{h0} = E_h[R_L/(R_L + r_p) + R_L\ \mu_{g2p}/(R_L + r_p)]$.

The screen and plate effects are additive. The second term would become zero if the screen were perfectly filtered.

Case (4)—Pentode with parallel-feed (series inductor)

The hum due to the plate circuit is low, but that due to the screen is high. Screen filtering is required for low total hum.

See Chapter 7, Sect. 2, equation (57).

$E_{h0} \approx E_h \cos\ \theta - R_L\ \mu_{g2p}/(R_L + r_p)$
where θ and R are as in Case (2).

References : Chapter 7 Refs. B3, B4, B5, B7.

Typical values (all cases)

Typical values for types 2A3 and 6V6 are given in Chapter 13, Sect. 10(v).

(iii) Hum levels in receivers and amplifiers*

It is convenient to express hum levels in dbm, rather than as so many db below maximum power output. This hum is measured with zero signal output.

Hum should, ideally, be completely inaudible. This ideal is capable of achievement, although at a price, so far as the hum introduced by the receiver or amplifier is concerned. Audible hum is a defect which, while it may not prevent the sale of the equipment, will certainly be an annoyance to a critical user.

Hum is objectionable firstly because of its direct effect with zero signal, and secondly because of its indirect effect in modulating the signal.

The maximum acceptable hum level may be determined by a listening test in a quiet residential area, or under actual conditions for a custom-built equipment. The listener for the test should be one having at least average, and preferably higher than average acuity of hearing for the lower frequencies.

Alternatively, the maximum permissible hum level may be calculated. For example if the predominant hum frequency is 120 c/s, the loudspeaker efficiency at 120 c/s is 3%, the angle of radiation at 120 c/s is 180°, and the listener is 1 foot from the

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*Contributed by the Editor.

loudspeaker, then the limit of audibility is about −35 dbm for an average listener, and −45 dbm for a very critical listener. A good quality receiver or amplifier should therefore have a hum level less than −35 dbm for 3% loudspeaker efficiency at the hum frequency. This quoted loudspeaker efficiency of 3% is a fairly typical average value over the a-f frequency band, but the effective efficiency at the hum frequency may be higher or lower than the average value. The efficiency at the hum frequency will be higher than the average value if bass boosting is used, or if the cabinet/loudspeaker combination accentuates the hum frequency. The efficiency at the hum frequency will be lower than the average value if the hum frequency is lower than the loudspeaker bass resonance or if the cabinet attenuates the hum frequency. In cases where the loudspeaker efficiency is higher or lower than 3%, the permissible hum level should be adjusted accordingly.

This calculation for hum is somewhat unrealistic since it is based on the supposition that the hum is predominantly a single frequency. Any higher frequency components will give a higher acoustical hum level without appreciably affecting the measured value.

Summing up

For critical home listening with low room noise and with loudspeakers of normal sensitivity, the hum level should not be above −40 dbm, with −50 dbm as a preferred limit.

Under other conditions, with higher background noise or a less critical audience, a somewhat higher hum level may not be found objectionable.

SECTION 5 : HUM NEUTRALIZING

(A) One form of hum neutralizing is that using a hum-bucking coil in series with the voice coil in speakers where the field coil is used as the filter choke.

(B) A valve hum neutralizing system which has certain applications where a substantially constant load is to be supplied is shown in Fig. 31.6. This circuit has been explained in detail elsewhere (Ref. 3) and neutralization is dependent upon the valve producing a hum voltage of the same value and 180° out of phase with that already existing in the plate supply voltage. The valve must therefore be capable of producing a gain of unity between grid and plate, the feedback resistance $R_c\,(= R_b + R_f)$ being adjusted to obtain this balance.

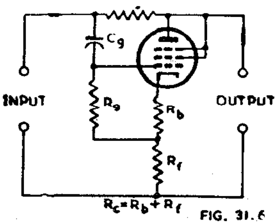

FIG. 31.6

Fig. 31.6. *Valve hum neutralizing circuit.*

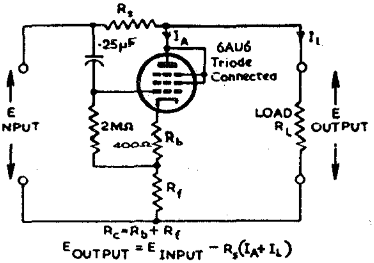

FIG. 31.7

Fig. 31.7. *Practical valve hum neutralizing circuit.*

A typical circuit is shown in Fig. 31.7 and the value of ripple reduction α obtained together with the values of R_c are plotted in Fig. 31.8 as a function of R_s.

The lowest ripple frequency which this circuit will suppress depends upon the time constant of R_gC_g which for this circuit is given by $T = R_gC_g/(1 - R_g/R_s)$ provided $\mu \gg 1$, and the internal resistance $R_0 = R_s\,\mu/(\mu + 1)$.

As the condition for neutralization does not involve the load impedance, the relatively high impedance of the regulator can be reduced to a low value for a.c. voltages by shunting the output by a large condenser.

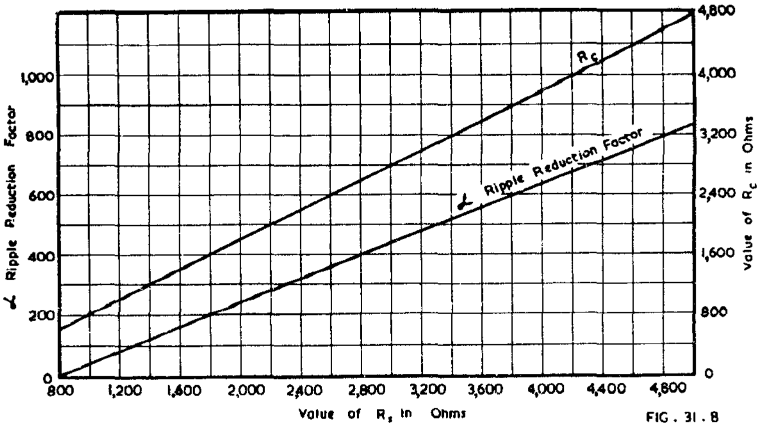

FIG. 31.8

Fig. 31.8. *Values of* α *and* R_c *as a function of* R_s *for the circuit of Fig.* 31.7.

In this way coupling between stages due to a high common impedance can be reduced.

Care must be taken that the value of input ripple to the circuit does not swing the valve beyond the linear position of its characteristics.

(C) Another form of neutralization, which is limited to pentode voltage amplifiers, is described in Chapter 12 Sect. 10(vi)D and Fig. 12.57.

(D) A form of neutralization suitable for use with multistage amplifiers is described in Ref. 4. Another form is described in Ref. 11.

(E) Various types of neutralizing are commonly used in radio receivers, for example, hum from the back bias supply may be neutralized at the grid of an output valve by hum from the B supply, with a suitable choice of output valve grid leak and plate load resistor for the a-f amplifier. In other cases the balance of these hum components may be adjusted so that the resultant neutralizes hum in the plate circuit of the output valve. More complicated neutralizing circuits even include hum components from the control and screen grids of the a-f amplifier in the balance at the grid of the output valve.

SECTION 6 : REFERENCES

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