RADIO DATA REFERENCE BOOK

Compiled by

G. R. JESSOP

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FOREWORD

As modern radio and electronic equipment becomes more and more complex, it is necessary for the radio designer, engineer, and amateur, to have available in convenient form a large amount of essential reference data.

In compiling this book, the aim has been to provide as wide a range of material as possible, which, if sought by the normal means would involve lengthy research through many volumes. The actual contents are a significantly different and wider cross section of the available information than that at present contained in other books of this type.

In general the data is presented in the form of curves, tables and charts with only sufficient text to permit its effective use. In adopting this method of presentation it has been assumed that the reader will have sufficient fundamental knowledge for the direct application of the data. Where theoretical information on any subject is required the reader is referred to the R.S.G.B. *Amateur Radio Handbook* or other appropriate reference book.

It is inevitable that in compiling a reference book of this nature a large and varied number of sources should be consulted. Acknowledgement, therefore, is made to the editors and authors of the many technical journals and text books to which reference has been made.

It is hoped that this new publication will fill a very real need in radio circles. Any suggestions that readers feel may improve this book will be welcomed by the author and every effort will be made to incorporate these in any subsequent edition.

The author would like to express his indebtedness in particular to Messrs. G. C. Fox, A.M.I.E.E. (G3AEX), R. F. Stevens (G2BVN), and G. M. C. Stone, A.M.I.E.E. (G3FZL), all of whom are members of the R.S.G.B. Technical Committee, for assistance in compiling data and reading proofs.

G. R. J.

GENERAL FORMULAE

Bias Resistor

The value of the resistance to be connected in the cathode lead for developing the required bias is—

$$R_k = \frac{E_k}{I_k} \times 1{,}000 \text{ ohms}$$

where E_k = bias voltage required (volts) and I_k = total cathode current (mA)

Capacitance

The capacitance of a parallel-plate capacitor is—

$$C = \frac{0{\cdot}224\,KA}{d} \text{ picofarads}$$

where K = dielectric constant (air = 1·0)
A = area of plate (sq. in.)
d = thickness of dielectric (in.)

If A is expressed in sq. cm. and d in cm.,

$$C = \frac{0{\cdot}0885\,KA}{d} \text{ picofarads}$$

For multi-plate capacitors, multiply by the number of dielectric thicknesses.

Capacitance of a coaxial cylinder—

$$C = \frac{0{\cdot}242}{\log_{10} \frac{r1}{r2}} \text{ picofarads per cm. length}$$

$r1$ = radius of outer cylinder, $r2$ = radius of inner cylinder.

Capacitors in Series or Parallel

The effective capacitance of a number of capacitors in *series* is—

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \text{etc.}}$$

For two capacitors only—

$$C = \frac{C_1 \times C_2}{C_1 + C_2}$$

The effective capacitance of a number of capacitors in *parallel* is—

$$C = C_1 + C_2 + C_3 + \text{etc.}$$

Decibels

The bel is defined as the common logarithm of the ratio of two powers. Normally the decibel (one-tenth of a Bel) is employed as a more convenient unit.

$$\text{Decibels (dB)} = 10 \times \log_{10} \frac{P_1}{P_2}$$

where P_1 and P_2 are the two power levels.

If equal impedances are employed:

$$\text{Decibels} = 20 \times \log_{10} \frac{V_1}{V_2}$$

$$= 20 \times \log_{10} \frac{I_1}{I_2}$$

where V_1, V_2 are the two voltage levels and I_1, I_2 the two current levels.

dB	Power Ratio	Voltage Ratio	dB	Power Ratio	Voltage Ratio
1	1·26	1·12	15	31·6	5·62
2	1·58	1·26	20	100	10
3	2·0	1·41	30	1000	31·6
4	2·51	1·58	40	10^4	10^2
5	3·16	1·78	50	10^5	316
6	3·98	2·0	60	10^6	10^3
7	5·01	2·24	70	10^7	3160
8	6·31	2·51	80	10^8	10^4
9	7·94	2·82	90	10^9	31600
10	10	3·16	100	10^{10}	10^5

Figures not given in the table above may be obtained from the table on page 85. If two dB figures are added, their corresponding power or voltage ratios must be multiplied together, e.g. 45 dB = 40 dB + 5 dB = 100 × 1·78 = 178 Voltage Ratio.

