

VALVE AND TRANSISTOR CHARACTERISTICS

61. A diode valve has the following I_a/V_a characteristic:

I_a (mA)	0.52	1.17	1.90	2.78	3.85	5.15	6.50
V_a (V)	25	50	75	100	125	150	175

This valve is placed in series with a resistor of $20,000\ \Omega$ and a battery of 200 V. A resistor of $60,000\ \Omega$ is connected between the anode and cathode of the diode. Determine the current through the diode.

[Ans. 3 mA]

62. The anode-voltage/anode-current characteristic of a certain diode is given by the following figures:

Voltage V_a (V)	0	5	10	15	20	25	30	35
Current I_a (mA)	0	3.1	8.9	17.0	26.8	38	51.4	66

Plot the dynamic characteristic curve if the load has a resistance of $2,500\ \Omega$. Hence find the load current, and the voltage across the load when the supply voltage is 50 V.

[Ans. 14.5 mA; 36.25 V]

63. The anode-voltage/anode-current characteristic of a certain diode is given by the following figures:

Voltage V_a (V)	2	5	10	15	20
Current I_a (mA)	2.3	6.3	13.7	22.0	31.0

Show that the relationship between I_a and V_a is of the form $I_a = KV_a^n$ and find the values of n and K .

[Ans. ≈ 1.14 ; ≈ 1]

64. In tests on a certain thyatron, with a steady value of negative grid voltage applied to the valve, the anode voltage was gradually

raised until the valve conducted. The corresponding grid and anode voltages at the point of conduction were:

Grid voltage (V)	-8.7	-8.0	-7.0	-6.0	-5.0	-4.0	-3.0	-2.0	-1.0	0.5
Anode voltage (V)	191	176	152	131	109	88	66	46	34.2	33.8

Plot the control characteristic, and estimate the control ratio over that portion of the graph which is approximately linear.

[Ans. 21.8]

65. A thyatron just becomes conducting with 200 V on the anode when the negative grid voltage is held at -8 V. The control ratio is 35. Find the minimum anode voltage for conduction when the grid is held at -20 V. Determine also the critical grid voltage, when the anode voltage is 340 V.

[Ans. 620 V; -12 V]

66. The linear parts of the control characteristics of a certain thyatron are given by the following expressions:

$$V_a = [-120 V_g - 160], \text{ when the temperature is } 40^\circ\text{C}$$

$$\text{and } V_a = [-70 V_g - 130], \text{ when the temperature is } 70^\circ\text{C,}$$

where V_a is the anode voltage in volts, and V_g is the grid voltage in volts.

Evaluate, for an anode voltage of 400 V, the change in critical grid voltage when the temperature of the valve rises from 40°C to 70°C .

[Ans. 2.8 V]

67. The thyatron of Question 66 is used as a controlled rectifier on a sinusoidal a.c. supply of peak value 350 V. Determine the striking angles for a d.c. grid bias of -4 V (a) when the temperature is 40°C , and (b) when it is 70°C .

[Ans. $66^\circ 5'$; $25^\circ 22'$]

68. Three triodes having amplification factors of 10, 20 and 30, and with mutual conductances 2, 5 and 3 mA/V respectively, are operated in parallel. Calculate the equivalent mutual conductance, the anode resistance and the amplification factor of the combination.

[Ans. 10 mA/V, $1,818\ \Omega$, 18.18]

69. A certain thoriated-tungsten filament operating at $1,900^{\circ}\text{K}$ gave a saturation current of 85 mA. Calculate the corresponding current for a pure-tungsten filament of the same area operating at $2,500^{\circ}\text{K}$. The Dushman constants are:

For thoriated tungsten

$$A = 3.0 \text{ amps}/(\text{cm})^2(^{\circ}\text{K})^2, \quad b = 30,500^{\circ}\text{K}.$$

For pure tungsten

$$A = 60.2 \text{ amps}/(\text{cm})^2(^{\circ}\text{K})^2, \quad b = 52,400^{\circ}\text{K}.$$

[Ans. 21.8 mA]

70. A certain filament operating at $2,100^{\circ}\text{K}$ was thought to give a saturation current 10,000 times as great as that when the operating temperature was $1,600^{\circ}\text{K}$. If this had been true what would the work function of the filament material have been?

[Ans. 5 V]

71. Calculate the space-charge-limited current density between parallel plates 2 mm apart when the voltage across them is 200 V.

[Ans. 165 mA/sq cm]

72. Two diodes each have an anode 4 mm in diameter and 2 cm long, but one of them has a filament 0.1 mm in diameter, while the other has an indirectly-heated cathode 1.5 mm in diameter. Calculate the space currents flowing in each valve when the anode voltage is 25 V.

[Ans. 17 mA; 41 mA]

73. Explain the conditions under which the current in a diode is given by the law $I = kV^{3/2}$. Show that the shape of the electrodes only affects the constant k .

74. Calculate the operating characteristics and life for a 10% evaporation of mass of an ideal tungsten filament having a length of 2 cm and a diameter of 2.5 mm when operated at a temperature of $2,600^{\circ}\text{K}$. Use the data given in the Table which has been published by Jones and Langmuir* for an ideal tungsten filament 1 cm long and 1 cm diameter. The density of the material is 19.

Filament Temperature	Filament Details					
	Heating watts W_f	Resistance R_f	Current I_f	Voltage V_f	Emission current I_e	Evaporation M' in grams/cm ² /sec
$2,600^{\circ}\text{K}$	263.0 W	$98.66 \times 10^{-6} \Omega$	1,632 A	$161.1 \times 10^{-8} \text{ V}$	2.25 A	2.76×10^{-8}

[Ans. Power radiated 13.17 W; Resistance 0.3155Ω ; Filament current 6.45 A; Voltage drop 2.04 V; Emission current 0.1125 A ; 376 hr]

75. A diode with parallel-plane electrodes 4 cm apart has an anode voltage which is 8 V negative with respect to the cathode. Calculate the maximum distance which an electron can travel from the cathode surface if it leaves it with an energy of 2 eV.

[Ans. 1 cm]

76. In a cylindrical diode the electric-field intensity at the cathode surface is 10^8 V/m , and the cathode temperature is $2,600^{\circ}\text{K}$. Determine the percentage increase in the zero-external-field thermionic-emission current because of the Schottky effect.

[Ans. 18.4%]

77. (a) A low- μ , plane-electrode triode has a grid-anode spacing of 0.19 cm, a grid-wire spacing of 0.127 cm and a grid-wire radius of 0.0064 cm. Estimate the amplification factor.

(b) In a cylindrical-electrode triode with an amplification factor of 20 the anode radius is 1.05 cm. The evenly-spaced grid wires are each of 0.04 cm radius, and are arranged to form a squirrel cage around a grid-wire circle of radius 0.5 cm. Determine the total number of grid wires.

(c) Derive the Vodges–Elder expressions* for the amplification factors of both high- μ , plane-electrode and cylindrical-electrode triode valves.

[Ans. (a) $\simeq 8$, (b) $\simeq 10$, (c) see the solution for the expressions]

78. The characteristics of a junction transistor are given in the following Table:

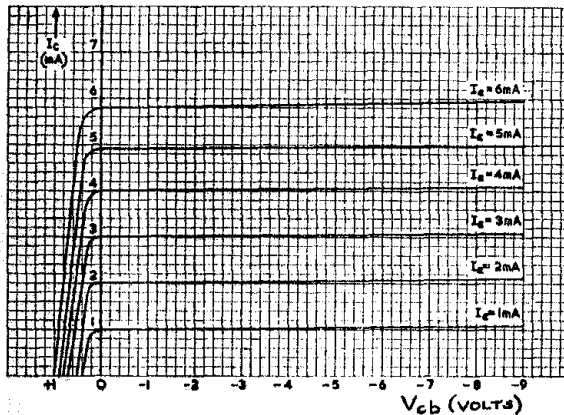
Collector Voltage V_{ce} (volts)	Collector Current (I_c) in mA		
	$I_b = 0$	$I_b = 40 \mu A$	$I_b = 80 \mu A$
1	0.2	1.90	3.7
4	0.3	2.05	4.0
7	0.4	2.20	4.3

The transistor is connected in a common-emitter stage with a collector load of $1,500 \Omega$, to supply voltage of $6V$ and a d.c. bias of $40 \mu A$. Plot the characteristics, draw the appropriate load line and calculate the power dissipated in the transistor.

