CHAPTER 18

MICROPHONES, PRE-AMPLIFIERS, ATTENUATORS AND MIXERS

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SECTION 1 : MICROPHONES

(i) General survey (ii) Carbon microphones (iii) Condenser microphones (iv) Crystal and ceramic microphones (v) Moving coil (dynamic) microphones (vi) Pressure ribbon microphones (vii) Velocity ribbon microphones (viii) Throat microphones (ix) Lapel microphones (x) Lip microphones (xi) The directional characteristics of microphones (xii) The equalization of microphones (xiii) Microphone transformers (xiv) Standards for microphones.

(i) General survey

Microphones may be divided into two basic groups, pressure- and velocity-operated. Any microphone that has its diaphragm exposed to sound waves on one side only, is a **pressure-operated type**—that is, the displacement of the diaphragm is proportional to the instantaneous pressure developed in the sound waves. At low frequencies a pressure-operated microphone is non-directional, that is to say it responds uniformly to sounds from all directions. As the frequency increases, however, the response becomes more and more uni-directional and there is a peak in the high frequency response for sound impinging directly on the diaphragm ; this peak may be reduced or eliminated by placing the diaphragm at an angle of 45° to 90° to the direction of the sound.

Examples of pressure-operated microphones are carbon, crystal, moving coil and pressure-ribbon microphones.

A **velocity-operated microphone** is one in which the electrical response corresponds to the particle velocity (or pressure-gradient) resulting from the propagation of a sound wave through the air. Examples are the free-ribbon velocity microphone and pressure-gradient microphones. There are also combinations of pressure-operated and velocity-operated microphones.

For good fidelity a microphone should have a wide frequency response without peaks, low distortion and good transient response. For public address a microphone need not have such a wide frequency response, particularly at the bass end, and a slight peak in the 3000 to 5000 c/s region is not usually considered detrimental, while distortion requirements are less stringent.

The output voltage from a microphone is approximately proportional to the sound pressure.

The peak r.m.s. sound pressure at a distance of 1 foot from a man's mouth is of the order of 10 dynes/cm^2 with conversational speech. It decreases 6 db each time the distance is doubled. When speaking with the mouth as close as possible to the microphone, the peak r.m.s. sound pressure is about 100 dynes/cm^2.

General references A5, D3, D4, D7, D11.

Microphone ratings

Microphones may be rated in terms of either voltage or power, as described in detail in Chapter 19 Sect. 1(iv). Ratings in common use include

Voltage ratings

A. Open circuit voltage (0 db = 1 V) for sound pressure 1 dyne/cm², expressed in dbv*.

B. Open circuit voltage (0 db = 1 V) for sound pressure 10 dynes/cm², expressed in dbv.

C. Volume units (as read by a standard Volume Indicator) for sound pressure 1 dyne/cm², expressed in vu.

D. High impedance grid circuit voltage (0 db = 1 V, Z = 40 000 ohms) for sound pressure 1 dyne/cm², expressed in dbv.

Power ratings

E. Output power† (0 db = 1 mW) for sound pressure 1 dyne/cm², expressed in dbm. ‡

F. Output power† (0 db = 1 mW) for sound pressure 10 dynes/cm², expressed in dbm.

G. Output power (0 db = 6 mW) for sound pressure 1 dyne/cm². This rating is now rarely used.

H. Output power (0 db = 6 mW) for sound pressure 10 dynes/cm². This rating is now rarely used.

J. Output power (0 db = 1 mW) for sound pressure 0.0002 dyne/cm². This is the R.M.A. Microphone System Rating G_M (R.M.A. Standard SE-105 ; see Chapter 19 Sect. 1(iv)D).

Voltage ratings—To convert from A to B, add + 20 db.

                    To convert from B to A, add − 20 db.

If a voltage rating is used for a low impedance microphone, the impedance across which the voltage occurs should be specified.

Volume units—This is not an official microphone rating, but is sometimes used as a convenient method of measurement. The Volume Indicator is effectively a voltmeter in which 0 vu = 0.77 volts r.m.s. across 600 ohms. To convert vu (Rating C) to voltage (rating A), add − 2 db. When the output from a low impedance microphone is quoted in terms of vu, it may be inferred that this is equivalent to the power output in milliwatts (Rating E).

Power ratings—The power rating is the power developed in a load of specified value. Power ratings E, F, G and H may be calculated one from the other as under :

To convert from	add	To convert from	add	To convert from	add
E to F	+20 db	F to J	− 94 db	H to G	− 20 db
E to G	− 8	G to E	+ 8	H to J	− 86
E to H	+12	G to F	+ 28	J to E	+ 74
E to J	−74	G to H	+ 20	J to F	+ 94
F to E	−20	G to J	− 66	J to G	+ 66
F to G	−28	H to E	− 12	J to H	+ 86
F to H	− 8	H to F	+ 8		

Relationship between voltage and power ratings ‡

Provided that the sound pressure is the same in both cases : Microphone rating in dbv (0 db = 1 volt) = microphone rating in dbm (0 db = 1 milliwatt) + correction factor (db)

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*dbv indicates a voltage, expressed in decibels, with 0 db = 1 volt.
†Also applies to effective output level.

‡In calculations involving Power Rating J there may be an error, not greater than 2.5 db, due to the Rating Impedance differing from the actual impedance.

where the correction factor (C.F.) is given by.

Z	=	25	50	150	250	600	25 000	40 000 ohms
C.F.	=	−16	−13	−8	−6	−2	+14	+16 db

Crystal and condenser microphones cannot be rated in terms of power, while other types of microphones can only be compared directly with crystal and condenser types on the basis of the voltage on the unloaded grid circuit. To make this comparison it is here assumed that the nominal secondary impedance of the transformer is 40 000 ohms and that the voltage across the secondary is the voltage that would occur across a resistance of 40 000 ohms which was dissipating a power equal to the output rating of the microphone. This voltage is here called the high impedance grid circuit voltage (Rating D).

To convert from	add	To convert from	add
A to D (crystal mics.)	0 db	F to D	− 4 db
B to D (crystal mics.)	−20 db	G to D	+ 24 db
C to D	− 2 db	H to D	+ 4 db
E to D	+16 db	J to D	+ 90 db

Typical microphone ratings (db)

Rating	A	B	D	E
Type	0 db = 1 V 1 dyne/cm²	0 db = 1 V 10 dynes/cm²	0 db = 1 V Z = 40 000 Ω 1 dyne/cm²	0 db = 1 mW 1 dyne/cm²
	dbv	dbv	dbv	dbm
Carbon (S.B.)	−50*	−30*	−23	−39
Condenser	−50 to −60	−30 to −40	−50 to −60	—
Crystal (sound cell)	−54 to −76	−34 to −56	−54 to −76	—
Crystal (diaphragm)	−46 to −65	−26 to −45	−46 to −65	—
Moving coil	—	—	−49 to −70	−65 to −86
Pressure ribbon	—	—	−61 to −65	−77 to −81
Velocity ribbon	—	—	−58 to −67	−74 to −83

*Measured across microphone (approximate resistance 100 ohms).

Type	F	G	H	J
	0 db = 1 mW 10 dynes/cm²	0 db = 6 mW 1 dyne/cm²	0 db = 6 mW 10 dynes/cm²	0 db = 1 mW 0.0002 dyne/cm²
	dbm	db	db	db
Carbon (S.B.)	−19	−47	−27	−113
Moving coil	−45 to −66	−73 to −94	−53 to −74	−139 to −160
Pressure ribbon	−57 to −61	−85 to −89	−65 to −69	−151 to −155
Velocity ribbon	−54 to −63	−82 to −91	−62 to −71	−148 to −157

(ii) Carbon microphones

An example of the **single button** type is the modern telephone inset, which gives an output of about 1 mW with close speaking. The frequency response is seriously peaked, while non-linear distortion and noise level are very high.

The **double button** (push-pull) type has a wider frequency range (70 to 7000 c/s

in one example), and the second harmonic distortion is considerably less, but the output is about 10 db lower than that of the single button type.

Carbon microphones require a source of low voltage to pass a current of from 10 to 50 mA through each button. When the circuit is broken by a switch there is a tendency for the carbon granules to cohere—this may be reduced by connecting two condensers and three inductors as shown in Fig. 18.1.

All carbon microphones have a tendency to blasting, while their other defects including high noise level limit their application. The principal advantage is the high output level.

References A5, A21, A23, D1, D3, D4, D7. D13, D14.

(iii) Condenser microphones

A condenser microphone consists of a stretched diaphragm and a back plate, with a polarizing voltage between them. Owing to the high impedance, the pre-amplifier must be mounted very close to the microphone. A possible circuit arrangement is shown in Fig. 18.2. The response may be made almost flat from 30 to 10 000 c/s with an incident angle of 90°—on the axis there is a high frequency peak of about 8 db as with all pressure microphones. The average response is about — 60 dbv across the microphone itself (0 db = 1 volt per dyne/cm^2).

References A5, A7, A23, D1, D3, D4, D7, D11, D13, D14.

The high frequency peak which occurs with microphones of standard size may be reduced by making the diaphragm smaller. A miniature condenser microphone with a diaphragm having the area of a human ear drum has been introduced with non-directional pickup characteristics (Refs. A18, A26). The output level from the pre-amplifier is — 50 dbm in a sound field of 10 dynes/cm^2.

(iv) Crystal and ceramic microphones

Crystal microphones are of two types, directly-actuated and diaphragm types. Directly-actuated (sound-cell) microphones, as a class, have lower sensitivity but flatter frequency characteristics and they are almost non-directional. Uniform response up to 17 000 c/s can be obtained. There is a resonance at the high frequency limit causing a rise of response (+ 12 db in a typical case)—this should be equalized or else high frequency attenuation provided.

The frequency response of diaphragm type crystal microphones is less uniform than with the sound-cell type, and varies from 80 to 6000 c/s for speech only (with a pronounced peak in the 3500 c/s region) and from 50 to 10 000 c/s (± 5 db) for improved fidelity. The diaphragm type is more directional at high frequencies than the sound-cell type. There are also cardioid directional crystal microphones—see (xi) below.
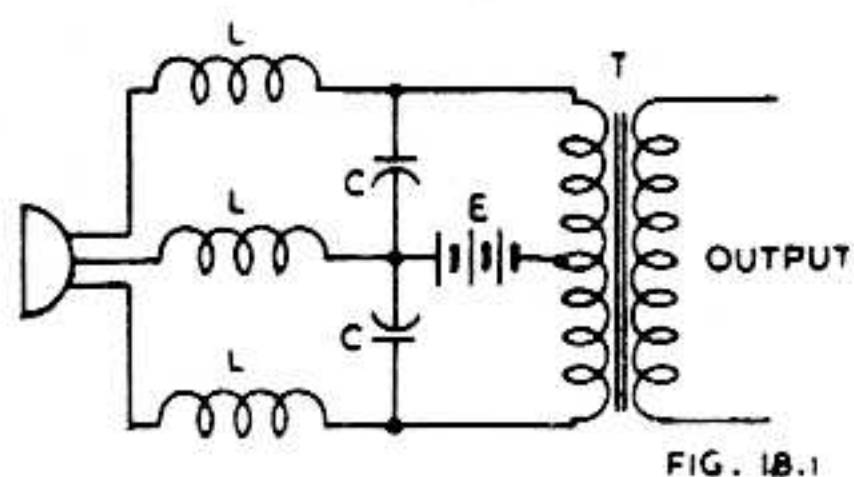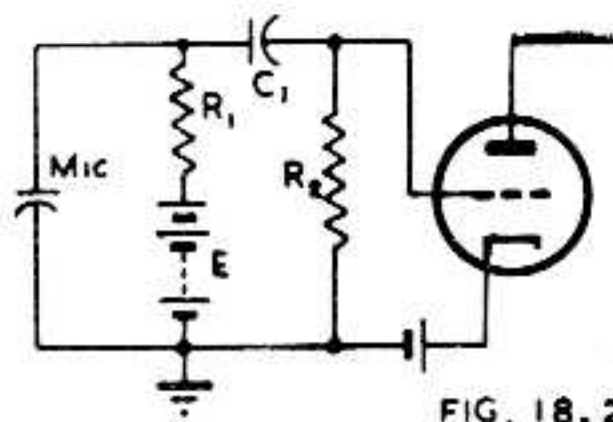

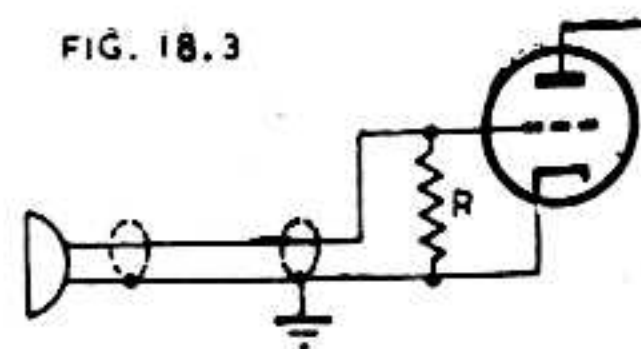Fig. 18.1. *Circuit diagram of double button carbon microphone with filter (optional) to reduce cohering (L = 0.0014 H, C = 0.02 μF, E = 4.5 to 6 V).*
Fig. 18.2. *Circuit diagram of condenser microphone.*
Fig. 18.3. *Circuit diagram of crystal microphone.*

All crystal microphones using Rochelle salt or similar materials tend to be affected by excessive humidity and temperatures above 125°F. Most of the crystals are now coated to provide considerable protection against humidity, although their use under tropical conditions appears to be risky.