Dynamic Resistance

In a parallel-tuned circuit at resonance the dynamic resistance is—

$$R_D = \frac{L}{Cr} = Q\omega L = \frac{Q}{\omega C} \text{ ohms}$$

where L = inductance (henries)
C = capacitance (farads)
r = effective series resistance (ohms)
Q = Q-value of coil
$\omega = 2\pi \times$ frequency (cycles/sec.)

Frequency—Wavelength—Velocity

The velocity of propagation of a wave is—

$$v = f\lambda \text{ centimetres per second}$$

where f = frequency (cycles per second)
λ = wavelength (centimetres)

For electromagnetic waves in free space the velocity of propagation v is approximately 3×10^{10} cm./sec., and if f is expressed in kilocycles per second and λ in metres—

$$f = \frac{300,000}{\lambda} \text{ kilocycles per second}$$

$$\lambda = \frac{300,000}{f} \text{ metres}$$

or

$$f = \frac{300}{\lambda} \text{ megacycles}$$

$$\lambda = \frac{300}{f} \text{ metres}$$

where f is in megacycles

Impedance

The impedance of a circuit comprising inductance, capacitance and resistance in series is—

$$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

where R = resistance (ohms)
$\omega = 2\pi \times$ frequency (c/s)
L = inductance (henries)
C = capacitance (farads)

The characteristic impedance Z_0 of a feeder or transmission line depends on its cross-sectional dimensions.

(i) Open-wire line:

$$Z_0 = 276 \log_{10} \frac{2D}{d} \text{ ohms}$$

where D = centre-to-centre spacing of wires } expressed in the same units
d = wire diameter

(ii) Coaxial line:

$$Z_0 = \frac{138}{\sqrt{K}} \log_{10} \frac{d_0}{d_i}$$

where K = dielectric constant of insulation between the conductors (e.g. 2·3 for polythene, 1·0 for air)
d_0 = inside diameter of outer conductor (in.)
d_i = outside diameter of inner conductor (in.)

Inductance of Single Layer Coils

$$L \text{ (in microhenries)} = \frac{a^2 N^2}{9a + 10l} \text{ approximately}$$

If the desired inductance is known, the number of turns required may be determined by the formula:

$$N = \frac{5L}{na^2}\left[1 + \sqrt{\left(1 + \frac{0.36n^2a^3}{L}\right)}\right]$$

where N = number of turns
a = radius of coil in inches
n = number of turns per inch
L = inductance in microhenries (μH)
l = length of coil in inches

Slug Tuning. The variation in inductance obtainable with adjustable slugs depends on the winding length and the size and composition of the core and no universal correction factor can be given. For coils wound on Aladdin type F804 formers and having a winding length of 0·3–0·8 in. a dust-iron core will *increase* the inductance to about twice the air-core value: a brass core will *reduce* the inductance to a minimum of about 0·8 times the air-core value.

Inductances in Series or Parallel

The total effective value of a number of inductances connected in *series* (assuming that there is no mutual coupling) is given by—

$$L = L_1 + L_2 + L_3 + \text{etc.}$$

If they are connected in *parallel*, the total effective value is—

$$L = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \text{etc.}}$$

When there is mutual coupling M, the total effective value of two inductances connected in series is—

$$L = L_1 + L_2 + 2\,M \text{ (windings aiding)}$$
$$\text{or } L = L_1 + L_2 - 2\,M \text{ (windings opposing)}$$

Stabilizer Dropper Resistance

The resistance to be connected in series with a gas-filled voltage stabilizer tube is—

$$R = \frac{E_s - E_r}{I} \times 1{,}000 \text{ ohms}$$

where E_s = unregulated h.t. supply voltage (volts)
E_r = regulated h.t. supply voltage (volts)
I = maximum permissible current in regulator tube (milliamperes)

Ohm's Law

For a unidirectional current of constant magnitude flowing in a metallic conductor—

$$I = \frac{E}{R} \qquad E = I\,R \qquad R = \frac{E}{I}$$

where I = current (amperes)
E = voltage (volts)
R = resistance (ohms)

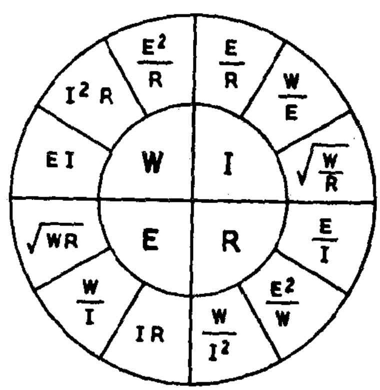

Fig. 1.