What will be the total voltage swing at the collector for an a.c. input signal current of $40 \mu A$ peak in the base?

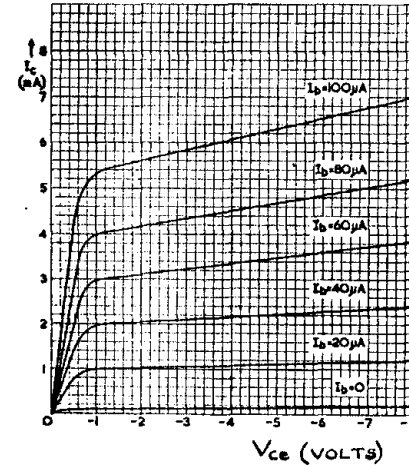
[Ans. 6 mW ; $\approx 4.9 \text{ V}$]

79. The output characteristics of a certain $p-n-p$ transistor for common-base and common-emitter connections are illustrated in the figures. Determine, from these curves, the values of $\alpha = -(\partial i_c / \partial i_e)_{V_{cb}}$ and $\alpha' = (\partial i_c / \partial i_b)_{V_{ce}}$.



Show how α' may be expressed in terms of α and vice-versa.

[Ans. 0.98 ; ≈ 57 ; $\alpha' = \alpha / (1 - \alpha)$; $\alpha = \alpha' / (1 + \alpha')$]



80. For a transistor used in the common-emitter configuration the relationship between collector current and collector voltage, with various fixed values of base current, are given in the following Table.

Collector Voltage (V)	Collector Current (mA)				
	Base Current $-30 \mu A$	Base Current $-50 \mu A$	Base Current $-70 \mu A$	Base Current $-90 \mu A$	Base Current $-110 \mu A$
-2	-0.9	-1.55	-2.2	-2.85	-3.55
-4	-0.92	-1.65	-2.4	-3.05	-3.77
-6	-0.95	-1.77	-2.55	-3.25	-4.0
-8	-0.98	-1.90	-2.75	-3.5	-4.2

Draw the static characteristics of the transistor and use these to determine the current gain when the collector voltage is -5 V .

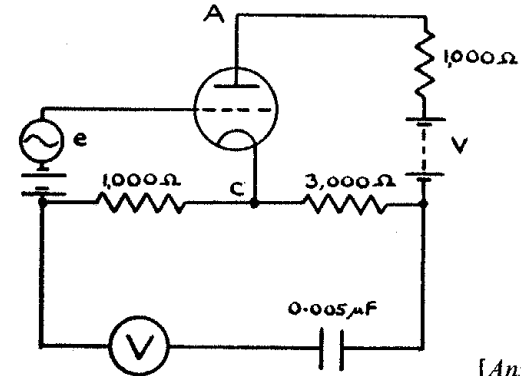
The transistor is to be used as a common-emitter amplifier with a load resistance of $1,800\ \Omega$ and a collector battery voltage of $-9\ \text{V}$. Draw the load line and use this to find the base current for a collector voltage of $-4\ \text{V}$.

[Ans. $37; 82\ \mu\text{A}$]

CHAPTER SIX

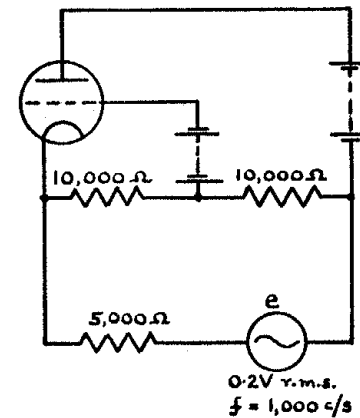
EQUIVALENT CIRCUITS OF VALVES AND TRANSISTORS

81. In the circuit illustrated the input signal e is $1\ \text{V r.m.s.}$ and the frequency is $2,000\ \text{c/s}$. Calculate the reading of the a.c. voltmeter if it has a resistance of $10,000\ \Omega$ and negligible reactance. The amplification factor of the valve is 20 and its anode resistance is $8,000\ \Omega$.



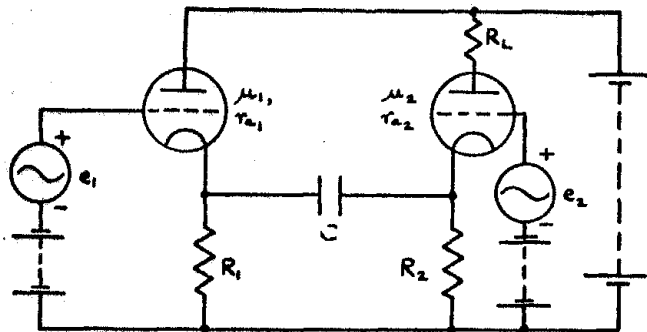
[Ans. $2.06\ \text{V}$]

82. Draw the equivalent circuit of the arrangement shown and find the r.m.s. a.c. anode current in the valve. The valve constants are $\mu = 20$ and $r_a = 5,000\ \Omega$.



[Ans. $35.9\ \mu\text{A}$]

83. Draw the equivalent circuit for the network illustrated, and write down the equations from which the various alternating currents and voltages may be calculated. Assume that, with the reference potentials shown, the voltage e_2 is 30° ahead of the voltage e_1 , and that the r.m.s. values of e_1 and e_2 are 1 V and 2 V, respectively.



84. Derive the current-source equivalent circuit for a triode valve, where the valve is supposed to be replaced by a current generator which supplies a current $g_m V_g$ flowing from anode to cathode within the valve, and which has the anode resistance r_a connected across the generator terminals. g_m is the mutual conductance of the valve and V_g the grid-cathode voltage.

85. Two triode valves have amplification factors of 20 and 40, and anode resistances of 5,000 and 10,000 Ω , respectively. The two anodes are joined together, and a load of resistance 20,000 Ω is connected between the anodes and the h.t. supply line. An alternating voltage of 4 V is applied between the grid and cathode of the first valve, and a voltage of 2 V, of the same frequency and phase, is applied between the grid and cathode of the second valve. Calculate the alternating voltage across the load resistor and the alternating component of the anode current in each valve.

[Ans. 68.6 V; 2.3 mA; 1.1 mA]

86. (a) Draw the equivalent circuit of a tetrode, including all inter-electrode capacitances, with an impedance Z_L in the anode circuit. Neglecting the grid-anode capacitance, simplify the circuit.

(b) Draw the equivalent circuit of a pentode, including all interelectrode capacitances, with an impedance Z_L in the anode

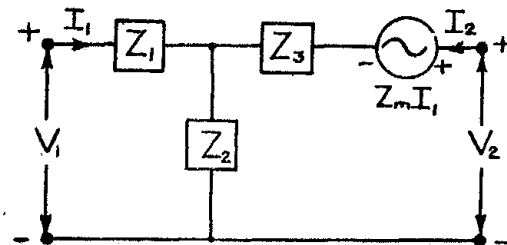
circuit. Show that, to a very good approximation, the input capacitance is equal to the control-grid/cathode and control-grid/screen-grid capacitances in parallel, and that the output capacitance is equal to the anode/cathode, anode/screen-grid and anode/suppressor-grid capacitances in parallel.