A crystal microphone is effectively a capacitance, of the order of 0.03 μF for a diaphragm type or 0.0004 to 0.015 μF for a sound-cell type. This is effectively in series

with the generated voltage and following grid resistor.   The following-grid resistor* (R in Fig. 18.3) should be from 3 to 5 megohms for a sound cell type, or 1 to 5 megohms for a diaphragm type.   A low resistance causes attenuation of low frequencies.

A long connecting cable will result in loss of output voltage, but will not affect the frequency response.   The loss is given by

$$\text{db loss} = 20 \log [1 + (L \times C_L)/C_M].$$

where L = length of cable in feet

   C_L = capacitance of cable in microfarads per foot

and C_M = capacitance of microphone in microfarads.

A few crystal microphones are equipped with step-down transformers for use in .. v impedance circuits.

Ceramic piezo-electric microphones have advantages over crystal types as regards high temperature and humidity.   These have substantially similar performance to that of crystal microphones.   One model has a nearly flat response from 30 to 10 000 c/s with an output level of -62 dbv (0 db = 1 V per dyne/cm²).

References to crystal and ceramic microphones : A5, A21, A23, D1, D3, D4, D7, D13, D14.

(v) Moving coil (dynamic) microphones

A dynamic microphone is, in essence, a small version of a dynamic loudspeaker, and some are even used in a dual capacity.   It is pressure-operated and there is the usual tendency towards a rise in the high-frequency response for sound waves impinging directly on the diaphragm.   It may be mounted vertically to make the microphone non-directional for horizontal sound waves, but this causes some attenuation of the higher frequencies.

In its simplest form the level frequency range is limited but in the more elaborate types it may extend from 60 to 10 000 c/s.   It is a general-purpose good-quality microphone widely used for public-address and indoor and outdoor broadcasts.
References A5, A21, A23, A32, D1, D3, D4, D7, D11, D13, D14.

(vi) Pressure ribbon microphones

The pressure ribbon microphone has a ribbon, suspended in a magnetic field, that is exposed on one side and terminated in an acoustical resistance on the other.   It is non-directional but has the characteristic, in common with all pressure types, of a high frequency response that is a function of the direction of the incident sound.   The distortion may be around 2% or 3% at low frequencies and 100 dynes/cm².

This construction is generally combined with a manual control of the size of an aperture on the enclosed side which gives control of the directional characteristics (e.g. R.C.A. 77-D).

A small unobtrusive pressure type ribbon microphone has been produced (R.C.A. BK-4A) which employs a small angle horn coupled to a cylindrical tube which in turn is coupled to the front of the ribbon by means of a round-to-rectangular connector of constant cross-section.   The back of the ribbon is coupled to the damped folded pipe or labyrinth by means of a rectangular-to-round connector.   This is non-directional, has a frequency response from 70 to 15 000 c/s and an effective output level of -61 dbm (sound pressure 10 dynes/cm²).   (Refs. A25, A21, D3.)

(vii) Velocity ribbon microphones

This is a free ribbon type in which the ribbon resonance is usually below the audible limit.   With good design it is capable of a very wide frequency response (e.g. 30 to 15 000 c/s for response $\pm$ 5 db), while over the most useful part of the range the variations of level are very slight and gradual.   It is strongly bi-directional.   This is undoubtedly the best type of microphone for high fidelity, particularly for transients, but it is not suitable for general use outdoors.   The distortion in one case is less than 0.33% at 80 c/s and 1000 dynes/cm². When a velocity microphone is placed very

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*For maximum values of grid resistance see Sect. 2(vi).

close to the source of sound, the low frequencies are strongly accentuated. For this reason, a good, quiet studio and correct placement of speakers at a reasonable distance is necessary if a normal velocity microphone is used for speech. The bi-directional characteristic is useful where there are two speakers, or two groups, arranged on opposite sides of the microphone.

One model incorporates a switch and compensating reactor to reduce the accentuation of low frequencies with close speaking (R.C.A. KB-2C, Ref. A27).

A modified form incorporates a large amount of acoustical resistance to give a nearly flat response at all frequencies when speaking very close to the microphone (1 to 6 inches away), and noise cancellation for sounds originating at a distance. This is particularly suitable for outdoor public address (R.C.A. KB-3A, Ref. A28).

References A5, A21, A23, A27, A28, D1, D3, D4, D7, D11, D13, D14.

(viii) Throat microphones

A throat microphone is one which is actuated by direct contact of the diaphragm with the throat. The high frequency response must be accentuated to obtain intelligible speech. Both carbon and magnetic types have been used (Refs. A19, D3).

(ix) Lapel microphones

Normal types of carbon, crystal, dynamic and velocity microphones have been used for this application (Refs. A21, D3).

(x) Lip microphones

The velocity ribbon microphone has been used for this application (Ref. A5).

(xi) The directional characteristics of microphones

Pressure microphones are **non-directional** (Curve A Fig. 18.4) for low frequencies but at high frequencies the response is a function of the angle of sound incidence— this effect becomes smaller as the diaphragm diameter is reduced.

Velocity ribbon microphones are **bi-directional** (Curve B) and the sound source should be on one, other or both sides.

There are various types of **uni-directional** microphones, among which the cardioid (Curve C) is most popular. This characteristic may be achieved by a carefully designed combination of a velocity and a pressure microphone. Similar characteristics may be achieved by the use of acoustical delay systems in combination with any pressure microphone such as dynamic or crystal. A reduction of response of about 15 db at the back of the microphone with respect to that at the front is obtainable with a typical cardioid microphone. A single-element ribbon type microphone has been developed which has a reduction of 20 to 25 db at the back of the microphone (Ref. A22). A complete survey of directional microphones is given by Olson (Refs. A17, D3).

Fig. 18.4. *Polar diagrams showing directional characteristics of microphones* (A) *Non-directional* ; (B) *bi-directional* ; (C) *cardioid.*

Polydirectional microphones provide a choice of two or three directional characteristics or a continuously variable characteristic. A typical example is the R.C.A. 77-D ribbon type.

The correct use of directional characteristics in microphone placement minimizes room reflection and reduces acoustical feedback and background noise.

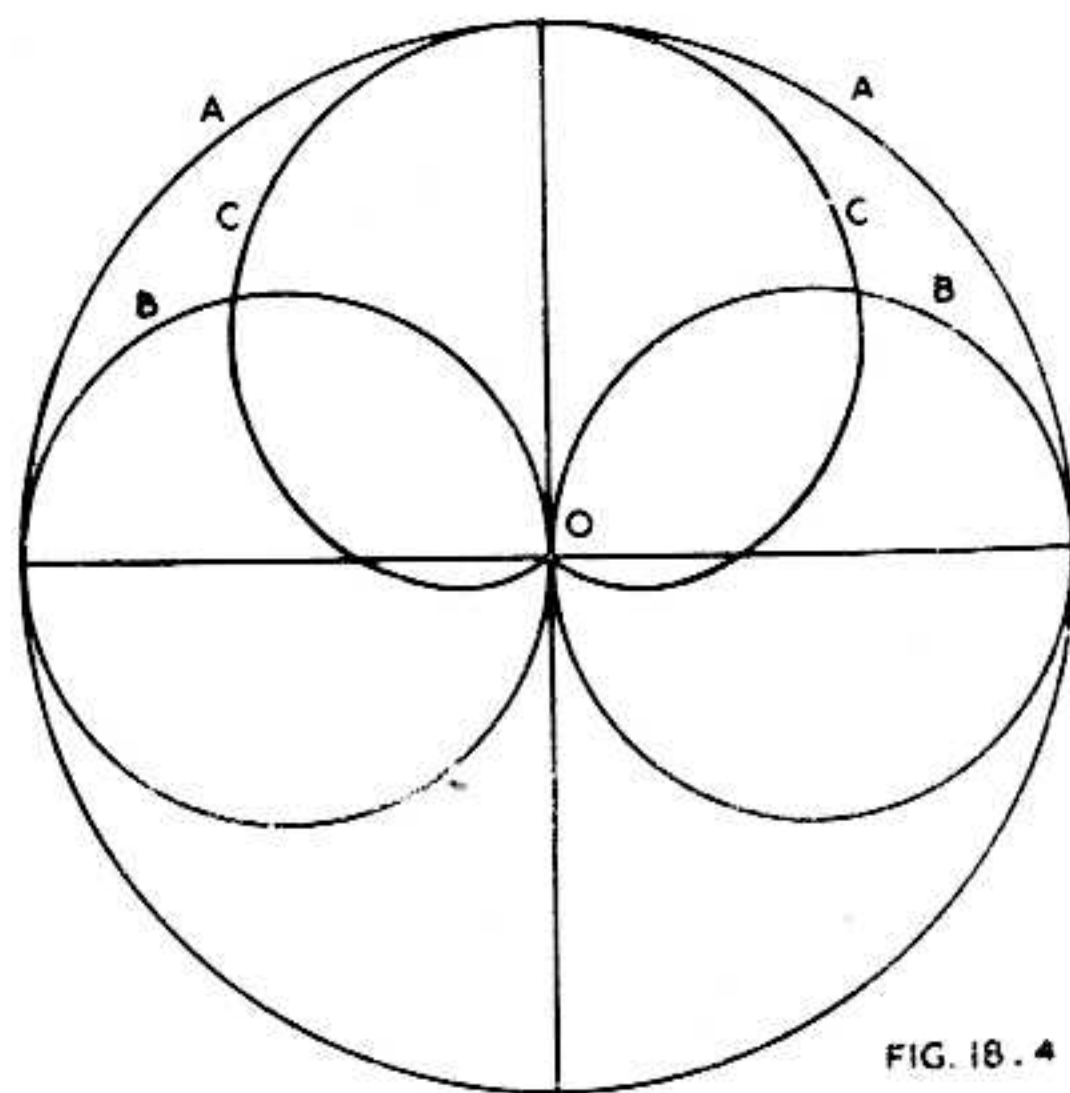References to directional microphones A17, A21, A23, D3, D13.

(xii) The equalization of microphones

It is usual, both in broadcasting and recording, to provide frequency equalization in the microphone or in its pre-amplifier to give a flat or any other desired characteristic. In other applications it is advisable to equalize, or at least to attenuate any high peaks in the response characteristics, so as to reduce acoustical feedback and other bad effects.

It is sometimes desirable to reduce the low-frequency response of a microphone (e.g. velocity type) to reduce the effects of accentuated low frequency response due to " close talking " or to reduce " building rumble."

(xiii) Microphone transformers

There is at present a very unhappy state due to the lack of accepted standards for microphone transformer output impedances. The American R.M.A. Standard for broadcasting is 150 ohms (Ref. A16). See also (xiv) below.

Most microphones are designed to work into an unloaded transformer. The best quality microphone transformers have special provision for reducing hum, such as outer steel shields, inner alloy shields and hum-bucking core construction. By this means it is possible to reduce hum to a level far below the level of random noise.

(xiv) Standards for microphones
(A) Microphones for sound equipment

The following summary is based on R.M.A. Standard SE-105 (Ref. A20).

A microphone is defined as an electro-acoustical transducer which converts acoustical energy into electrical energy, the waveform in this conversion remaining substantially unaltered.

The field response of a microphone at a given frequency is defined by

$$20 \log_{10} (E/p)$$

where E is the open circuit voltage generated by the microphone at its accessible terminals and p is the undisturbed sound pressure in dynes/cm^2 at the specified frequency . . . . , the microphone being placed at a specified angle with respect to the wave front.

The electrical impedance of a microphone at a given frequency is equal to the complex quotient at the specified frequency of the alternating voltage applied to the accessible terminals divided by the resulting alternating current when the microphone is placed in a free air field . . . . It shall be expressed in terms of its magnitude and phase angle and plotted as a function of frequency.

The nominal microphone impedance is the electrical impedance at 1000 c/s. The nominal impedance of low-impedance microphones shall lie between 120 and 180 ohms, or between 19 and 75 ohms. The nominal impedance of high impedance magnetic microphones shall lie between 20 000 and 80 000 ohms. The nominal impedance of any other microphone shall be specified.

The microphone system rating G_M (sensitivity) is described in Chapter 19 Sect. 1(iv)D.