Power

In a d.c. circuit the power developed is given by—

$$W = E\,I = \frac{E^2}{R} = I^2 R \text{ watts}$$

where E = voltage (volts)
I = current (amperes)
R = resistance (ohms)

Q

The Q value of an inductance is given by—

$$Q = \frac{\omega L}{R}$$

where $\omega = 2\pi \times$ frequency (cycles/sec.)
L = inductance (henries)
R = effective series resistance (ohms)

Q Factor of Single Tuned Circuit

$$Q = \frac{f_0}{f_1 - f_2}$$

Where f_0 is the frequency giving maximum response, f_1 and f_2 the frequencies either side of f_0 where the response falls to 0·71 of maximum. All frequency measurements must be expressed in the same units.

Q factors of between 50 and 200 are typical for modern coils.

Reactance

The reactance of an inductance and a capacitance respectively is given by—

$$X_L = \omega L \text{ ohms} \qquad X_C = \frac{1}{\omega C} \text{ ohms}$$

where $\omega = 2\pi \times$ frequency (cycles/sec.)
L = inductance (henries)
C = capacitance (farads)

The total reactance of an inductance and a capacitance in series is $X_L - X_C$.

Resistances in Series or Parallel

The effective value of several resistances connected in series is—

$$R = R_1 + R_2 + R_3 + \text{etc.}$$

When several resistances are connected in parallel the effective total resistance is—

$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \text{etc.}}$$

for two resistances—

$$R = \frac{R_1 \times R_2}{R_1 + R_2}$$

Resonance

The resonant frequency of a tuned circuit is given by—

$$f = \frac{1}{2\pi\sqrt{LC}} \text{ cycles per second}$$

where L = inductance (henries)
C = capacitance (farads)

If L is in microhenries (μH) and C is in picofarads (pF = $\mu\mu$F), this formula becomes—

$$f = \frac{10^6}{2\pi\sqrt{LC}} \text{ kilocycles per second}$$

The basic formula can be rearranged thus:

$$L = \frac{1}{4\pi^2 f^2 C} \text{ henries} \qquad C = \frac{1}{4\pi^2 f^2 L} \text{ farads}$$

Since $2\pi f$ is commonly represented by ω, these expressions can be written as—

$$L = \frac{1}{\omega^2 C} \text{ henries} \qquad C = \frac{1}{\omega^2 L} \text{ farads}$$

Time Constant

For a combination of inductance and resistance in series the time constant (i.e. the time required for the current to reach $1/\epsilon$ or 63 per cent of its final value) is given by—

$$t = \frac{L}{R} \text{ seconds}$$

where L = inductance (henries)
R = resistance (ohms)

For a combination of capacitance and resistance in series the time constant (i.e. the time required for the voltage across the capacitance to reach $1/\epsilon$ or 63 per cent of its final value) is given by—

$t = CR$ seconds where C = capacitance (farads), R = resistance (ohms) (see also page 65)

Transformer Ratios

The ratio of a transformer refers to the ratio of the number of turns in one winding to the number of turns in the other winding. To avoid confusion it is always desirable to state in which sense the ratio is being expressed: e.g. the "primary-to-secondary" ratio n_p/n_s. The turns ratio is related to the impedance ratio thus—

$$\frac{n_p}{n_s} = \sqrt{\frac{Z_p}{Z_s}}$$

where n_p = number of primary turns
n_s = number of secondary turns
Z_p = impedance of primary (ohms)
Z_s = impedance of secondary (ohms)

Valve Characteristics

Amplification Factor (μ) = Valve Anode Resistance (R_a) × Mutual Conductance (g_m), R_a being measured in thousands of ohms and g_m measured in mA per volt.

Alternatively—

$$g_m = \frac{\mu}{R_a}, \qquad R_a = \frac{\mu}{g_m}$$

Stage Gain

$$\text{Amplification } (A) = \frac{\mu \times R_1}{R_1 + R_a}$$

where R_1 is the anode load measured in the same units as R_a. If R_1 is small compared with R_a, e.g. television r.f. stages—

$$A = g_m \times R_1 \text{ (approximately)}$$

Stage Gain in Resistance Coupled A.F. Amplifier

$$\text{Medium Frequencies} \quad G_m = \frac{\mu R}{R + R_a}$$

High Frequencies $G_h = \dfrac{G_m}{\sqrt{(1 + \omega^2 C_1^2 r^2)}}$

Low Frequencies $G_l = \dfrac{G_m}{\sqrt{\left(1 + \dfrac{1}{\omega^2 C_2^2 \rho^2}\right)}}$

where $R = \dfrac{R_1 R_2}{R_1 + R_2}$

$r = \dfrac{R R_a}{R + R_a}$

$\rho = R_2 + \dfrac{R_1 R_a}{R_1 + R_a}$

μ = amplification factor of valve

$\omega = 2\pi$ frequency

R_1 = anode load resistor
R_2 = grid leak
R_a = valve anode resistance
C_1 = total shunt capacity
C_2 = coupling capacitor