87. The hybrid parameters of a certain transistor are: $h_{11} = 35 \Omega$, $h_{21} = -0.976$, $h_{22} = 1.0 \mu\text{mhos}$ and $h_{12} = 7 \times 10^{-4}$. Calculate the values of r_{11} , r_{12} , r_{21} , r_{22} , α , r_e , r_b , r_c and r_m .
[Ans. 718.2 Ω ; 700 Ω ; 976 k Ω ; 1 M Ω ; 0.976; 18.2 Ω ; 700 Ω ; \approx 1M Ω ; 975.3 k Ω]

88. Draw three equivalent circuits which can be used to represent the transistor under small-signal conditions. Show how analyses of these circuits permit all the elements of the equivalent networks of the common-emitter and common-collector circuits to be expressed in terms of the elements of the common-base arrangement.

89. Sketch common-cathode, common-emitter and common-collector transistor amplifier circuits and then draw their equivalent triode-valve configurations.

90. Show that the arrangement illustrated, which is frequently used as a transistor equivalent circuit, does not, in general, satisfy the reciprocity condition.



Determine the condition that must be satisfied for reciprocity to apply.

[Ans. $Z_m = 0$]

91. A transistor has a current amplification factor of 0.96 at low frequencies and the alpha cut-off frequency is 5 Mc/s. Determine the

current amplification factor at 10 Mc/s and calculate the frequency at which the current amplification factor falls to 0.6.

[Ans. 0.43; 6.25 Mc/s]

92. The current amplification factor α of a common-base junction transistor, operating at a frequency f is given by:

$$\alpha = \alpha_0 \left\{ \frac{1}{1 + j(f/f\alpha)} \right\}$$

where α_0 is the low-frequency value of α and $f\alpha$, called the alpha cut-off frequency, is that frequency where $\alpha = \alpha_0/\sqrt{2}$.

Derive a corresponding expression for the current amplification factor when the transistor is used in the common-emitter configuration and give the corresponding cut-off frequency in terms of α_0 and $f\alpha$.

$$\left[\text{Ans. } \frac{\alpha_0}{(1 - \alpha_0) + j(f/f\alpha)}; f\alpha(1 - \alpha_0) \right]$$

CHAPTER SEVEN

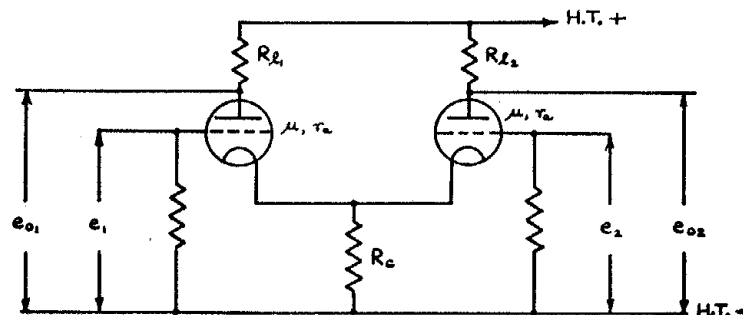
ELECTRONIC COMPUTING CIRCUITS

93. A common-cathode difference amplifier is illustrated in the diagram. Draw the equivalent circuit for the arrangement and prove that, if

$$(R_{i_1} + r_a)/(\mu + 1) \ll R_o$$

and

$$(R_{i_2} + r_a)/(\mu + 1) \ll R_o$$



the output voltages e_{o1} and e_{o2} are

$$-\mu R_{i_1}(e_1 - e_2)/(R_{i_1} + R_{i_2} + 2r_a)$$

and

$$\mu R_{i_2}(e_1 - e_2)/(R_{i_1} + R_{i_2} + 2r_a)$$

respectively.

Show also that if $e_2 = 0$ and $R_{i_1} = R_{i_2}$, the circuit may be used to produce push-pull signals from a single source of voltage.

94. A cascode type of difference amplifier is shown in the diagram. Analyse the operation of the circuit and show that the output voltage $e_o = \mu(e_1 - e_2)/2$.

CHAPTER EIGHT
RECTIFICATION

99. A high-vacuum diode, with an internal resistance of $150\ \Omega$, supplies power to a $1,000\text{-}\Omega$ load from a 300-V r.m.s. source. Find:

- (a) the mean load current,
- (b) the r.m.s. alternating load current,
- (c) the d.c. power supplied to the load,
- (d) the input power to the anode circuit,
- (e) the rectification efficiency,
- (f) the ripple factor.

[Ans. (a) 117 mA; (b) 184 mA; (c) 13.8 W; (d) 39.1 W;
(e) 35.3%; (f) 1.21]

100. A gas diode, for which the striking and extinction voltages may both be taken as 10 V , supplies power in a half-wave rectifier circuit to a $1,000\text{-}\Omega$ load from a 300-V r.m.s. source. Calculate:

- (a) the mean load voltage,
- (b) the d.c. power supplied to the load,
- (c) the input power to the anode circuit,
- (d) the rectification efficiency,
- (e) the ripple factor.

[Ans. (a) 130 V; (b) 16.9 W; (c) 43.7 W;
(d) 38.7%; (e) 1.225]

101. Calculate the regulation and efficiency for a half-wave rectifier circuit, from no load to 80 mA . The transformer r.m.s. secondary voltage is 230 V and the internal resistance of the diode is $500\ \Omega$. Find also the current at which maximum power is obtained.

[Ans. 40 V; 40.6 to 24.9%; 103.5 mA]

102. A full-wave single-phase rectifier employs a double-diode valve, the internal resistance of each element of which may be assumed constant at $500\ \Omega$. The transformer r.m.s. secondary voltage

from the centre tap to each anode is 300 V and the load has a resistance of $2,000\ \Omega$. Evaluate:

- (a) the mean load current,
- (b) the r.m.s. alternating load current,
- (c) the d.c. output power,
- (d) the input power to the anode circuit,
- (e) the rectification efficiency,
- (f) the ripple factor,
- (g) the regulation from no-load to the given load.

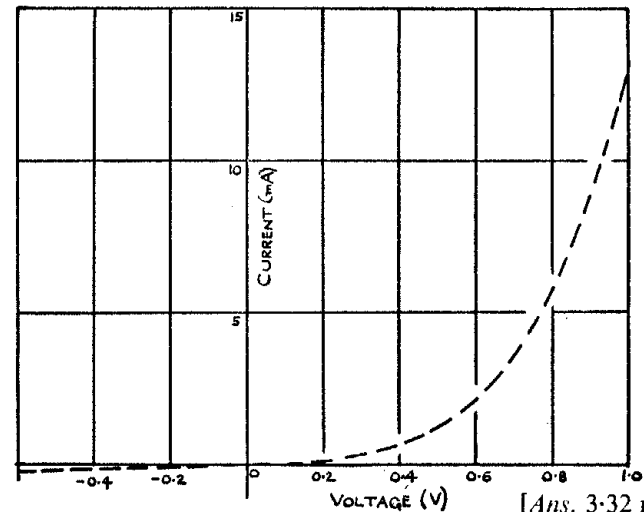
[Ans. (a) 108 mA; (b) 120 mA; (c) 23.3 W; (d) 36 W;
(e) 64.8%; (f) 0.482; (g) 54 V]

103. A moving-iron ammeter and a simple moving-coil ammeter are placed in series with the load in a half-wave rectifier circuit. The reading on the a.c. instrument is 5 A . What is the reading of the other ammeter?

Calculate the instrument readings if the other half-wave is also rectified. Assume sinusoidal waveforms.

[Ans. 3.18 A; 7.07 A; 6.37 A]

104. A metal rectifier has the voltage-current characteristic shown. A sinusoidal alternating voltage, with a maximum value of 2 V , is applied to the rectifier, in series with a non-inductive resistor of value $80\ \Omega$ and a moving-coil ammeter of negligible resistance. Calculate the reading of the instrument.



[Ans. 3.32 mA]

105. The rectifying element of a single-phase half-wave rectifier circuit has a resistance of $10\ \Omega$ in the forward direction and its resistance in the reverse direction may be taken as infinite. A resistor and a capacitor in parallel form the load and the capacitance is so great that the voltage across it is practically constant during both the charging and discharging periods. The resistance of the load is such that current flows through the rectifying element for one-sixth of each cycle of the a.c. supply voltage.