The microphone rating impedance (R_{MR}) is a pure resistance to be taken from the table below

Magnitude of nominal microphone impedance	Rating impedance
19 to 75 ohms	38 ohms
75 to 300 ohms	150 ohms
300 to 1 200 ohms	600 ohms
1 200 to 4 800 ohms	2 400 ohms
4 800 to 20 000 ohms	9 600 ohms
20 000 to 80 000 ohms	40 000 ohms
80 000 ohms or more ohms	100 000 ohms

The directional pattern of a microphone at a specified frequency is the variation in the field response at that frequency for different angles of sound incidence measured from a specified zero position. Zero position refers to that microphone orientation in which the direction of the wave propagation lies along the axis of normal usage . . . .

This pattern shall be plotted in the form of a polar diagram as a function of the angle of incidence.   The electrical output at any one angle, E_θ, shall be referred to the output at the zero position, E_0, by the relation $20 \log_{10} (E_\theta/E_0)$.

The directional characteristic of a **bi-directional microphone** shall be at least — 20 db for all frequencies of a specified frequency range for sounds arriving from any point in a plane perpendicular to the axis of normal usage.   For a **uni-directional microphone** the angle of minimum response . . . . shall be on an average of at least — 10 db, the average to be based on minimum values for a number of frequency bands.

Standards for microphones : Refs. A8, A15, A16, A20.

(B) Microphones for radio broadcasting

Extract from R.M.A. Standard TR-105-B (Ref. A16).   The nominal impedance of all microphones intended for broadcasting service shall be 150 ohms ± 10% when measured at a single frequency of 1000 c/s ± 10%.

SECTION 2 : PRE-AMPLIFIERS

(i) Introduction   (ii) Noise   (iii) Hum   (iv) Microphony   (v) Valves for use in pre-amplifiers   (vi) Microphone pre-amplifiers   (vii) Pickup pre-amplifiers (viii) Gain-controlled pre-amplifiers   (ix) Standard pre-amplifiers for broadcasting   (x) Standard pre-amplifiers for sound equipment.

(i) Introduction

A pre-amplifier is a voltage amplifier suitable for operation with a low level input and whose output is intended to be connected to another amplifier operating at a higher input level.   Pre-amplifiers are commonly used with low-level microphones and pickups.   When a pre-amplifier has to feed the a-f amplifier in a typical radio receiver, the output voltage is usually taken for design purposes as 1 volt r.m.s. across a high impedance.   This allows for a volume control between the pre-amplifier and the main amplifier.   In some cases it is necessary to incorporate the volume control in the pre-amplifier itself in order to avoid overloading with abnormally high input levels.   In such cases this volume control is usually placed between the first and second stages of the pre-amplifier—with very high input levels it may be necessary to incorporate either a volume control or a fixed attenuator prior to the first grid.

A pre-amplifier follows the same general principles of design as any other voltage amplifier (see Chapter 12) except that particular attention has to be paid to hum, noise and microphony, all of which tend to be troublesome.

(ii) Noise

(A) The characteristics of random noise

Random noise includes both **thermal agitation noise** and **valve noise.**   The energy of such noise is distributed uniformly over the frequency spectrum.   The distribution of amplitude with time has been covered in Ref. B1—occasional peaks exceed four times the r.m.s. value.

Random noise voltages must be added in quadrature—that is to say as the root of the sum of the squares.

(B) Circuit noise

The **thermal agitation noise** of resistors has been covered in Chapter 4 Sect. 9(i)1 and in Chapter 23 Sect. 6.

When two or more resistances are in parallel, the total thermal agitation noise is that corresponding to the resultant resistance.   For example, if a microphone having a d.c. resistance of 30 ohms is loaded by a resistance of 100 ohms, the noise voltage is that corresponding to 23 ohms.

When a resistance R is shunted by a capacitance C, the thermal agitation voltage is decreased, and at 30°C (80°F) is given by

$$e = 1.29 \times 10^{-10}\sqrt{RF_0[\tan^{-1}(F_2/F_0) - \tan^{-1}(F_1/F_0)]} \tag{1}$$

where R = resistance in ohms
C = capacitance in farads
$F_0 = 1/(2\pi RC)$
F_1 = upper frequency limit
and F_2 = lower frequency limit.

(See Reference B19, also B8 giving chart and B45 giving theory).

In any network comprising L, C and R it is only the resistive elements which generate noise voltages.

References to circuit noise : A23, B8, B13, B28, B40, B44, B45, B51, D1, D2, D9, D12.

(C) Valve noise

Valve noise has been covered in a general way in Chapter 23 Sect. 6. In this chapter we are only concerned with its effects in pre-amplifiers.

It is convenient to express the **shot-effect noise** of a triode in terms of an **equivalent noise resistance** (R_{eq}) at room temperature, connected from grid to cathode in a noiseless valve. The value of R_{eq} for triodes is given approximately by

$$R_{eq} \approx 2.5/g_m \tag{2}$$

where R_{eq} = equivalent noise resistance in ohms
and g_m = mutual conductance in mhos at operating point.

Pentodes produce additional noise due to the random partition of the cathode current between screen and plate, known as **partition noise.** In general, the noise energy from a pentode will be from 3 to 5 times as great as that from a triode producing the same amplification.

There are other, but minor, sources of noise in valves. The **flicker effect** produces low frequency variations, while any gas in the valve causes **ionization noise.**

References to valve noise : B2, B7, B13, B17, B40, B44, B51, D1, D2, D9.

(D) Methods used in the design of amplifiers to ensure low noise level

Noise in low level amplifiers is due to three principal causes—noise in the plate load resistor of the first stage, valve noise, and noise in the grid (input) circuit. If the stage gain is of the order of 20 or more, the effect of noise in the following stage may usually be neglected. Obviously any unnecessary loss of signal voltage through any form of attenuator between the signal source and the grid should be avoided.

Noise in the plate load resistor (**current noise**) may be avoided by using some form of special low-noise resistor, such as a high-stability cracked carbon resistor described in Chapter 4 Sect. 9(i)m. The plate supply voltage may be from 100 to 180 volts—if, as is usual, a higher supply voltage is available, it is merely necessary to incorporate a RC filter to drop the voltage and by-pass any noise and hum components. Such components are frequently required for decoupling in any case. Composition resistors may be used as screen resistors with pentode valves, because the noise voltage is by-passed to earth. Current noise, however, occurs in the grid circuit due to the negative grid current of the valve. Cathode bias resistors (if used) should be wire wound.

Valve noise may be made low, if necessary, by the use of a r.e.c. **triode valve** in the first stage. The equivalent resistance for shot-effect valve noise is inversely proportional to the mutual conductance (see eqn. 2) so that a high mutual conductance at the operating point is desirable if reduction of shot-effect noise is the principal object. Triodes in common use have published values of mutual conductance from 1000 to 5000 μmhos giving calculated values of noise resistance from 2500 to 500 ohms respectively under published conditions. The noise resistance of a resistance loaded valve is greater than that for the same valve under published conditions. For example type 6J5 operating with a plate current of 1 mA has $g_m = 560\mu$mhos and a calculated noise resistance of 4500 ohms, which is about 4 times the value under published conditions.

The calculated values of noise resistance for three typical **r.c. pentodes** are given below :

Operating conditions : E_{bb} = 180 volts ; R_L = 0.1 megohm.

Type	6J7 or 1620	6SJ7	6AU6
g_m (working)*	1000	1200	1700 μmhos
Noise resistance	8000	6000	2000 ohms

*Actually the slope of the dynamic characteristic.

There are two other possible sources of valve noise. **Leakage in the valve** from the grid to any other electrode, and particularly to any positive potential electrode, is a possible source of valve noise. **Reverse grid current** is another source of valve noise.   It is advisable to use valves which have been tested and selected both for low leakage and reverse grid current, if a very low valve noise level is desired.   Under all circumstances the d.c. resistance from grid to cathode should be as low as possible, and no composition resistors should be used in the grid circuit.

If the input source, whether microphone or pickup, is of low impedance and is coupled to the grid by means of a **step-up transformer**, it is usually not necessary to design for minimum valve noise.   It is then only necessary to design the input circuit so that the impedance of the microphone reflected on to the grid is at least twice, and preferably four times, the valve noise resistance. With a low impedance microphone and transformer this may readily be accomplished by selecting a transformer secondary impedance of the order of 25 000 or 40 000 ohms.   Valve noise will then have a negligibly small effect on the total noise, and pentodes or high-mu triodes may be used satisfactorily.

It is usual to employ as high a ratio in the microphone transformer as is possible, consistent with the frequency response required—very high step-up ratios can be used where the frequency response is not very important.   Even in " high fidelity " applications (with a frequency range from 30 to 15 000 c/s) by using nickel-alloy cores, it is practicable to obtain a reflected secondary impedance up to 100 000 ohms, although somewhat lower values are more common.

For the measurement of noise in amplifiers see page 829.

(iii) Hum

The general features of power supply hum filtering and neutralization have been covered in Chapter 31 Sections 4 and 5.   Hum due to conditions within the valves and hum due to circuit design and layout have been covered in Chapter 31 Sect. 4. Hum in voltage amplifiers has been covered in Chapter 12 Sect. 10(vi).

In pre-amplifiers the permissible hum voltage on the grid of the first valve depends on the maximum signal level at this point.   If a high ratio transformer is used, with a reflected secondary resistance of 25 000 ohms or more, the signal level will be high and an extremely low hum level will not be necessary.   On the other hand, if a low level pickup is coupled directly to the grid circuit without a step-up transformer, extreme care and ingenuity will be required to make the hum inaudible.

Some of the precautions which may be necessary in certain cases to reduce hum to a sufficiently low level are given below—

1. Complete electrostatic shielding of first pre-amplifier valve and associated components and wiring.   The grid and plate circuits should be separately screened, so that there is negligible capacitive coupling between them—in the case of single-ended valves this requires care in wiring and either a shield or its equivalent between grid and plate.

2. Electromagnetic and electrostatic shielding of microphone transformer (if any). The more elaborately screened microphone transformers may include two or three concentric magnetic shields of permalloy or equivalent, with copper shields between (Ref. D2).   For the lowest hum levels, hum-bucking is sometimes also provided in the transformer.

3. It is usual for the pre-amplifier to be built on a separate, preferably non-magnetic, chassis situated a considerable distance from the main amplifier chassis carrying the power transformer and filter chokes.   If this is not possible, the power transformer should be designed to have low leakage flux and be mounted independently of the chassis, with the laminations vertical, and all a-f transformers should either be avoided or elaborately screened.

4. If insufficiently screened a-f transformers are used in the pre-amplifier, they should be oriented experimentally to the position giving least hum pickup.

5. With very low level pre-amplifiers it sometimes happens that less hum is obtained with a direct earth connection to a metal stake in damp soil than to a water pipe

6. The leads from the power transformer to the valve heaters should be twisted, mounted as far as possible from all hum-sensitive components and wiring, and covered with earthed metal braid (for details see Ref. B42).

7. The loop formed by the valve, grid connection, input source and return lead to cathode should include as small an area as possible. Single-ended valves are preferable to double-ended types in this respect.

8. Metal valves are less sensitive to magnetic fields than glass types—they may sometimes be used with advantage if magnetic fields are unavoidable (Ref. B42).

9. If glass valves are used in a magnetic field they should be mounted so as to produce the minimum hum. This occurs when the flux vector is perpendicular to the valve axis and normal to the plane of the grid side rods. The ratio of maximum to minimum hum voltage is of the order of 30 to 40 db. Similar results occur with metal valves but the ratio is only from 10 to 20 db. Glass types may be fitted with a metal shield if desired (Ref. B42).

10. The waveform of the heater current should be closely sine wave, to eliminate capacitance coupling effects with harmonic frequencies.

11. A low leakage socket (e.g. isolantite or polystyrene) may be used to reduce leakage. With single-ended valves, leakage causing hum may occur from the heater pins to the grid or to the plate—the latter is normally the more serious because the grid pin is protected from hum leakage by adjacent pins. With double-ended valves the only possible socket leakage is from the heater pins to the plate. Valves with synthetic resin bases may have appreciable base leakage—for this reason, valves of the all-glass type (e.g. miniature) are preferable to those with separate bases.

One way of avoiding this trouble is to use a pentode valve with the plate, or plate and suppressor, earthed or returned to the cathode. The screen then is used as the anode, and the valve is thus effectively a triode with approximately the same characteristics as with the screen connected to the plate. The screen dissipation should be checked to see that it does not exceed the maximum, but it may be reduced, if necessary, by increasing the grid bias. See (v) below for application to type 6AU6.

12. A low resistance potentiometer may be connected across the heater supply, with the moving arm earthed—this may be adjusted for minimum hum. In some cases less hum may be obtained with the moving arm returned to a point of positive (or sometimes negative) voltage of the order of 5 to 50 volts (see Fig. 17.19A). Minimum hum may be obtained by optimum adjustment of both potentiometer and voltage.