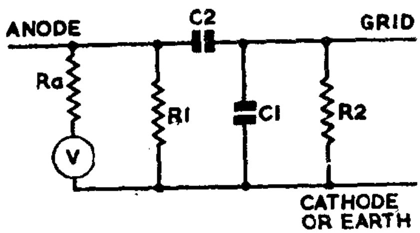

Fig. 2. Input $V = \mu . e_g$

Given C_1 C_2, R_2 and x = fractional response required.

At highest frequency $r = \dfrac{\sqrt{(1 - x^2)}}{\omega C_1 x}$, $R = \dfrac{r R_a}{R_a - r}$, $R_1 = \dfrac{R R_2}{R_2 - R}$

At lowest frequency $C_2 = \dfrac{x}{\omega \rho \sqrt{(1 - x^2)}}$

Note the gain will be effected by the cathode and screen by-pass capacitors.

Negative Feedback

Voltage Feedback

$$\textit{Gain with feedback} = \frac{A}{1 + Ab}$$

where A is the original gain of the amplifier section over which feedback is applied (including the output transformer if included) and b is the fraction of the output voltage fed back.

$$\textit{Distortion with feedback} = \frac{d}{1 + Ab} \textit{ approximately}$$

where d is the original distortion of the amplifier.

$$\textit{Effective output Impedance} = \frac{R_a}{1 + \mu b}$$

where μ is the amplification factor of the output valve and R_a its anode resistance.

Current Feedback

This form of feedback may be obtained by omitting the bypass capacitor across the cathode bias resistor. Current feedback results in an increase of effective output impedance and is not recommended for output stages.

Equivalent R.F. Noise Resistance

Saturated Diode $R_{eq} = \dfrac{0{\cdot}05}{I_a}$ ohms

Space Charge Limited Diode	$R_{eq} = \dfrac{0{\cdot}0333}{I_a}$ ohms
Triode	$R_{eq} = \dfrac{2{\cdot}5}{g_m}$ ohms
Pentode	$R_{eq} = \dfrac{I_a}{I_a + I_{g2}}\left(\dfrac{2{\cdot}5}{g_m} + \dfrac{20 I_{g2}}{g_m^2}\right)$ ohms
Triode Mixer	$R_{eq} = \dfrac{4{\cdot}0}{g_c}$ ohms
Pentode Mixer and Multigrid Mixer	$R_{eq} = \dfrac{I_a}{I_a + I_{g2}}\left(\dfrac{4{\cdot}0}{g_c} + \dfrac{20 I_{g2}}{g_c^2}\right)$ ohms

I_a and I_{g2} are measured in amps., g_m and g_c are in amps. per volt.

Noise Factor

Noise factor may be calculated from $F = \dfrac{e}{2kT} I_d R_s$

where e electron charge = $1{\cdot}59 \times 10^{-19}$ coulomb
k Boltzman's constant = 1.372×10^{-23} joules per °K
T Temperature of source resistance (°K)
I_d Noise diode anode current (Amps)
R_s Source resistance (Ohms)

At normal temperature (290°K) the above formula becomes
(*a*) as a ratio $F = 20\, I_d R_s$
(*b*) in decibels $F = 10_{\log}\,(20\, I_d R_s)$