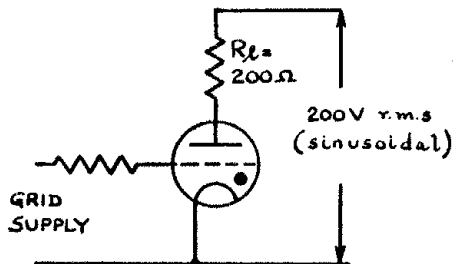
Determine the resistance of the load and the efficiency of rectification.

[Ans. $585\ \Omega$; 89.4%]

106. The grid voltage of the thyatron shown in the diagram is such that conduction begins 60° after the start of each cycle. Calculate:

- the r.m.s. value of the load current,
- the r.m.s. value of the voltage across the thyatron,
- the total power delivered by the a.c. supply.

The drop in the valve during conduction is $10\ \text{V}$.



[Ans. (a) $0.63\ \text{A}$; (b) $155\ \text{V}$; (c) $77\ \text{W}$]

107. A single-phase full-wave rectifier circuit, employing a single L-type filter, is to supply $120\ \text{mA}$ at $300\ \text{V}$ with a ripple that must not exceed $10\ \text{V}$. Design a suitable filter if the supply frequency is

(a) $50\ \text{c/s}$, (b) $60\ \text{c/s}$.
[Ans. A 10-H choke and a $4\text{-}\mu\text{F}$ capacitor are suitable in both cases]

108. A full-wave rectifier is used to supply power to a $2,000\text{-}\Omega$ load. Two 20-H chokes and two $16\text{-}\mu\text{F}$ capacitors are available for filtering purposes. Calculate, approximately, the ripple factors for the following cases:

- one choke only in series with the load,

- two chokes in series with the load,
- one capacitor only in parallel with the load,
- two capacitors in parallel with the load,
- a single, L-type filter using one choke and one capacitor,
- a single, L-type filter using two chokes in series and two capacitors in parallel,
- a double, L-type filter, each section consisting of one choke and one capacitor.

The supply frequency should be taken as (i) $50\ \text{c/s}$, (ii) $60\ \text{c/s}$.

[Ans. (i) (a) 0.074 ; (b) 0.037 ; (c) 0.090 ; (d) 0.045 ; (e) 0.0037 ; (f) 0.0009 ; (g) 2.95×10^{-6}

(ii) (a) 0.062 ; (b) 0.031 ; (c) 0.075 ; (d) 0.0375 ; (e) 0.0025 ; (f) 0.0006 ; (g) 1.42×10^{-6}]

109. Outline the design of a power supply, from a single-phase full-wave rectifier, using a π -section filter, to give a d.c. output of $250\ \text{V}$ at $50\ \text{mA}$ and with a ripple factor not exceeding 0.01% . The supply frequency should be taken as (i) $50\ \text{c/s}$, (ii) $60\ \text{c/s}$.

[There is no unique solution to this problem]

110. In a full-wave rectifier circuit, employing a 20-H choke in a π -section filter, what would be the power dissipated in a resistor R which replaced the choke and gave the same ripple factor, with an output current of $100\ \text{mA}$? The supply frequency should be taken as (i) $50\ \text{c/s}$, (ii) $60\ \text{c/s}$.

Repeat the calculation for the case where the output current is only $10\ \text{mA}$.

[Ans. (i) $125.7\ \text{W}$; $1.257\ \text{W}$; (ii) $150.8\ \text{W}$; $1.508\ \text{W}$]

CHAPTER NINE

VOLTAGE AND CURRENT STABILIZATION

111. A stabilized power supply to give 280 V at 40 mA employs a 'Stabilivolt' tube. The tube current at full load is 20 mA and the d.c. supply voltage is 420 V. Determine the value of the series resistor.

Calculate also the variation of output voltage if the input voltage varies by $\pm 5\%$, and the variation of output voltage if the load current varies by ± 10 mA. The 'Stabilivolt' has four gaps, and the impedance of each gap may be taken as 40Ω .

[Ans. $2,333 \Omega$; ± 1.43 V; ± 1.6 V]

112. The d.c. input voltage to a simple glow-discharge stabilizer is V_i , and the limiting resistor has a resistance R . The resistance of the load is R_L . Discuss how the values of V_i and R are chosen when the tube and load are specified.*

A certain tube has a maximum allowable current of 40 mA, and a minimum specified current of 5 mA. The working voltage of the tube is 150 V, and may be assumed constant. If the input voltage V_i varies by 10%, plot curves showing (a) the relation between the maximum and minimum values of load current I_{Lmax} and I_{Lmin} , if $I_{Lmax} + I_{Lmin} = 30$ mA, and (b) the relation between the minimum value of V_i and $(I_{Lmax} - I_{Lmin})$.

113. Two glow-discharge tubes in series, each having a running voltage of 100 V, are connected to a d.c. supply of voltage 400 V. They supply a load taking a current of 20 mA. The normal tube current is 30 mA. Calculate the resistance of the series resistor.

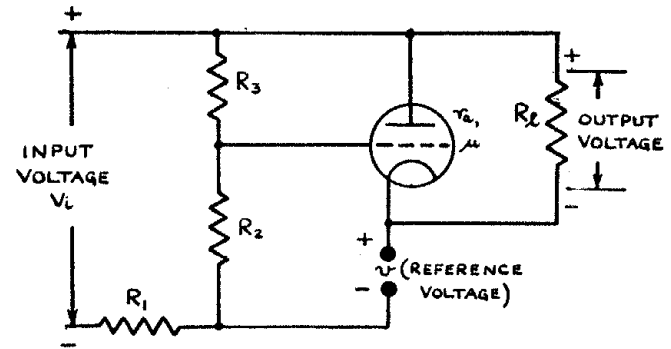
If the specified current range of each tube is 10 to 50 mA, find the range of input voltage over which stabilization is effective, and the range of load resistance.

[Ans. $4 \text{ k}\Omega$; 320 V to 480 V; $5 \text{ k}\Omega$ to ∞]

114. Derive an expression for the ratio of the percentage change of output voltage to the percentage change of input voltage for the simple parallel-valve voltage stabilizer shown, if the load resistor

R_L is constant. Hence show that stabilization in such a circuit is impossible without a reference voltage and that the larger the value of the mutual conductance of the valve the better the stabilization.

Assume that the valve characteristics are linear and that the heater voltage of the valve remains constant.

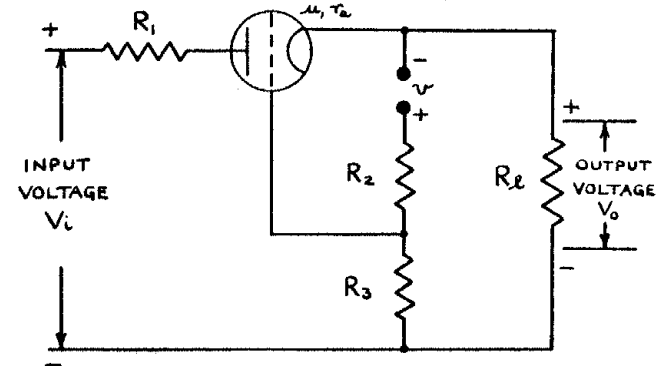


$$\left[\text{Ans. } \frac{1}{1 + \frac{v}{V_i} \left[\frac{R_1(\mu R_3 - r_a)}{r_a(R_2 + R_3)} - 1 \right]} \right]$$

115. The equivalent circuit of a series-valve stabilizer is illustrated. Find the change in output voltage for a 10% change of input voltage if $R_1 = 10 \text{ k}\Omega$, $R_2 = 1 \text{ M}\Omega$, $R_3 = 16 \text{ M}\Omega$, $V_i = 2,700$ V, $v = 100$ V, $\mu = 300$, $r_a = 100 \text{ k}\Omega$ and $R_L = 260 \text{ k}\Omega$.