13. A low resistance potentiometer may be used to inject heater voltage in anti-phase to the hum at some convenient point such as the suppressor of a pentode valve. In this case a single heater winding is satisfactory with one potentiometer as in (12) above, together with one anti-phase control for each low level stage (Ref. B26).

14. In very low level stages the heaters are sometimes supplied with direct current. However, with good design (including the use of a high step-up ratio transformer) it is possible to achieve, with a.c. heating, a hum level which is entirely inaudible with a frequency range up to 15 000 c/s. Thus a d.c. heater is not really necessary, but rather an alternative method of achieving a similar result. If the frequency band of the amplifier is 5000 c/s or less, the hum usually dominates the noise, even with the best design—in such a case d.c. heater supply may be desirable.

There are many possible methods of providing the d.c. supply for the heaters, including

(a) Connecting the heaters of the low level valves in series at the low voltage end of the plate supply, with a shunt—if necessary—across either the heaters or the plate circuit. This method is most convenient when a heavy plate current is drawn by the amplifier, so that no power is wasted by a shunt across the plate circuit (e.g. Fig. 17.35A). It has the disadvantage that the heater current of the

low-level valves is dependent upon the total plate current of the amplifier, which is liable to vary. Ref. B52.

(b) The heaters may be connected in series, and supplied from a separate full-wave rectifier and filter, using a thermionic or selenium rectifier—alternatively a selenium bridge circuit may be used. Refs. B25, B52.

(c) The heaters may be connected in parallel, and supplied from a selenium or other suitable rectifier, using either a full-wave or bridge circuit. Refs. B25, B52.

All methods employing rectified and filtered heater supply have a ripple component which may be large enough to cause audible hum.

15. A r-f oscillator with a frequency of 30 or 40 Kc/s may be used as an alternative to d.c. heater supply (Ref. B25).

16. If a.c. is supplied to the heater of the first stage, the voltage of this stage alone may be decreased to about 70% to 85% of normal. This is only permissible with a limited number of valve types and even so may require selection of valves. A cathode current well under 1 mA is essential (Ref. B20).

17. The cathodes of all pre-amplifier valves should preferably be earthed directly to the chassis. However, in practice this is sometimes inconvenient and it may be found that a minimum capacitance of 100 μF shunted across the bias resistor from cathode to chassis is satisfactory. High resistance grid-leak bias has not been found satisfactory for low level operation.

18. An electrostatic shield in the power transformer is essential, even where the transformer concerned supplies only heaters.

19. The pre-amplifier valves may be de-magnetized in a decreasing a.c. field. This is only useful when the valves have become magnetized by some means.

20. Magnetic shielding of power leads and all conductors carrying a.c. may be accomplished by the use of an iron pipe, flexible conductor or—most effective—a permalloy wrap similar to that used for continuous loading of submarine cable (Ref. B51).

Additional notes on hum with pentode valves

1. Hum due to lack of sufficient filtering in the plate supply may be neutralized by some suitable form of neutralizing circuit (e.g. Fig. 12.57).

2. The hum voltage caused by a magnetic field decreases more rapidly than the gain as the load resistance is decreased. A low load resistance is therefore desirable if there is a strong magnetic field (Ref. B42).

3. Hum caused by heater-to-plate leakage is also reduced more rapidly than the gain as the load resistance is decreased.

4. In pentode valves operating with low input levels there is a further source of hum in that the magnetic field of the heater varies the partition of current between plate and screen and so introduces hum. This hum is worse with remote cut-off valves than with those having sharp cut-off characteristics. This form of hum may be made zero by a suitable adjustment of grid or screen voltage (Ref. B46). See also Refs. B23 (Jan. 1949) and B50.

(iv) Microphony

There are very large variations between valves with regard to microphony, and special low-level types are recommended. Individual selection is, however, desirable in addition if the valves are required to operate at very low levels. In all cases some improvement may be made by a cushion socket and a thick rubber pad around the valve.

(v) Valves for use in pre-amplifiers

It is generally desirable to use valve types manufactured and tested for low level operation (e.g. types 12AY7, 1620 and 5879) but even with any one of these types there are large variations in hum, noise and microphony. If a particular pre-amplifier is required to meet stringent test conditions it is advisable to select valves to meet its requirements, and to use the balance of the valves in other less-stringent pre-amplifiers, or in later sockets of the same pre-amplifier.

A choice is possible in the American range between pentode types 1620 and 5879. The former is very much more expensive than the latter, and its use can generally be avoided by careful design.

If the designer decides to use ordinary radio valves for the first stage in a pre-amplifier, it is advisable to test and select the valves in accordance with the following procedure. A sufficient number of valves should be operated for about 48 hours under the same electrode voltages as in the pre-amplifier. They should then be tested for reverse grid current, and only those with reverse grid currents less than 0.1 μA should be used in very critical positions. If a sensitive microammeter is not available, a 1.0 megohm grid resistor may be cut in and out of circuit and the change in plate current measured—see Chapter 3 Sect. 3(iv)A. Low reverse grid current not only reduces the noise, but also permits a higher grid resistor to be used. The valves with low reverse grid currents should then be tested in the first socket of the pre-amplifier for noise, hum and microphony.

Some single-ended pentodes have one heater pin adjacent to the plate, and very high leakage resistance is required to avoid hum (except when this heater pin is earthed).

Type 6AU6 may be used as a triode with earthed plate and suppressor, using the screen as the anode, to reduce hum from leakage between heater and plate.

This device is only suitable for the first stage in the pre-amplifier owing to the limited screen dissipation rating (0.65 watt). The following operating conditions are suggested with a plate supply voltage of 180 volts (Ref. B48) :

Load resistance	0.05	0.1	0.25 megohm
Cathode bias resistance	450	750	1600 ohms
Plate current	2.4	1.3	0.59 mA
Stage gain*	21	23	21

*With following grid resistor 0.5 megohm.

Characteristics of some special low-noise valve types

Type 5879 is a 9-pin miniature low-noise pentode with published $g_m = 1000$ μmhos at a plate current of 1.8 mA. The grid resistor (pentode or triode operation) may be up to 2.2 megohms under maximum rated conditions, while the voltage gain with 180 volts supply is 87 with $R_L = 0.22$ megohm and following grid resistor 0.47 megohm. As a pentode, the noise referred to No. 1 grid with a bandwidth of 13 000 c/s is of the order of 7.2 μV with grid resistor* 0.1 megohm, with only 10% exceeding 16 μV. It may also be used as a triode having $\mu = 21$, $g_m = 1530$ μmhos and $I_b = 5.5$ mA at $E_b = 250$, $E_c = -8$ volts. As a triode, the noise under the same conditions as for the pentode is of the order of 6 μV with only 10% exceeding 12 μV.

Conditions : Triode operation	Hum
1. One side of heater earthed, cathode by-passed (40 μF), zero grid resistance—median value	9 μV
2. One side of heater earthed, cathode unbypassed, zero grid resistance—median value	100 μV
3. One side of heater earthed, cathode by-passed (40 μF), grid resistor 0.1 mΩ—median value	13 μV
4. Centre-tapped resistance across heater supply, returned to fixed bias point (+ 20 to + 50 volts) will reduce hum on most valves to less than	20 μV
5. Centre-tapped resistance across heater supply, returned to voltage to give minimum hum, cathode by-passed (40 μF), grid resistor 0.1 megohm—median value	3.5 μV
—less than 10% exceeding	8 μV.

When adjusted for minimum hum, this feeds a small hum bucking signal into the grid to oppose other minor sources of hum in the amplifier (Ref. B16).

Type 12AY7 is a low noise twin triode (Ref. B17) with $\mu = 40$, $g_m = 1750$ μmhos and $I_b = 3$ mA at $E_b = 250$, $E_c = -4$ volts. The following tests were made with a grid resistor 0.1 megohm and plate load resistor 20 000 ohms. Shot-effect noise (40 to 13 000 c/s) referred to the grid—median valve 4.7 μV, maximum limit 8 μV.

*The noise due to the grid resistor alone is about 3.8 μV.

Hum referred to the grid—median valve 3.9 μV, maximum limit 12 μV with cathode resistor by-passed (40 μF).

When used in a typical circuit, placed with the electron stream in a magnetic field* of 1 gauss, the hum voltage on the grid is about 10 μV.

With a grid resistor of 30 000 ohms, approximately 4 μV of hum per volt of heater potential per $\mu\mu$F of capacitance between heater circuit and grid circuit will appear at the grid.   If the heater voltage is 6.3, this will give approximately 25 μV per $\mu\mu$F of coupling.   For applications see Figs. 18.7A, 18.7B.

(vi) Microphone pre-amplifiers

The limit on practicable amplification is placed by the noise level caused by the thermal agitation noise in the grid circuit of the first stage together with some valve noise.   The thermal agitation noise alone is at a level of about $-$ 129 dbm with a matched load (Ref. B28), or $-$ 132 dbm without loading, for a bandwidth of 15 000 c/s.   If the effective microphone level is taken as $-$ 60 dbm, with an unloaded microphone the maximum possible signal-to-noise ratio will be 72 db, or 69 db with a loaded microphone.   In practice with multiple mixers and other contributing factors†, a broadcast station overall noise can be considered satisfactory if within 10 db of the thermal noise.

If the valve noise is at least 3 db below the thermal agitation noise, it may be neglected as an approximation since the resultant is given by the root of the sum of the squares, and the additional noise will be less than 1 db.   This may be put in the alternative form, that the equivalent valve noise resistance should be less than half the effective thermal agitation noise resistance.

In the case of crystal microphones the whole of the microphone noise arises from the grid resistor, but the signal-to-noise ratio is worst for values of about 0.1 megohm, and improves as the grid resistor is made smaller or larger than this value.   For low noise the resistor should be at least 5 megohms, but better signal-to-noise ratio is obtained with 50 megohms and even better with no grid resistor at all (Ref. B19).

However, for ordinary applications, a resistance of 5 megohms is a good compromise, giving a noise voltage of about 4 μV or $-$ 108 dbv (0 db = 1 V).   The noise resistance of a triode or pentode valve is negligibly small in comparison.   This permits a signal-to-noise ratio of at least 60 db with all diaphragm types and the more sensitive sound cell types.   With the less sensitive sound cell types a very high grid resistance may be necessary.

Values of grid resistor greater than 1 megohm may only be used satisfactorily in low-level pre-amplifiers where the valve is one specially manufactured or tested for this class of service, under a specification which ensures that the reverse grid current is very low.   With a maximum reverse grid current of 0.2 μA and with μ not greater than 40, a grid resistor up to 5 megohms may be used provided that the plate load resistor is not less than 0.05 megohm from a plate supply of 150 volts, or proportionately higher than 0.05 megohm for voltages greater than 150 volts.

Hum from the plate supply may be made as small as desired by filtering, neutralizing, and possibly the use of a triode in the first stage.   Hum from other sources, including a.c. heaters, may be made completely inaudible in wide frequency range amplifiers (up to 15 000 c/s) by careful design, using some of the methods in (iii) above.

Pre-amplifiers for use with crystal microphones

The pre-amplifiers described below (A, B and C) have an output level of about 1 volt r.m.s. and are suitable for use with a diaphragm type crystal microphone.