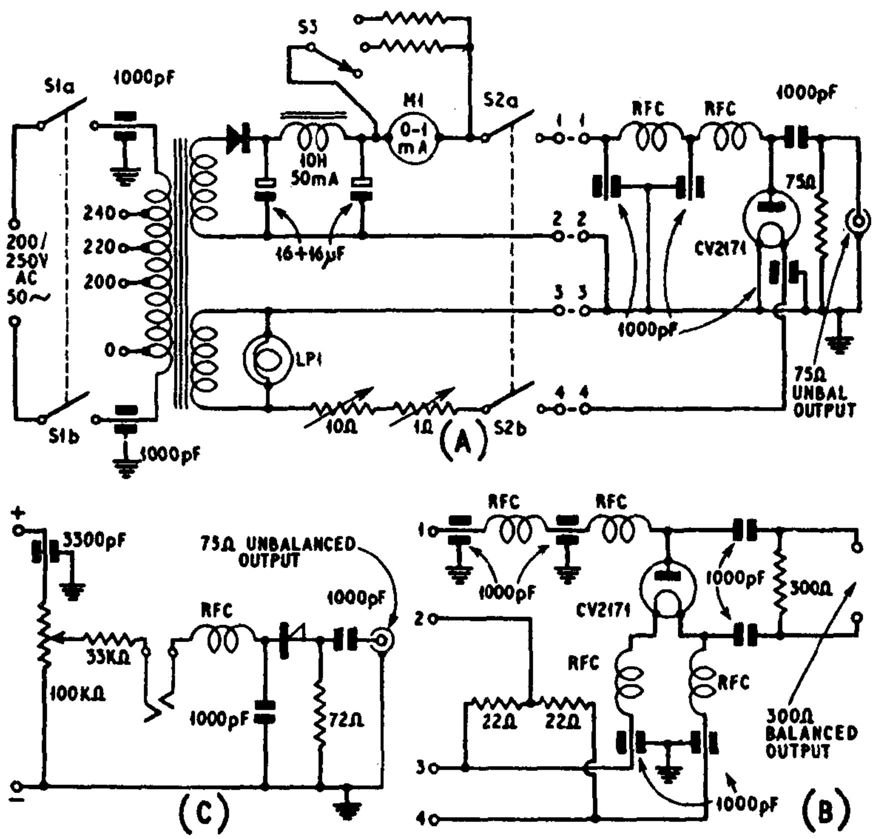

Fig. 3. Noise generator circuits. (a) For unbalanced input. (b) For balanced input. (c) Germanium diode noise generator for unbalanced inputs.