Calculate also the change in output voltage produced by a 10% change of R_L .

Make the same assumptions as in the previous problem.



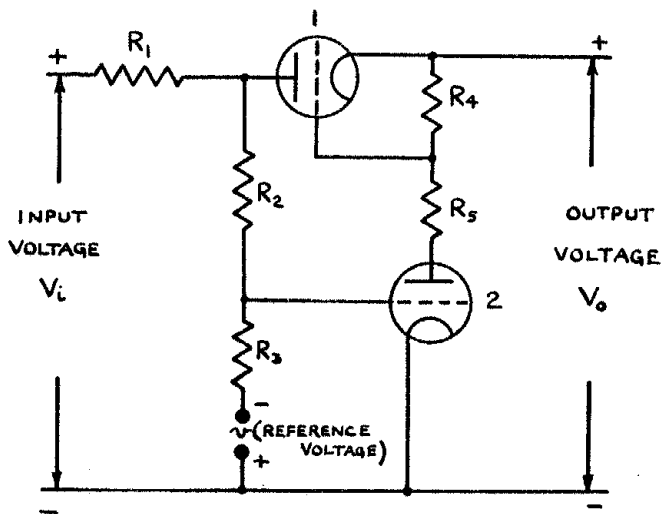
[Ans. 14 V; 3.5 V]

116. The diagram shows one form of thermionic-valve voltage stabilizer. Derive an expression for the ratio of the percentage change of output voltage to the percentage change of input voltage of the stabilizer if the load resistor is constant. Hence, show that theoretically, perfect stabilization is obtained when

$$R_3\mu_2(r_{a_1} + \mu_1 R_4) = (R_2 + R_3)(R_4 + R_5 + r_{a_2})$$

where μ_1 and μ_2 are the amplification factors of valves 1 and 2 respectively and r_{a_1} and r_{a_2} are the corresponding anode resistances.

Make the same assumptions as in the previous two problems.



[Ans. $1/(1 - Av/BV_i)$]

$$\text{where } A = \mu_2\{(R_1 + R_2 + R_3)(R_1 + r_{a_1} + \mu_1 R_4) - R_1^2\} \\ - R_3\mu_2(R_1 + r_{a_1} + \mu_1 R_4) \\ - R_1(R_4 + R_5 + r_{a_2})$$

$$\text{and } B = R_3\mu_2(r_{a_1} + \mu_1 R_4) - (R_2 + R_3)(R_4 + R_5 + r_{a_2})$$

117. The anode voltage V_a , the grid voltage V_g and the anode current I_a of a triode are related by the expression

$$V_a = r_a I_a - \mu V_g - c r_a^*$$

where c is a constant which is normally small.

Show that a 10% change of the heater voltage of the triode in

Question 115 causes the output voltage of the stabilizer to change by about 4.2 V (assume that c is originally zero, and that it changes by 0.8 mA for a 10% change of heater voltage).

118. The voltage/current characteristic of a certain barretter is given by the following figures:

Voltage (V)	80	100	120	140	160	180
Current (A)	0.476	0.495	0.498	0.500	0.502	0.514

A number of valve heaters having a total resistance of 100 Ω are connected in series with this barretter. Find the current through the circuit when the input voltage is 200 V.

When the input voltage changes by $\pm 10\%$ calculate the corresponding current variation.

[Ans. 0.5 A; 0.004 A]

CHAPTER TEN

AMPLIFIERS

119. A certain triode operates with an anode voltage of 250 V and a grid voltage of -8 V. The anode current is then 9 mA. If the valve is used with a load having a resistance of $10,000 \Omega$, what is the value of the supply voltage required?

If the h.t. supply voltage is fixed at 430 V, calculate the resistance of the load to keep the valve working at the same operating point.
[Ans. 340 V; 20 k Ω]

120. A voltage amplifier employs a valve operating with an anode current of 9 mA and a negative bias of 8 V. Find the value of the resistance of a cathode resistor to give the required bias.

Determine also a suitable value for the cathode by-pass capacitance, if the signal frequency is (a) 1,000 c/s, or (b) 100 c/s.
[Ans. 889 Ω ; 2 μ F; 20 μ F]

121. A low-frequency amplifier has a gain of 60 db. The input circuit is of 600Ω resistive impedance and the output is arranged for a load of 10Ω . What will be the current in the load when an alternating voltage of 1 V is applied at the input?

Express the gain of the amplifier in nepers.
[Ans. 12.9 A; 6.9 nepers]

122. A triode valve with an amplification factor of 20 and an anode resistance of $8,000 \Omega$ is used as an amplifier with an inductive load of inductance 0.8 H and resistance $1,000 \Omega$. Determine the gain and phase shift of the amplifier at a frequency of 300 c/s and sketch the vector diagram of the arrangement. The input voltage is 5 V.

By calculating the gain and phase shift of the amplifier at a frequency of 2,000 c/s, show that both frequency distortion and phase-shift distortion occur.

[Ans. 3.92/— 133°; 14.97/— 143.8°]

123. By analysing the equivalent circuit of the RC-coupled amplifier correlate the sinusoidal and pulse responses of the amplifier.

124. A triode amplifier operating at a frequency of 10,000 c/s has a resistive load of $90,000 \Omega$. Calculate the voltage gain. The valve has an amplification factor of 60 and an anode resistance of $40,000 \Omega$. The interelectrode capacitances are $C_{ga} = 3.0 \mu\mu$ F, $C_{gc} = 3.0 \mu\mu$ F and $C_{aa} = 3.6 \mu\mu$ F.

Find the gain of this stage when it forms the first section of a two-stage amplifier. The two stages are identical. Make any reasonable assumptions.
[Ans. 41.6; 39.1/160.2°]

125. Calculate the gain, the input capacitance and the input resistance of a triode amplifier when the load is a coil having an inductance of 20 mH and a resistance of $2,500 \Omega$, and the frequency is 10,000 c/s. The amplification factor of the triode is 20 and the anode resistance is $7,700 \Omega$. The interelectrode capacitances are $C_{ga} = 3.4 \mu\mu$ F, $C_{gc} = 3.4 \mu\mu$ F and $C_{aa} = 3.6 \mu\mu$ F.
[Ans. 5.4/— 160.4°; 24.2 $\mu\mu$ F; — 2.564 M Ω]

126. A valve with an amplification factor of 80 and an anode resistance of $50,000 \Omega$ has a load resistor of $100,000 \Omega$ connected between the anode and the positive h.t. supply terminal. Between the cathode and the negative h.t. terminal is a resistor of $2,000 \Omega$ with a capacitor of 1μ F connected in parallel. An alternating voltage v_i is applied between the grid and the negative h.t. terminal, and the output voltage v_o is measured across the anode load. Calculate the maximum and minimum values of the ratio v_o/v_i .

At what frequency is the magnitude of v_o/v_i equal to 0.707 of its maximum value?
[Ans. 53.3; 25.6; 121.2 c/s]

127. The first stage of a resistor-capacitor coupled amplifier employs a valve with an amplification factor of 20 and an anode resistance of $7,700 \Omega$. The resistance of the load is $50,000 \Omega$, the coupling capacitor has a capacitance of 0.01μ F, and the grid leak (including the resistive component of the input impedance of the next stage) has a resistance of $500,000 \Omega$. The input capacitance of the next stage is $200 \mu\mu$ F. Evaluate the gain of the stage at intermediate frequencies.

Find also the frequencies at which the gain falls to $1/\sqrt{2}$ of its intermediate-frequency value and calculate the frequency range over which the gain is greater than 14.