(A) Single stage pentode pre-amplifier (Fig. 18.5)

This is the simplest possible pre-amplifier, with a voltage gain of 118 (41 dbvg‡). The input voltage to provide the specified output level is $-$ 41 dbv (0 db = 1 V). It may therefore be used with an average diaphragm-type crystal microphone with a

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*Flux densities from 1 to 3 gauss are found quite frequently as far as 7 inches from a typical radio power transformer.
†The effective noise bandwidth of a studio amplifier is usually wider than 15 Kc/s.
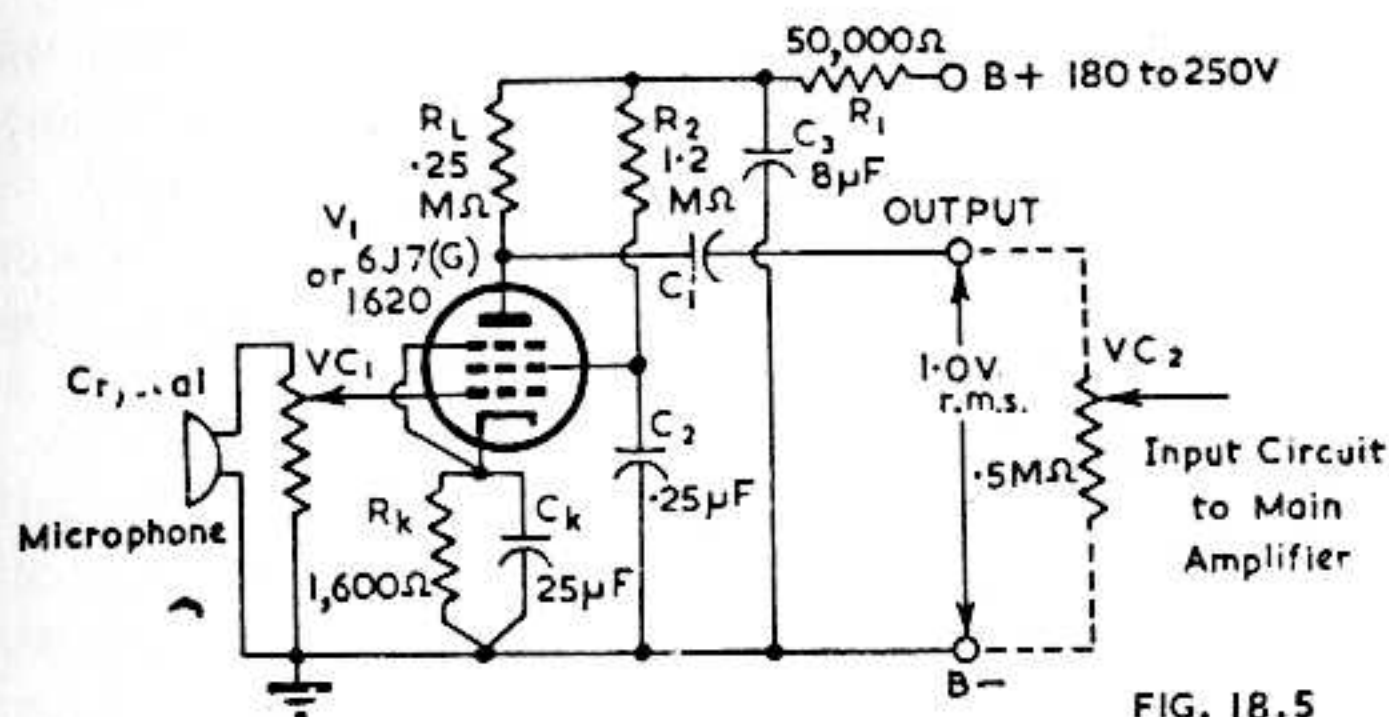‡dbvg – decibels of voltage gain—See Chapter 19 Sect. 1(ii).

Fig. 18.5. Single stage pentode pre-amplifier for use with diaphragm-type crystal microphone.

sound pressure of 10 dynes/cm^2, allowing a margin of 5 db for attenuation by the volume controls.

This is reasonably satisfactory for simple public address systems, home recording and amateur transmitters, although the margin of gain is small. It may also be used to feed the pickup terminals of any normal radio receiver.

Higher gain (45 dbvg*) may be obtained by the use of a selected type 6AU6 with $R_L = 0.22$ megohm, $R_2 = 0.43$ megohm and $R_k = 1700$ ohms. Under these conditions VC_2 may be adjusted to give about 10 db attenuation, VC_1 set to provide the desired output level under average conditions, and VC_2 then used as the control—this will prevent overloading of the valve.

The recommended maximum value of VC_1 is 1 megohm. Higher values may be used without damage to the valve, on account of the plate and screen resistors, but the operating point may be seriously shifted by reverse grid current, leading to distortion and loss of gain. Normally VC_1 would be set at maximum, and only reduced for very close working.

This arrangement has many limitations, and the noise level is high, but it is good enough for the simplest and cheapest applications mentioned above.

(B) Single stage pentode pre-amplifier followed by cathode follower (Fig. 18.6)

This circuit has the advantage over Fig. 18.5 that the pre-amplifier may be some distance from the main amplifier, the two being linked by a low impedance line, and that low impedance mixing may readily be applied. The gain and performance are very similar to those of Fig. 18.5 except that the second volume control would normally be incorporated in the low impedance line (reflected impedance about 400 ohms).

Fig. 18.6. Single stage pentode pre-amplifier followed by cathode follower, for use with diaphragm-type crystal microphone.

This circuit has the disadvantage that the cathode follower stage may give rise to audible hum. It should therefore be restricted to use with a sensitive type of crystal microphone or to applications where a low hum level is not essential.

(C) A preferred arrangement is a good transformer in the cathode circuit of the 6J5, stepping down from 20 000 ohms primary impedance to any desired line impedance.

(D) Cathode follower as low-noise input stage

Fig. 18.6A shows the conventional cathode follower, and Fig. 18.6B shows the modified circuit for use as a low-noise input stage in connection with crystal microphones

*dbvg = decibels of voltage gain—see Chapter 19 Sect. 1(ii).

or pickups. It has been shown (Ref. B53) that the modified circuit will have the same stability as the conventional circuit if $R_4 = (1 + G)R_1$, where G is the voltage gain of the valve defined as the ratio of the voltage across R_3 to that across R_1. If Z_L is high, as it will be if coupled to another valve grid, then G will be approximately constant and a real number. In a properly designed circuit R_4 can be made considerably higher than R_1.
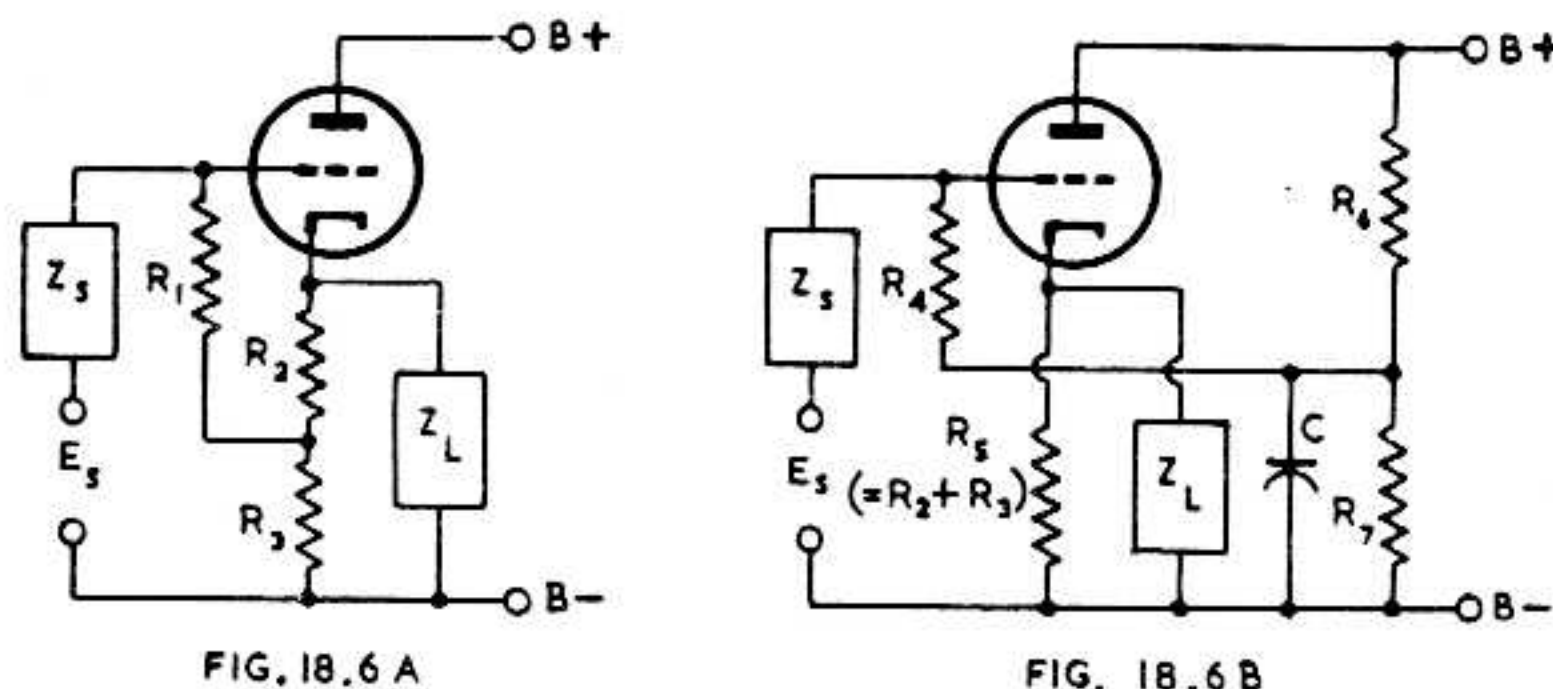

FIG. 18.6 A   FIG. 18.6 B

Fig. 18.6A. Conventional cathode follower circuit.
Fig. 18.6B. Modified cathode follower for use as low-noise input stage with crystal microphone or pickup. (Ref. B53).

The circuit of Fig. 18.6B shows an improvement in signal to noise ratio compared with that from the conventional circuit, the ratio being $\sqrt{(R_4/R_1)}$ for thermal noise produced by R_1 and R_4. For noise generated in R_2 and R_3, noise from the power supply, valve noise and hum and microphony voltages other than those due to capacitance coupling or resistance leakage into the grid circuit, the noise ratio is

$$\frac{R_4}{R_1}\left|\frac{Z_s + R_1}{Z_s + R_4}\right|.$$

When Z_s is large compared with R_1, this represents an improvement by a factor R_4/R_1. When $Z_s = R_1$ the ratio is $1/2$ or 6 db. When $Z_s = jR_1$ it is approximately $1/\sqrt{2}$ or 3 db. When Z_s is small the ratio is negligible.

Thus if Z_s is a crystal microphone or pickup, its impedance will rise as the frequency is reduced, and in the conventional circuit this causes an increase in noise level at low frequencies. The modified circuit shows a distinct improvement under these conditions.

Great care should be taken with the insulation of the grid circuit.

Pre-amplifiers for use with low-impedance microphones

In broadcast stations it is usual to have a gain of about 30 or 40 db in the pre-amplifier, and for this to be followed by mixing (with a loss of about 18 db for four or
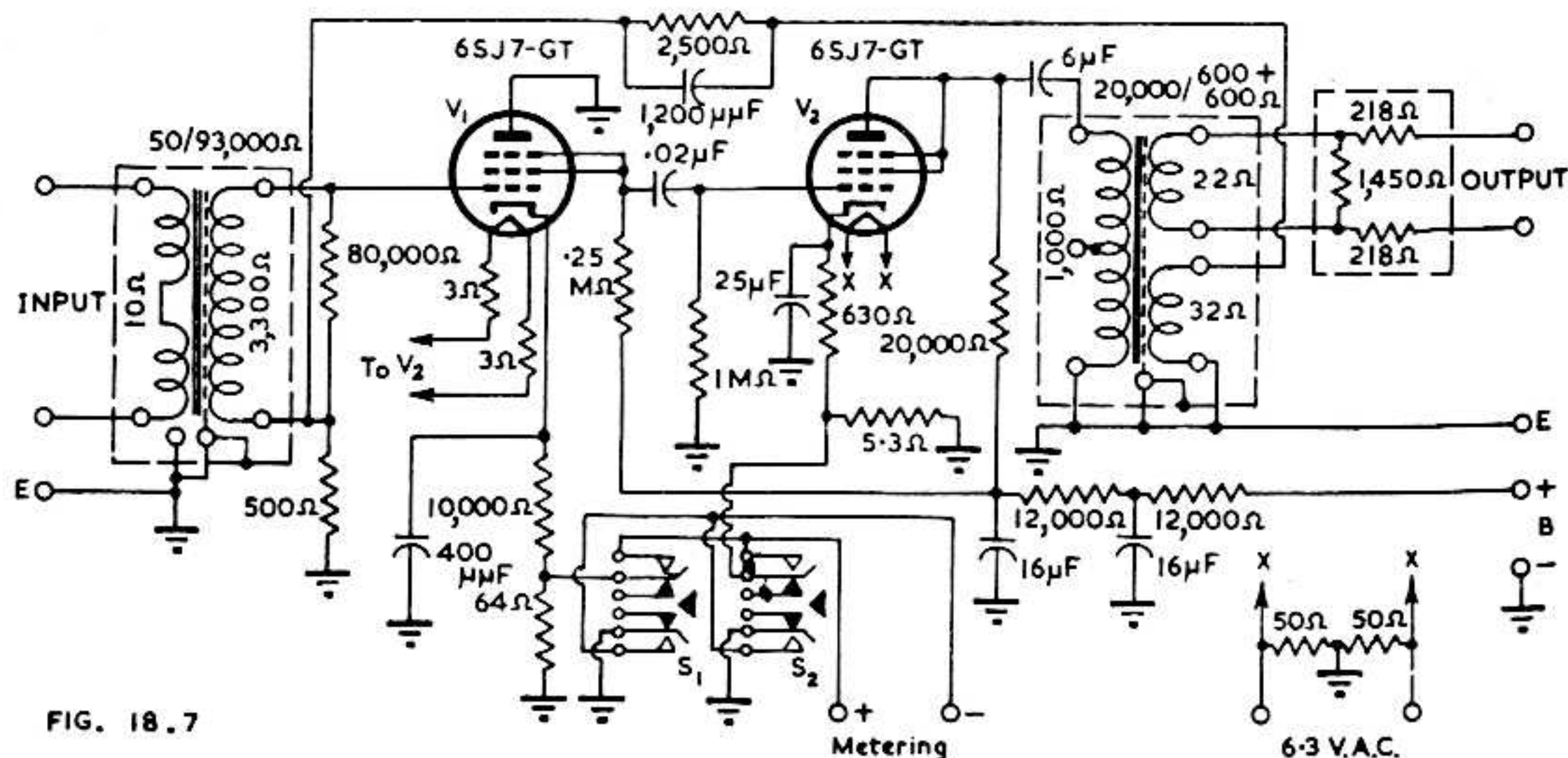
FIG. 18.7

Fig. 18.7. Two stage broadcast station microphone pre-amplifier with gain of 29 db.

five channels) and by a second amplifier with a gain of about 40 db followed by a master gain control with a minimum loss of 6 db and a third amplifier with a gain of 40 or 50 db with an output level of + 18 dbm. The total gain is sufficient for full output to be obtained with the lowest possible input level (say − 70 to − 80 dbm). The minimum signal-to-noise ratio is usually 60 db at − 60 dbm (alternatively 65 db at − 50 dbm).