NOISE DIODE CURVES

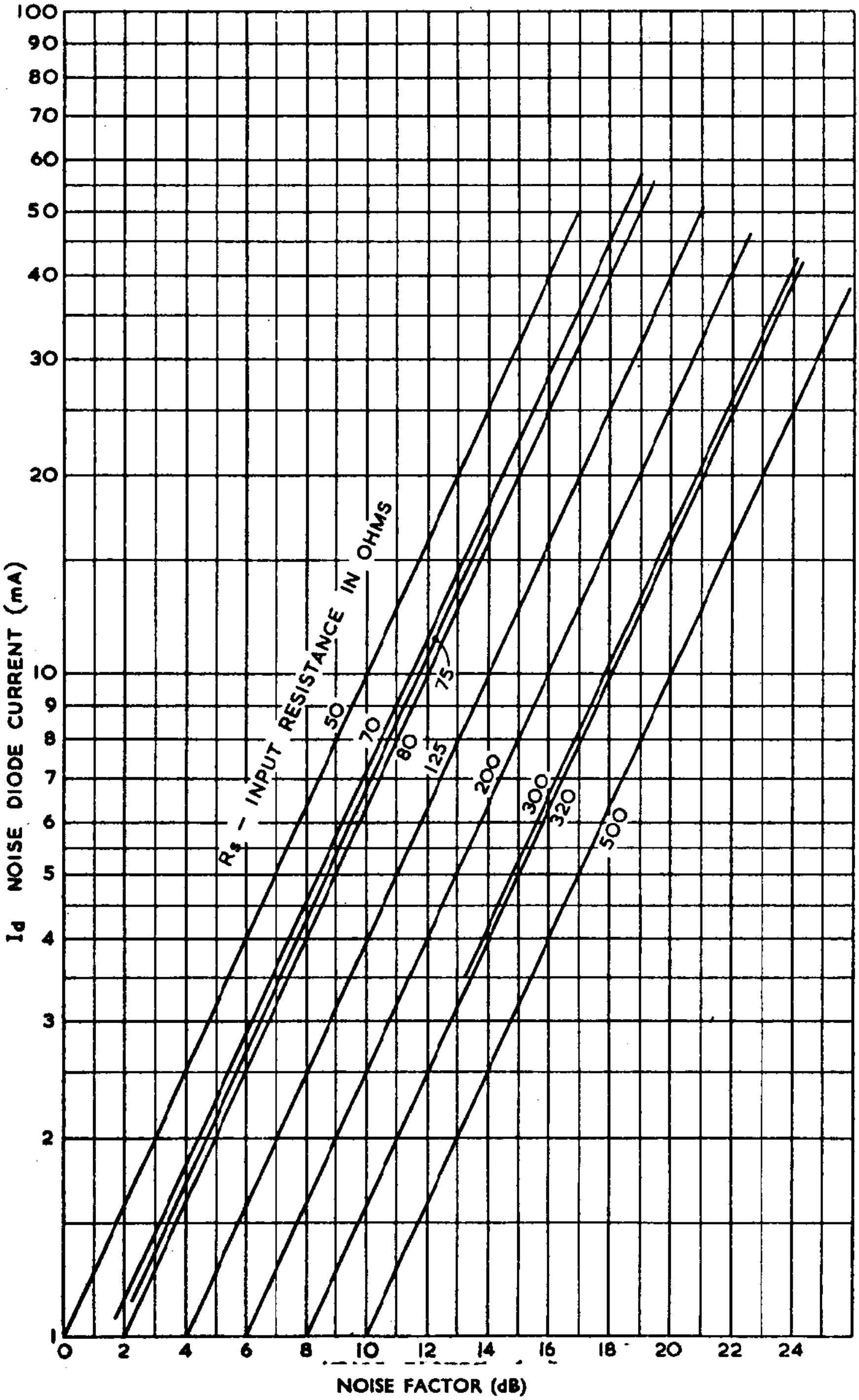

Fig. 4. Noise diode current—noise factor curve for various source resistors (R_S)

R.F. POWER AMPLIFIERS

In a class C p.a., the anode current consists of a series of pulses which may occupy between 40° and 180° of each complete r.f. cycle of 360°, depending on the characteristics of the valve and the purpose for which it is used. The operating conditions can rarely be calculated precisely, but an accuracy is obtainable which is sufficient to permit of intelligent transmitter adjustment. For all power amplifier design, valve characteristic curves extending into the positive grid region showing anode and grid currents are required. Curves of a typical triode valve are shown in Fig. 8 and these are used in the worked examples.

Fundamental Relationship

Fig. 5 shows a skeleton circuit for a triode power amplifier and Fig. 6 the relationship between the various voltages and currents in this circuit. It should be particularly noted that the peak value of anode current is drawn at an instant when the anode voltage has reached a low value and the grid voltage has reached a maximum positive value. In designing an amplifier this point has to be selected on the I_a/V_a and I_g/V_a curves. The anode voltage should never be allowed to fall below the value of the positive grid voltage as this results in excessive driving power being required and may damage the grid of the valve; on the other hand, the efficiency will be greater when the anode voltage swings down to a very low value. With practice, it becomes easy to select a suitable working point by inspection of the valve characteristics; until skill is obtained, the value of minimum anode voltage may be taken as 20 per cent. of the d.c. anode voltage for initial calculations.

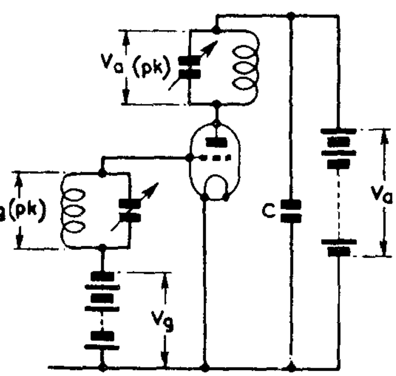

Fig. 5. Basic circuit of class C amplifier.

Fig. 7 shows the conditions when anode modulation is applied to the amplifier. Modulation is accomplished by varying the anode voltage; at the crest of modulation the anode voltage is doubled and the peak r.f. anode voltage is also doubled. Normally the peak value of the r.f. grid voltage is unchanged since no modulation is applied to the driver stage; since the peak anode current is increased at the modulation crest, a greater value of positive grid voltage is required. This is achieved by reducing the value of d.c. grid bias or occasionally by applying some modulation to the driver.

When designing a power amplifier, it is necessary to decide during what part of each cycle the anode current shall flow. In general short angles of flow produce high efficiencies but demand greater driving power and take greater peak emission from the cathode of the valve than do large angles. This may result in reduced valve life. The angle can be chosen for each individual case bearing those factors in mind; in the design data that follows, typical angles have been chosen and these may be adopted for most normal applications. It should be noted that the angle "θ" used in the design curves of Figs. 9 and 10 is one-half of the angle of flow; this is done to simplify the formulæ.

Class C Telegraphy

It is first necessary to decide the values of V_a and I_a, the product of which is the anode input. This is, of course, limited by the power that the valve