[Ans. — 17.1; 31 c/s; 121,000 c/s; 44 to 84,960 c/s]

128. A two-stage resistor-capacitor coupled amplifier is to be designed with an overall mid-frequency gain of at least 6,000 and with the gain only 5% below the mid-frequency value at a frequency of 100 kc/s. Pentodes are available which have

$$C_{ao} + C_{ac} = 10.5 \mu\mu\text{F}$$

and g_m is 5.2 mA/V. It may be assumed that $10 \mu\mu\text{F}$ of stray capacitance shunts the equivalent circuit of one stage. Determine the value of the load resistance required and the actual overall gain at mid frequency.

[Ans. 17.2 k Ω ; 7,992]

129. Draw the equivalent circuit for one stage of an inductor-capacitor coupled amplifier, and explain how the frequency-response characteristic of the amplifier may be examined.

130. By considering an RC-coupled amplifier employing pentodes show that it is not possible to increase bandwidth without a commensurate sacrifice in gain and vice-versa.

Calculate the maximum figure of merit (gain \times bandwidth) for a pentode which has $g_m = 5.7$ mA/V, $C_{ao} = 6.6 \mu\mu\text{F}$ and $C_{ac} = 2.6 \mu\mu\text{F}$.

[Ans. 98.6]

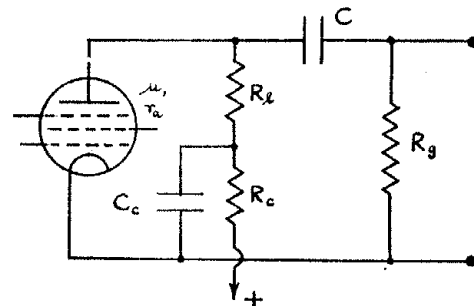
131. Three non-identical RC-coupled valve amplifier stages are cascaded. The bandwidth limits f_1 and f_2 for the individual amplifiers are given in the Table below.

Amplifier	Frequency f_1 (c/s)	Frequency f_2 (kc/s)
1	100	250
2	80	350
3	50	550

Obtain equations from which the overall bandwidth limits could be calculated.

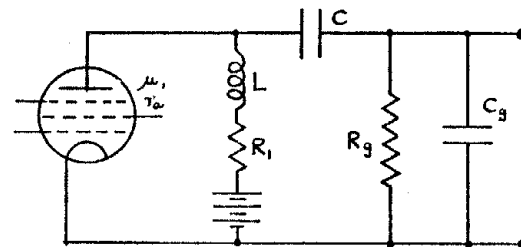
[See the solution for the equations]

132. The circuit illustrated provides an anode-load impedance that rises with decrease of frequency and can compensate for the reduction in gain at low frequencies caused by capacitor C .



Assuming that R_g and r_a are large with respect to R_L , that the shunting effect of C and R_g on the load is negligible and that R_c is large compared with the reactance of C , show that if $C_c R_L = C R_g$, the low-frequency gain is independent of frequency.

133. The circuit illustrates one method of extending the upper limit of the frequency range of an RC-coupled amplifier where an inductor L counteracts the effect of C_c in reducing the load impedance at high frequencies.



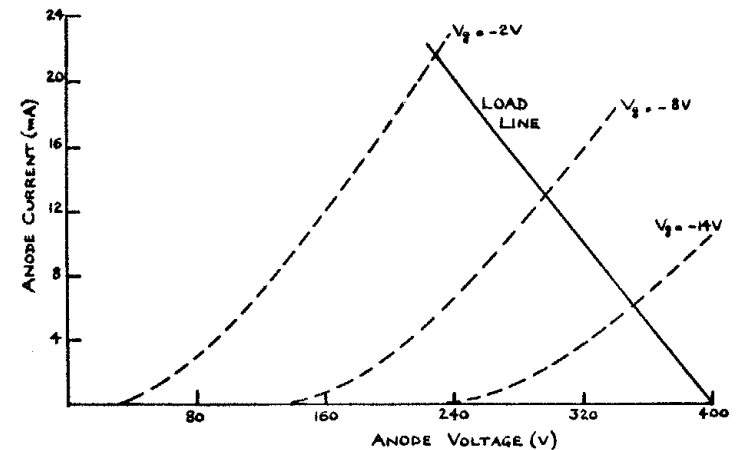
Analyse the circuit to find a desirable relation between L , C_c and R_L .

[Ans. For best flatness of the response curve $L = 0.414 C_c R_L^2$ but a single value of L is not satisfactory for simultaneous flat gain and constant time delay and a compromise is necessary.]

134. Assuming the characteristic curves for a triode valve to be equidistant straight lines, prove that the maximum possible anode-circuit efficiency for a class-A amplifier, coupled to a resistive load through an ideal transformer, is 50%.

Show also that the theoretical maximum efficiency for the simple series-fed, class-A, power amplifier is 25%.

135. A transformer-coupled amplifier has the following constants:
 Amplification factor of valve = 10.
 Anode resistance of valve = 8,000 Ω.
 Ratio of secondary to primary turns of transformer = 3.
 Effective leakage inductance of transformer referred to primary = 0.5 H.
 Total effective shunt capacitance of transformer referred to primary = 1,000 μμF.
 Total effective resistance of transformer referred to primary = 15,000 Ω.
 Resistance of primary winding of transformer = 3,500 Ω.
 Inductance of primary winding of transformer = 70 H.
 Obtain a curve showing how the gain of the amplifier varies with frequency.



[Ans. 13.575 mA; 10.2; 4.9%]

136. A triode in an amplifier has an anode resistance of 8,000 Ω and an amplification factor of 16. It is coupled to the following stage by a transformer with a step-up ratio of 3. The secondary of the transformer is loaded with a resistance of 450 kΩ. Calculate the stage gain at a frequency where the primary reactance is 5 kΩ.

[Ans. 24.3]

137. A triode valve operates from a 300-V supply and its load is a resistor of 2,000 Ω coupled through an ideal transformer of ratio 1:1. When a sinusoidal voltage is applied between the grid and the cathode of the valve, the maximum and minimum values of anode current are 150 mA and 20 mA. When the alternating grid voltage is zero, the anode current is 80 mA. Determine the power delivered to the load, the efficiency and the approximate percentage of second-harmonic current.

[Ans. 4.23 W; 0.17; 3.85%]

138. Determine the mean current, fundamental gain and second-harmonic distortion for a triode valve which has the anode-current/anode-voltage characteristics shown in the figure, when it is operating with a grid bias of -8 V, an anode supply voltage of 400 V and a load resistor of 8,000 Ω. The peak input signal is 6 V.

139. The anode current of a triode can be expressed as $[I_a + B_0 + B_1 \cos \omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + B_4 \cos 4\omega t]$ when the input voltage to the grid is sinusoidal, and of the form $v_g = V_g \cos \omega t$. Obtain a 5-point schedule by the Espley* method for determining B_0, B_1, B_2, B_3 and B_4 in terms of the anode currents for $\omega t = 0, \pi/3, \pi/2, 2\pi/3$ and π .

[Ans. $B_0 = (I_{max} + 2I' + 2I'' + I_{min})/6 - I_a$
 $B_1 = (I_{max} + I' - I'' - I_{min})/3$
 $B_2 = (I_{max} - 2I_a + I_{min})/4$
 $B_3 = (I_{max} - 2I' + 2I'' - I_{min})/6$
 $B_4 = (I_{max} - 4I' + 6I_a - 4I'' + I_{min})/12$

where I_{max}, I', I_a, I'' and I_{min} are the anode currents for $\omega t = 0, \pi/3, \pi/2, 2\pi/3$ and π respectively]

140. The following figures refer to a certain 25-W triode valve which delivers power to a resistive load by means of a choke-capacitor coupling.

Grid voltage $V_g = 0$.

Anode voltage V_a (V)	24	60	100	150	180
Anode current I_a (mA)	10	30	68	120	154

Grid voltage $V_g = -10.7$ V.

Anode voltage V_a (V)	123	150	200	250
Anode current I_a (mA)	10	25	66	120

Grid voltage $V_g = -21$ V.