A pre-amplifier gain of 40 db may result in·over-loading of the pre-amplifier and distortion if used with very high microphone input levels—a device may be incorporated to give an optional attenuation of 10 db in the pre-amplifier and thus reduce its total gain to 30 db when there is danger of overloading.

A typical microphone pre-amplifier with a gain of 29 db is shown in Fig. 18.7. Both valves are connected as triodes, the first stage using the screen as the anode, and the gain without feedback is 47 db. When operated with an input level of − 60 dbm, the signal to noise ratio is 62 db. The maximum power output is 10 mW (+ 10 dbm) at which the distortion is less than 1%—for this level to be reached, the input level must be − 29 dbm. The frequency response is from 30 to 10 000 c/s with less than 0.5 db variation. This circuit may be criticized on the choice of valve type for the first stage of a low level pre-amplifier. Type 5879, 1620 or Z729 could be used to advantage in the first stage.

by a separate resistor, duly by-passed. This would reduce the noise from the plate load resistor. Secondly the choice of valve type is not the most generally satisfactory for the first stage of a low level pre-amplifier. Type 5879 or 1620 could be used to advantage in the first stage.
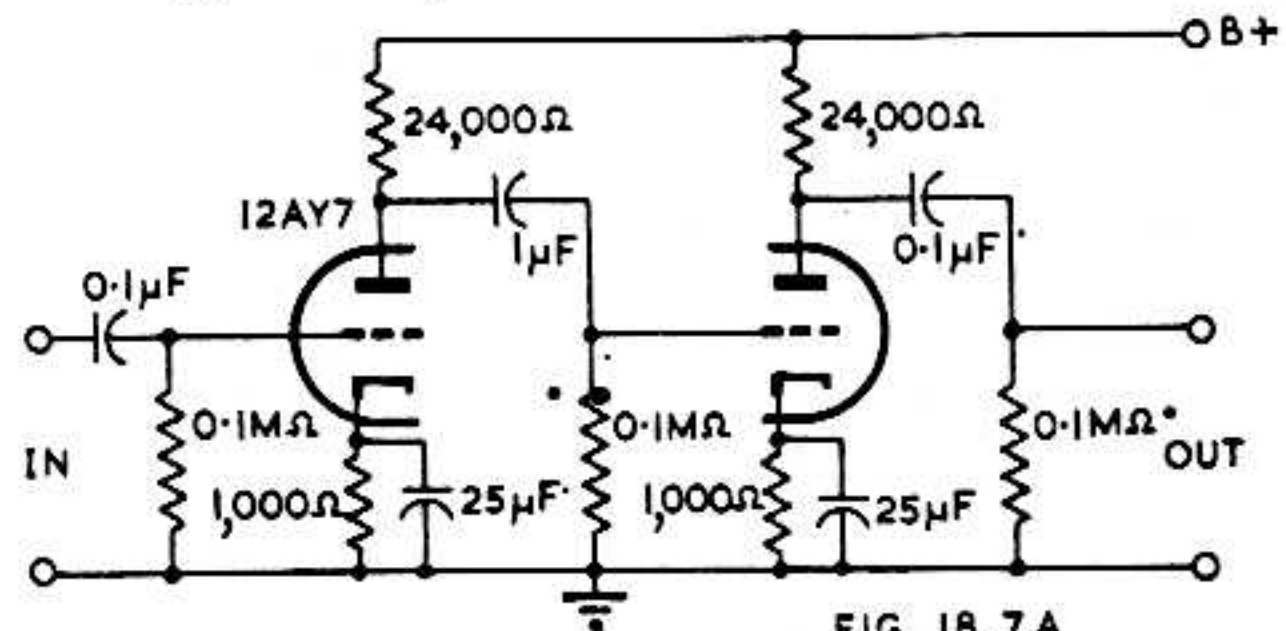
Fig. 18.7A. *Two-stage pre-amplifier using twin triode type 12AY7 (Ref. B17).*

A two-stage pre-amplifier using type 12AY7 twin triode is shown in Fig. 18.7A. This has a total gain of 50 db, and the average noise and hum level referred to the input grid is 11 µV (Ref. B17).

A balanced pre-amplifier employing cross-neutralization and negative feedback is shown in Fig. 18.7B, using a.c. on the heaters. The frequency response is flat from
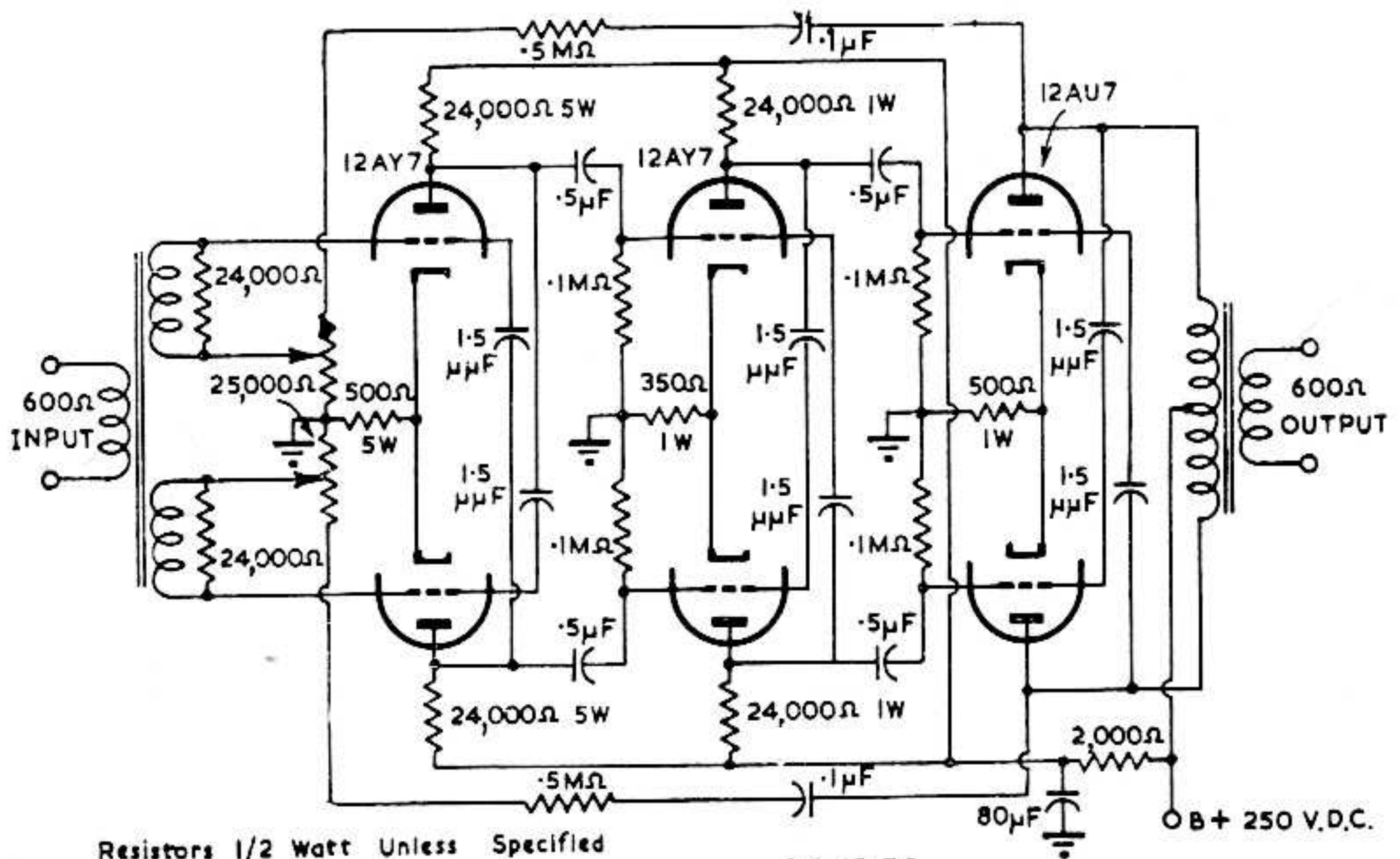
Fig. 18.7B. *Three-stage balanced cross-neutralized pre-amplifier using two 12AY7 valves and 12AU7 (Ref. B17).*

30 to 20 000 c/s, the average noise is 87 db down from the + 24 dbm level and the distortion is 0.55% at 24 dbm output. The combined hum and noise voltages are only 7.6 db above the theoretical value on the poorest valves, and only 2.2 db on the average (Ref. B17).
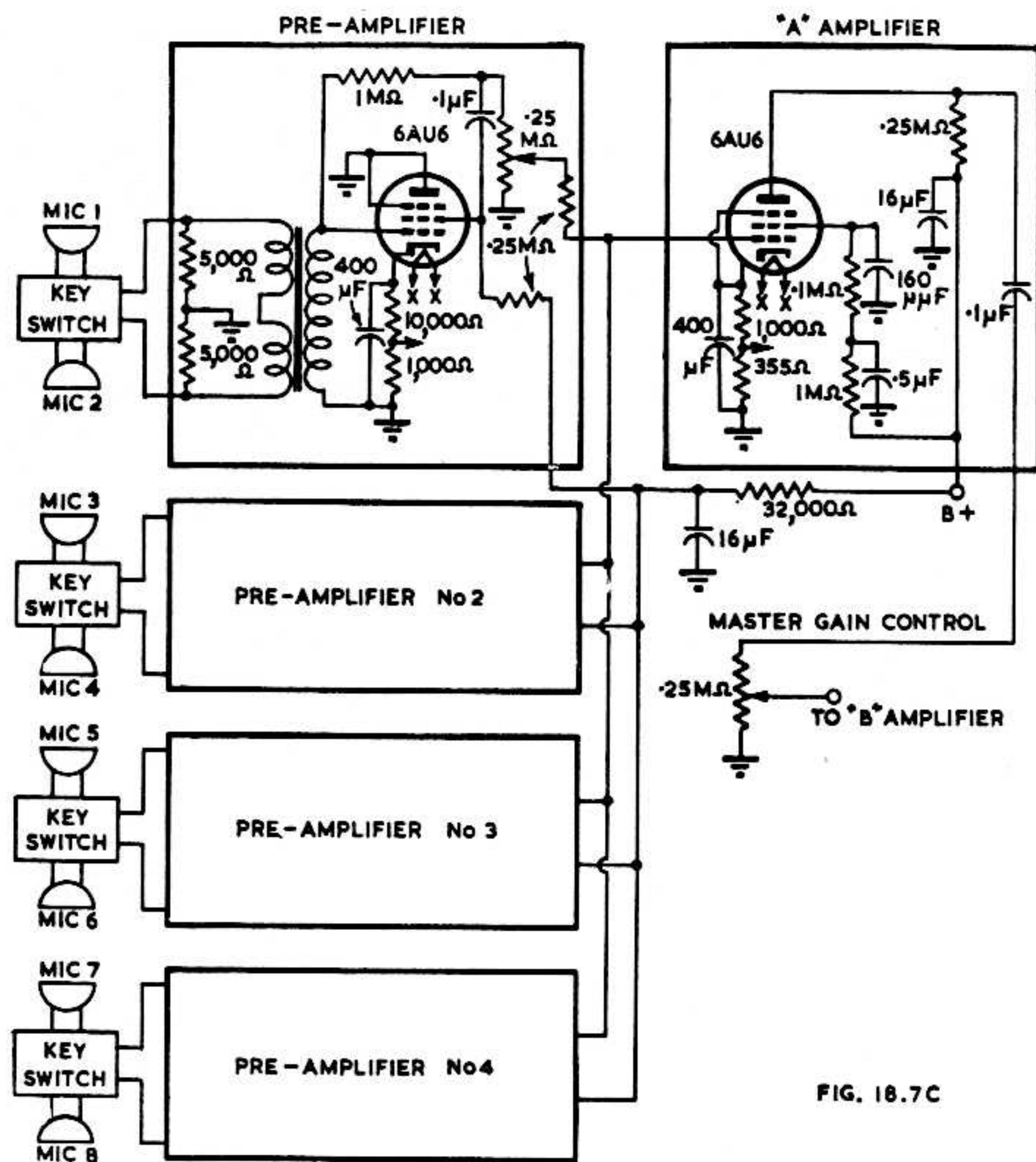
The essential amplifying and attenuating circuits of the four pre-amplifiers and one "A" amplifier of a single unit equipment for studio use are shown in Fig. 18.7C. Each pre-amplifier has a 3-position key. In the pre-amplifiers, type 6AU6 is used as a triode with earthed plate and suppressor, and negative feedback is applied from plate circuit to grid. Each pre-amplifier has a separate attenuator normally "holding" 6 db. The "A" amplifier uses type 6AU6 as a high gain pentode followed by the master gain control normally "holding" 20 db.

The "B" amplifier of the same equipment is shown in Fig. 18.7D, and has negative feedback from the secondary of the output transformer to the cathode of V_6.

With all controls set at maximum, an input of − 86 dbm gives an output of + 8 dbm. The distortion is less than 1% at 18 dbm output. The noise level through any one channel is 60 db or more below output level with input − 60 dbm, output + 8 dbm.

A pre-amplifier circuit used by the B.B.C. is described in Ref. B41. A special low-noise microphone amplifier for acoustical measurements is described in Ref. B54.

A pre-amplifier for the Western Electric type 640AA condenser microphone, using subminiature valves, is described in Ref. B43. Extremely high insulation resistance is required in the network between the microphone and the first grid, particularly in the coupling capacitor.

Fig. 18.7C. Essential amplifying and attenuating circuits of pre-amplifiers and "A" amplifier of single unit equipment for studio use (Ref. B18). See also Fig. 18.7D.

References to microphone pre-amplifiers : A16, A24, B19, B28, B41, B43, B48, B53, B54.
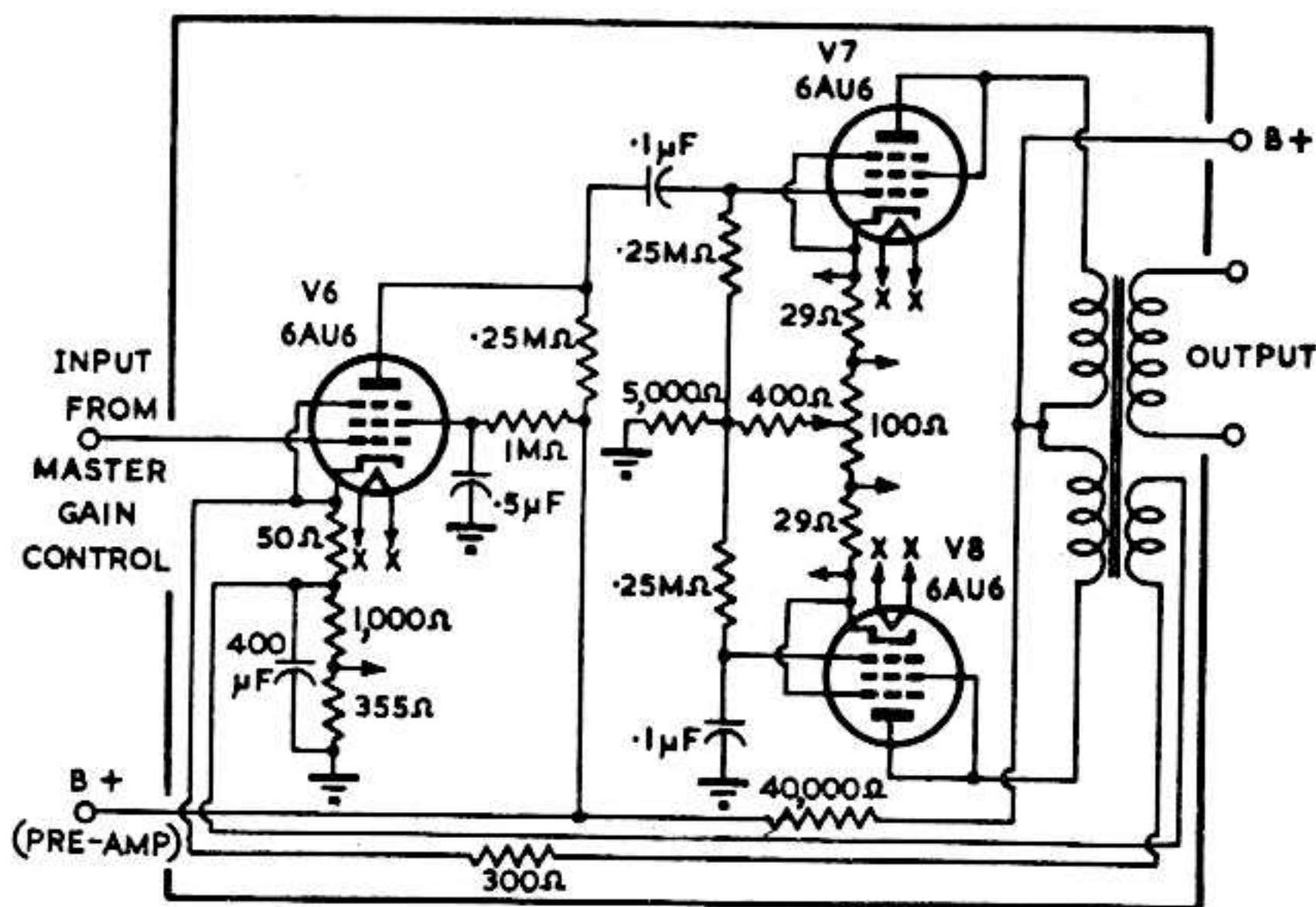

FIG. 18.7D

Fig. 18.7D. "B" amplifier of same equipment as Fig. 18.7C (Ref. B18).

(vii) Pickup pre-amplifiers
This subject has been covered in Chapter 17 Sect. 5.

(viii) Gain-controlled pre-amplifiers
This subject has been covered in Chapter 16 Sect. 5.

(ix) Standard pre-amplifiers for broadcasting
(Extracts from R.M.A. Standard TR-105-B, Ref. A16.)

Standard input signal is 2.45 millivolts r.m.s. in series with 150 ohms (for purposes of calculating insertion gain this corresponds to an input level of − 50 dbm).

Standard output level for feeding telephone lines is + 18 dbm ; for feeding radio transmitters is + 12 dbm. The equivalent " complex wave " level is 10 db lower than these sine wave equivalent testing level values (i.e. + 8 vu and + 2 vu respectively) to provide a margin of 10 db for peaks.

Source and load impedances—600/150 ohms.

Frequency range and harmonic distortion—see Ref. A16.

Signal to noise ratio (noise below standard output)—minimum 65 db (50-15 000 c/s).

(x) Standard pre-amplifiers for sound equipment
(Extracts from R.M.A. Standard SE-101-A, Ref. A30.)

To operate from a **source impedance** of 150 ohms and into a load impedance of 600 and/or 150 ohms.

Noise level—for measurement see Chapter 19 Sect. 6.

Amplifier gain is defined as the ratio, expressed in db, of the power delivered to the load to the power which would be delivered to the same load if the amplifier were replaced by an ideal transformer which matches both the load and source impedances. Frequency response, distortion and power output—see Ref. A30.

SECTION 3 : ATTENUATORS AND MIXERS

(i) Potentiometer type attenuators (volume controls) (ii) Single section attenuators—constant impedance (iii) Single section attenuators—constant impedance in one direction only (iv) Multiple section attenuators (v) Electronic attenuators (vi) Mixers and faders—general (vii) Non-constant impedance mixers and faders (viii) Constant impedance mixers and faders.

An attenuator is a resistance network used for the purpose of reducing voltage, current or power in controlled (and usually known) amounts. An attenuating network is sometimes called a " pad."

In this section only a brief outline is given of the most popular audio frequency applications of attenuators. Additional information is available from the references.

(i) Potentiometer type attenuators (volume controls)

The continuously variable volume control is widely used in radio receivers and a-f amplifiers (Fig. 18.8). The voltage ratio is proportional to the resistance ratio only when the load across the output terminals is very much greater than R. Characteristics commonly used include linear and several types of logarithmic characteristics of resistance versus angular rotation—see Chapter 38 Sect. 3(viii). The input loading is constant (R) only when the output load resistance is infinite. When the output terminals are connected to the grid of a valve which does not draw grid current, the input capacitance together with strays will bring about some change in frequency characteristics as the setting is varied. Direct current through R and through the moving contact should be avoided if a composition type resistor is used, to avoid noise.
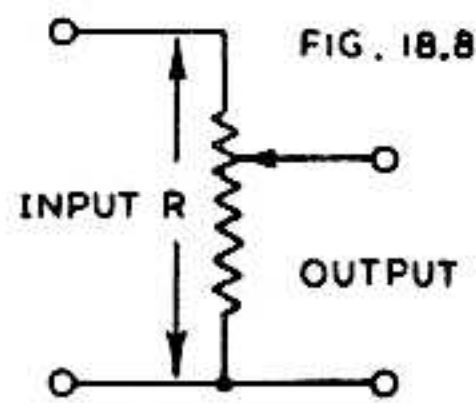
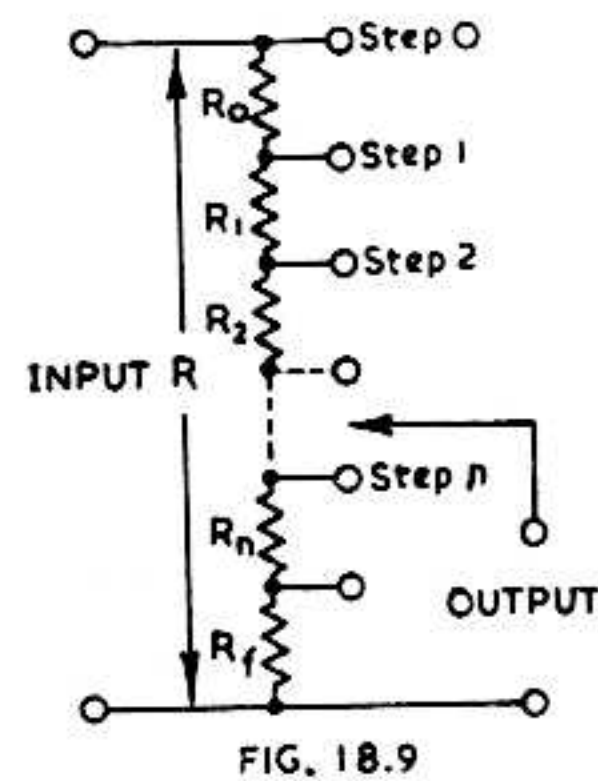Fig. 18.8. Continuously variable volume control (potentiometer).

Fig. 18.9. Step-type volume control.

The step-type volume control (Fig. 18.9) has some advantages over the continuously variable type—it is more reliable, has lower noise as the contact is being moved, and the degree of attenuation is definitely known. In all the best designs, wire-wound resistors are used. It is usually designed with logarithmic characteristics so that there is a constant step (in decibels) between successive tapping points, e.g. 2 db. The method of calculating R_0, R_1 etc. is given below.

Let R = total resistance of attenuator (Fig. 18.9)

N = voltage ratio corresponding to the decibel step between successive tapping points (N less than unity)

and $M = (1 - N)$.

Then $R_0 = MR$; $R_1 = MNR$; $R_2 = MN^2R$ etc.

$R_n = MN^nR$; $R_f = R - R_0 - R_1 - R_2 \ldots - R_n$.

As a practical case take R = 100 000 ohms with 2 db steps.

Then $N = 0.794$ and $M = 1 - 0.794 = 0.206$. By simple calculation $R_0 = 20\,600$; $R_1 = 16\,340$; $R_2 = 12\,980$; $R_3 = 10\,300$; $R_4 = 8\,190$; $R_5 = 6\,500$; $R_6 = 5\,170$; $R_7 = 4\,100$; $R_8 = 3\,260$; $R_9 = 2\,590$ and $R_{10} = 10\,000$ ohms (all values correct to three significant figures).

Slide rule or logarithm accuracy is sufficient for most purposes ; for greater accuracy see Ref. C9.

(ii) Single section attenuators—constant impedance

It is assumed that it is required to maintain constant input and output impedances (Z), that the attenuator is terminated at both ends with resistive impedances Z, and that all impedances are purely resistive. The T type section in Fig. 18:10 may be designed to provide any desired attenuation.

Let $K = E_i/E_0$, this being the voltage or current ratio corresponding to the desired attenuation in db (K being greater than unity).