Anode voltage V_a (V)	220	250	300	350
Anode current I_a (mA)	10	27	67	119

Grid voltage $V_g = -32$ V.

Anode voltage V_a (V)	312	350	400
Anode current I_a (mA)	10	29	68

The h.t. supply voltage is 300 V. Determine the approximate resistance of the load for maximum undistorted power output. Calculate this maximum value of power and the efficiency.

[Ans. 1.95 k Ω ; 4 W; 16%]

141. (a) Show mathematically that in a push-pull amplifier circuit employing two identical valves all even harmonics are suppressed in the output.

(b) Two triodes in a push-pull amplifier each have an anode-voltage/anode-current characteristic passing through the quiescent point (250 V, 30 mA) which is given by the following figures:

Anode voltage (V)	150	175	200	225	250	275	300	325
Anode current (mA)	0	3	9	18	30	43	58	73

Draw the two curves with one inverted, and then obtain the composite characteristic. Find, from the curves, the anode resistance at the quiescent point of (i) each valve, (ii) the composite valve.

[Ans. (i) 2,000 Ω ; (ii) 1,000 Ω]

142. Two power triodes, each having characteristics as defined by the figures in the following Tables, operate in class-A push-pull. Draw the composite characteristics if the quiescent point is at

$V_a = 200$ V, $V_g = -20$ V. Draw also the composite load line for an anode-to-anode load of 5 k Ω .

Determine the power output of this push-pull amplifier when the peak input to each valve is 20 V.

Grid voltage $V_g = 0$.

Anode voltage V_a (V)	0	40	80	120
Anode current I_a (mA)	0	13	32	52

Grid voltage $V_g = -20$ V.

Anode voltage V_a (V)	0	40	80	120	160	200	240
Anode current I_a (mA)	0	0	0	5	15	30	47

Grid voltage $V_g = -40$ V.

Anode voltage V_a (V)	0	40	80	120	160	200	240	280	320
Anode current I_a (mA)	0	0	0	0	0	3	9	19	33

[Ans. ≈ 1.53 W]

143. (a) Show that the maximum possible efficiency of a class-B audio-frequency amplifier, for sinusoidal signals, is 78.5%.

(b) A class-B amplifier operates from a 500-V, h.t. supply. The relation between the maximum permissible peak anode current (in amperes) and the minimum anode voltage is $I_{\max} = 10^{-3} V_{\min}$. If transformer losses are neglected, what is the maximum a.c. power which can be obtained, and what is the efficiency?

(c) Show that for a class-C amplifier where the angle of flow is 120° the maximum efficiency is 89.6%.

[Ans. (b) 31.25 W; 39.3%]

144. The anode current in a class-C amplifier may be regarded as triangular pulses having a peak value of 2.5 A and an angle of flow of 90°. The grid voltage varies sinusoidally and the anode-current/grid-voltage characteristic is linear. If the h.t. supply is 2.5 kV and the r.m.s. current delivered to a 750- Ω load is 0.8 A, what is the efficiency of the amplifier?

If the peak-to-peak amplitude of the anode voltage is 4 kV find the instantaneous anode voltage when anode current commences to flow.

[Ans. 61.9%; 1,086 V]

145. A triode valve with an amplification factor of 50 and an anode resistance of $30,000\ \Omega$ has for its anode load a parallel resonant circuit, of ' Q ' = 45, which contains a resistor R of $15,000\ \Omega$. The circuit resonates at $20,000\ \text{c/s}$. A second coil L_2 is coupled magnetically to the resonant-circuit coil L , the mutual inductance M between the coils being 1 mH. Calculate the voltage between the terminals of L_2 when a voltage of 1 V at a frequency of $20,500\ \text{c/s}$ is applied between the grid and cathode of the valve.

[Ans. 3.485 V]

146. A pentode in a tuned-amplifier circuit has an anode resistance of $500\ \text{k}\Omega$ and a mutual conductance of $5\ \text{mA/V}$. In its anode circuit is a $20\text{-}\mu\text{H}$ coil with a ' Q ' of 50, and this is tuned to parallel resonance at $1,592\ \text{kc/s}$. The output voltage is fed to a second stage of input resistance $500\ \text{k}\Omega$ through a coupling capacitor of negligible reactance. Calculate the gain of the stage at resonance.

[Ans. 48]

147. An amplifier has a gain of 20, without feedback. If 10% of the output voltage is fed back by means of a resistive negative-feedback circuit, determine the actual amplification.

[Ans. 6.67]

148. An amplifier employing a pentode with an amplification factor of 1,000 and a mutual conductance of $5\ \text{mA/V}$ has a $200\text{-k}\Omega$ load resistor. Calculate the voltage amplification (a) without feedback, (b) with 5% negative voltage feedback.

Determine also the effective constants of the valve when feedback is used.

[Ans. 500; 19.2; $\mu' = 19.6$; $r_a' = 3.92\ \text{k}\Omega$; $g_m' = 5\ \text{mA/V}$]

149. A certain audio-frequency amplifier has a nominal gain of 120 and gives an output voltage of 60 V to its output transformer, with 10% second-harmonic distortion. How much feedback must be used to reduce the distortion to 1%? Find also the additional gain required ahead of the feedback amplifier, in order to give the same output voltage.

[Ans. Feedback factor = -0.075; 10]

150. A multistage amplifier, when operated without feedback and with normal supply voltage, has a gain of 24,000. When the supply voltage falls by 25% the amplification is only 16,000. Show that if a negative-feedback potentiometer across the output is used to feed back $1/1,000$ of the output voltage to the input, the amplification is nearly independent of variations in supply voltage.

[Ans. Gain for normal supply voltage = 960; gain when supply voltage falls by 25% from its normal value = 941]

151. An amplifier employing pentodes with anode slope resistance r_a and mutual conductance g_m has three identical resistor-capacitor coupled stages, each coupling circuit having capacitance C and resistance R_p . The anode load resistance in each stage is R_l . A fraction β of the amplifier output voltage is fed back to the input without phase-shift.

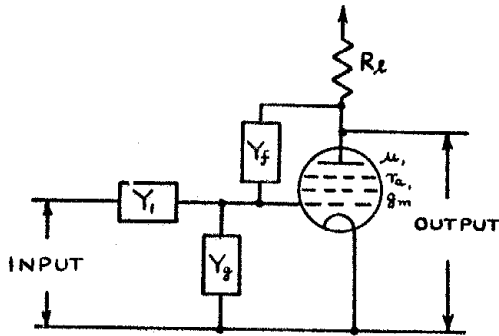
Use Nyquist's criterion to find the maximum value of β which may be employed without causing instability.

Assume that R_p and r_a are large compared with R_l and neglect interelectrode and stray capacitances.

[Ans. $8/(g_m R_l)^3$]

152. Show that the output impedance of a cathode-follower stage, which employs a valve with a mutual conductance of $4\ \text{mA/V}$, is about $250\ \Omega$ but the input impedance is high.

153. Draw the equivalent circuit of the feedback arrangement illustrated in the diagram and use Millman's network theorem* to find the overall gain. Obtain also, expressions for the output and input admittances of the network. If a pentode is used in the circuit, for which the anode resistance r_a is $1\ \text{M}\Omega$ and the mutual conductance g_m is $2\ \text{mA/V}$, and $Y_1 = Y_f = 2 \times 10^{-6}\ \text{mho}$ and $Y_o = 0.2 \times 10^{-6}\ \text{mho}$, show that the gain is approximately unity. Under the same conditions, prove that the value of the output impedance is approximately $[2/g_m]$, and that the input impedance is approximately Y_1 .



Compare the results with the corresponding ones for a cathode follower.

$$\begin{aligned} & [Ans. Y_1(Y_f - g_m) / \\ & \{(Y_1 + Y_f + Y_2)(Y_a + Y_1) + Y_f(Y_1 + Y_2 + g_m)\} = A \text{ say,} \\ & \text{where } Y_1 = 1/R_L \text{ and } Y_a = 1/r_a; \\ & Y_a + Y_f(Y_1 + Y_2 + g_m) / (Y_1 + Y_f + Y_2); \\ & Y_1\{Y_2 + (1 - A)Y_f\} / (Y_1 + Y_2 + Y_f) \end{aligned}$$

154. (a) Show that, for an amplifier which possesses voltage feedback, the output impedance is reduced in a ratio numerically equal to the voltage gain without feedback. Repeat the calculation for a circuit provided with current feedback, and thus prove that the output impedance is increased in the same ratio as the reduction in gain.

(b) Plot a Nyquist diagram* for a single-stage amplifier having a resistive load and negative voltage feedback, and investigate the stability of the circuit.

155. A junction transistor has the following constants: $r_{11} = 550 \Omega$, $r_{12} = 500 \Omega$, $r_{21} = 1.9 \text{ M}\Omega$, $r_{22} = 2 \text{ M}\Omega$. Determine the input resistance of a common-base amplifier stage using this transistor as the load resistance varies from zero to infinity.

If the resistance of the source at the input of the amplifier is zero find the output resistance of the arrangement.

Calculate, also, the maximum possible voltage gain.

$$[Ans. 75 \text{ to } 550 \Omega; 2.72 \times 10^5 \Omega; 3,454]$$

156. Derive expressions for the voltage amplification, the current amplification, the input resistance, the output resistance and the power gain of a common-base transistor-amplifier stage.

$$\begin{aligned} [Ans. & \frac{(r_m + r_b)R_L}{r_b(r_o - r_m + R_L + r_e) + r_e(r_c + R_L)}; \\ & (r_m + r_b)/(r_b + r_c + R_L); \\ & (r_e + r_b) - r_b(r_b + r_m)/(r_b + r_c + R_L); \\ & r_c - \frac{r_b(r_m - R_g - r_e)}{R_g + r_e + r_b} \\ & \frac{(r_m + r_b)^2 R_L}{(r_b + r_c + R_L)\{r_b(r_c - r_m + R_L + r_e) + r_e(r_c + R_L)\}} \end{aligned}$$

where r_b , r_c , r_e and r_m are the usual transistor parameters, R_g is the internal resistance of the source, and R_L is the load resistance]

157. Derive expressions for the voltage and current gains and the input and output resistances of the following transistor amplifiers:

(a) a common-emitter circuit, (b) a common-collector circuit.

$$\begin{aligned} [Ans. (a) & \frac{R_L}{r_b + \{(r_b + r_e)(r_c + R_L)/(r_e - r_m)\}}; \\ & (r_e - r_m)/(r_e + r_c - r_m + R_L) \\ & r_b + \frac{r_e(r_c + R_L)}{r_c + r_e - r_m + R_L} \\ & (r_e - r_m) + \frac{r_e(r_b + r_m + R_g)}{r_b + r_e + R_g} \\ (b) & \frac{r_o R_L}{r_b(r_o - r_m + r_e + R_L) + r_c(r_e + R_L)}; \\ & r_c/(r_e + r_c - r_m + R_L); \\ & r_b + \frac{r_c(r_e - R_L)}{r_e + r_c - r_m + R_L} \\ & r_e + \frac{(r_c - r_m)(r_b + R_g)}{r_b + r_c + R_g} \end{aligned}$$

where r_b , r_c , r_e and r_m are the usual transistor parameters, R_g is the internal resistance of the source, and R_L is the load resistance]

158. A junction transistor whose parameters are $r_{11} = 820\Omega$, $r_{12} = 800\Omega$, $r_{21} = 1.98\text{ M}\Omega$ and $r_{22} = 2\text{ M}\Omega$ is used in a single-stage, common-emitter amplifier, with a load resistance of 430Ω .

Calculate the voltage gain, the current gain and the input resistance.
 [Ans. — 15.2; ≈ 99 ; $\approx 2,755\Omega$]

159. Derive the following expressions for the common-base transistor amplifier:

$$\text{Voltage gain} = \frac{-h_{21}}{h_{11}h_{22} - h_{12}h_{21} + h_{11}/R_L}$$

$$\text{Current gain} = h_{21}/(h_{22}R_L + 1)$$

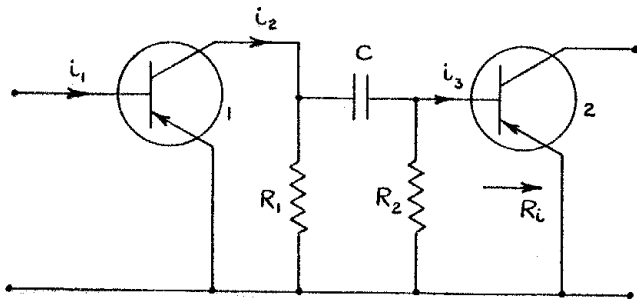
$$\text{Input resistance} = \frac{(h_{11}h_{22} - h_{12}h_{21}) + h_{11}/R_L}{h_{22} + 1/R_L}$$

where h_{11} , h_{12} , h_{21} and h_{22} are the usual hybrid parameters and R_L is the load resistance.

160. The hybrid parameters for a common-emitter transistor amplifier circuit are $h_{11}' = 800\Omega$, $h_{21}' = 47$, $h_{12}' = 5.4 \times 10^{-4}$ and $h_{22}' = 80\mu\text{mhos}$. The load resistance is $20\text{ k}\Omega$. Calculate the voltage and current gains.

[Ans. — 598; 18]

161. Determine the response of an RC-coupled common-emitter transistor amplifier at low and intermediate audio frequencies by analyzing the circuit illustrated.

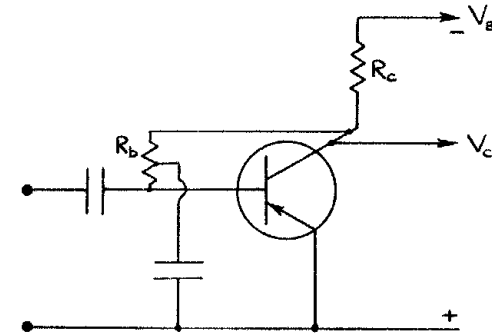


Draw an approximate high-frequency equivalent circuit for the common-base transistor arrangement and show how the high-frequency response of an RC-coupled common-emitter amplifier may be calculated.

[See the solution for the response expressions]

162. A transistor biasing circuit giving a measure of stabilization of the working point is illustrated. Obtain a relationship between the stability factor S , the parameters R_b and R_c and the current amplification α of the transistor.

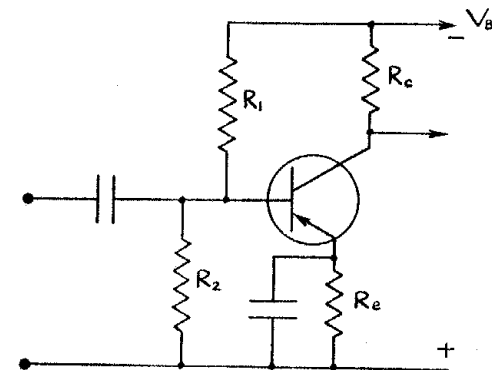
In a typical case $R_c = 10\text{ k}\Omega$, $R_b = 100\text{ k}\Omega$ and $\alpha = 0.98$. Determine S .



$$[\text{Ans. } S = \frac{R_b + R_c}{R_c + (1 - \alpha)R_b}; 9.2]$$

163. A transistor bias stabilization circuit is illustrated. Show that the stability factor S is given by $(R_b + R_e)/\{R_e + R_b(1 - \alpha)\}$ where $R_b = R_1R_2/(R_1 + R_2)$.

In a typical circuit $R_1 = 50\text{ k}\Omega$, $R_2 = 20\text{ k}\Omega$, $R_e = 2.5\text{ k}\Omega$ and $\alpha = 0.98$. Find S .



[Ans. 6]