Then $R_1 = Z\left(\dfrac{K-1}{K+1}\right)$ and $R_2 = \dfrac{2ZK}{K^2-1}$　　　　(1)

It is possible to select any desired values of attenuation in a single T section by varying the values of the three resistors by means of a tapping switch. Values of R_1 and R_2 are given in Table 1 on page 796.

The Π type section in Fig. 18.11 is equivalent to the T type section in Fig. 18.10 provided that the values of the resistances are given by

$$R_3 = Z\left(\frac{K^2-1}{2K}\right) \text{ and } R_4 = Z\left(\frac{K+1}{K-1}\right) \qquad (2)$$

Values of R_3 and R_4 are given in Table 1 on page 796. For formulae giving transformations from T to Π or from Π to T forms see Ref. C12.

Both T and Π sections may be arranged in a " balanced " form for use with an earthed centre-tap—in this case the series resistors R_1 and R_3 are divided into two halves, one on each side of the centre (for table of formulae see Ref. D6). They may also be designed to match unequal source and load impedances (see Refs. C7, C12, D6, D11).

For the derivation of the equations above, see Ref. C13.

If the output impedance is increased beyond the design value, the input impedance will be increased (although to a less extent) and the attenuation will be reduced— see Refs. C6, C12, D6.

There are many other forms of constant impedance attenuators, but none does more than the T or Π section—they may be preferred for practical reasons in certain applications. See Refs. C12, D6, D8, D11.

(iii) Single section attenuators—constant impedance in one direction only

The L section of Fig. 18.12 may be used when it is not necessary for the looking-backwards output impedance of the attenuator to be constant. In this case

$R_5 = Z(K-1)/K$ and $R_6 = Z/(K-1)$　　　　(3)

For further information see Refs. C12, D2.

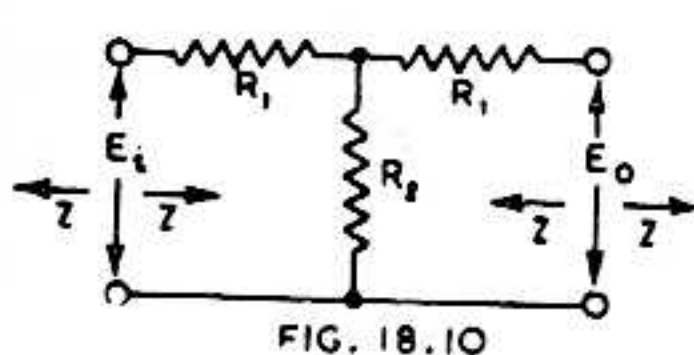The values of R_5 and R_6 have been tabulated for steps from 1 to 10 db (Table 1 on page 796).
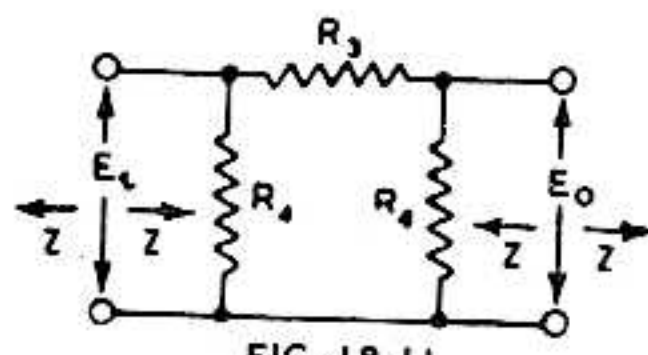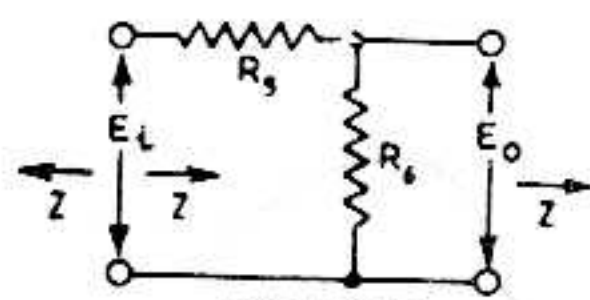

Fig. 18.10. Constant impedance T section attenuator.

Fig. 18.11. Constant impedance Π section attenuator.

Fig. 18.12. The L type single section attenuator.

The values of resistances given in Table 1 are for $Z = 100$ ohms. For any other value of Z, the tabulated values of resistances should be multiplied by $(Z/100)$. See Figs. 18.10, 18.11 and 18.12.

TABLE 1 (SINGLE T, Π AND L SECTIONS)

		T section		Π section		L section	
db	K	R_1	R_2	R_3	R_4	R_5	R_6
1	1.122	5.76	866	11.6	1740	10.9	819
2	1.259	11.46	430	23.2	874	20.6	386
3	1.413	17.10	284	35.2	585	29.3	242
4	1.585	22.6	210	47.6	443	36.9	171
5	1.778	28.0	164	61.0	357	43.8	129
6	1.995	33.2	134	74.6	302	49.9	100.5
7	2.239	38.2	112	89.3	262	55.4	80.7
8	2.512	43.1	94.6	106	232	60.2	66.1
9	2.818	47.6	81.2	123	210	64.5	55.0
10	3.162	51.9	70.3	142	193	68.4	46.2

The following references will be found helpful in supplying further general information on attenuators :

Periodicals C6, C12 (the most comprehensive of all), C13, C17 (the basic treatment). Books D2, D6, D8, D11 (brief treatments are given in several other books).

(iv) Multiple section attenuators

Any convenient number of Π sections may be connected in tandem, and the effective resultant is the " ladder " attenuator of Fig. 18.13 in which the two parallel resistors at the end of each section and the commencement of the next are drawn as a single equivalent resistor $(R_4/2)$. The values of R_3 and R_4 are calculated as for a single Π section (eqn. 2 and Table 1) to provide the desired attenuation per stage. The value of R_8 is given by $R_4 Z/(R_4 + Z)$. The minimum attenuation is 3.5 db on tapping point P_1. The input impedance varies considerably as the tapping point is changed but may be made constant, if desired, by inserting resistors at the points marked X. The output impedance also varies, although less so than the input impedance. This device may also be used when the impedance of the source differs from Z.
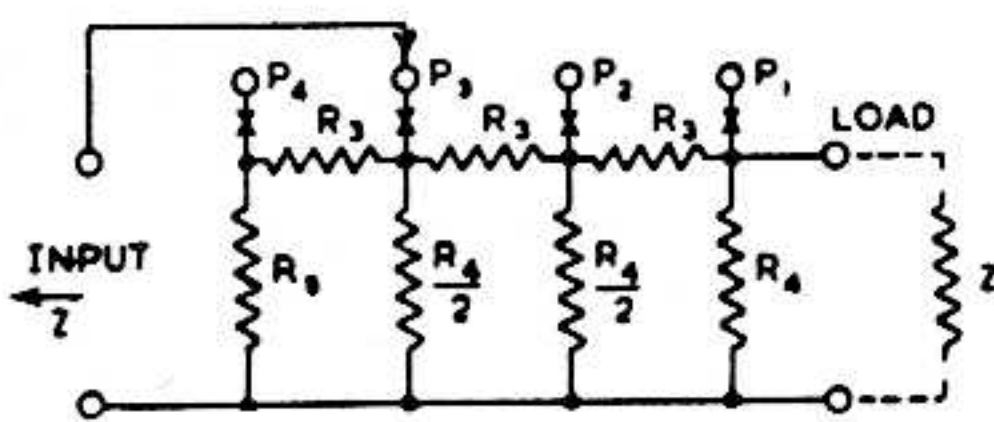

FIG. 18.13

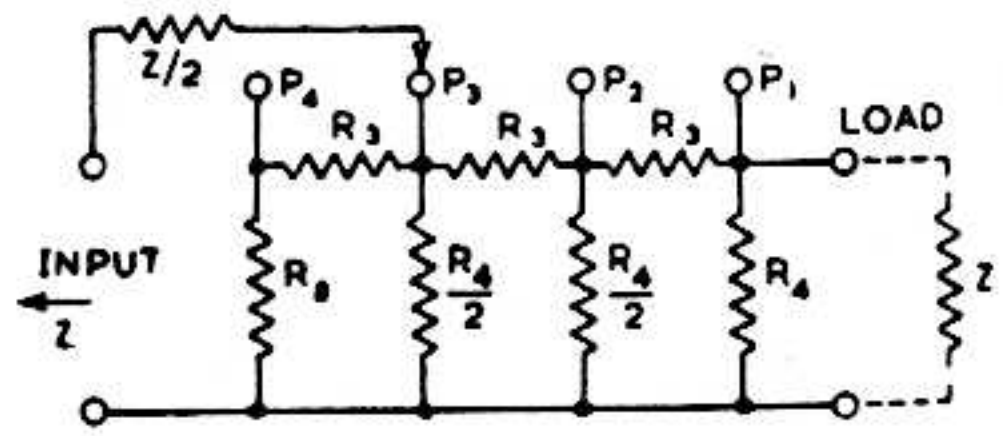Fig. 18.13. *Ladder attenuator* (Π *section*).

FIG. 18.14

Fig. 18.14. *Modified form of ladder attenuator.*

A modified form of ladder attenuator is shown in Fig. 18.14 which has a minimum attenuation of 6 db but whose input impedance is nearly constant except for high values of attenuation and whose output impedance is nearly constant except for low values of attenuation. This can only be used when the impedance of the source is equal to Z. The values of R_3, R_4 and R_8 are the same as in Fig. 18.13. This is the commonest type for broadcast station " mixer " control equipment.

A form of ladder attenuator suitable for connecting a low impedance line to a high impedance grid circuit is shown in Fig. 18.15. This is built up from three L sections and the input impedance is equal to Z under all conditions but the output impedance varies (this being unimportant). The values of R_5 and R_6 are given by eqn. (3) and Table 1, while R_7 is given by $ZR_6/(Z + R_6)$. As an example take $Z = 600$ ohms and 2 db steps. Then the voltage ratio corresponding to 2 db is $K = 1.259$. From eqn. (3)

$R_5 = 600 \times 0.259/1.259 = 123.6$ ohms

FIG. 18.15
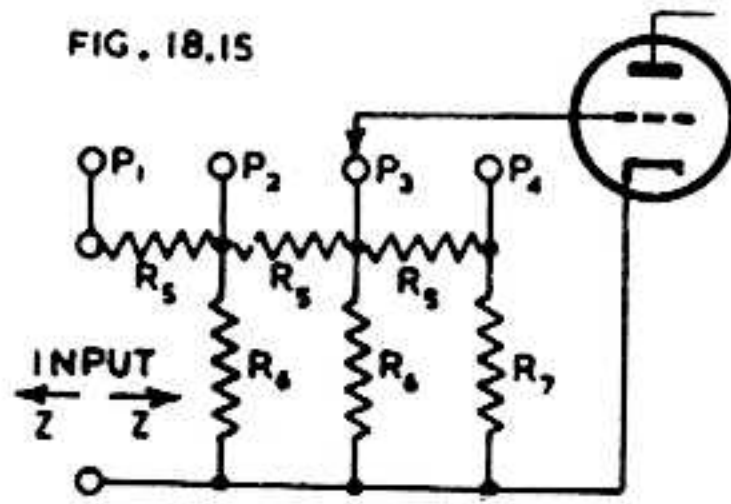
Fig. 18.15. Ladder attenuator for connection to high impedance grid circuit (L section).

$$R_6 = 600/0.259 = 2316 \text{ ohms}$$
while $R_7 = 600 \times 2316/2916 = 477$ ohms.

References to multiple section attenuators : C11, C12 (Part 6) ; C14, D2, D6, D11. References to non-uniform sections, C11, C14.

A multiple T section attenuator is shown in Fig. 18.16. This has the advantage of no loss in the zero attenuation position, and is suitable for use in positions where no power loss is permissible, such as an attenuator on a tweeter loudspeaker. The values of resistors for 1 db steps for $Z = 100$ ohms are tabulated below—for any other impedance multiply the resistances by $(Z/100)$.

Loss (db)	Series arm (each)	Shunt arm	Loss (db)	Series arm (each)	Shunt arm
1	5.8 ohms	867 ohms	6	33.2 ohms	134 ohms
2	11.4	430	7	38.2	112
3	17.1	284	8	43.0	94.5
4	22.6	209	9	47.6	81.3
5	28.0	164 (total)	10	52.0	70.2 (total)

(v) Electronic attenuators

For some purposes an electronic attenuator may be advantageous, and one practicable circuit is a cathode follower in which the screen voltage may be varied, while in addition the desired value of cathode resistor may be selected by means of a tapping switch (Fig. 18.17). Any sharp cut-off pentode valve is suitable, but one with high mutual conductance will limit the maximum attenuation. A valve with $g_m = 2000$ μmhos has an attenuation range from 4 to 74 db with values of cathode resistors from 1000 ohms to 0.1 ohm ; this may be extended by about 10 or 20 db by screen voltage
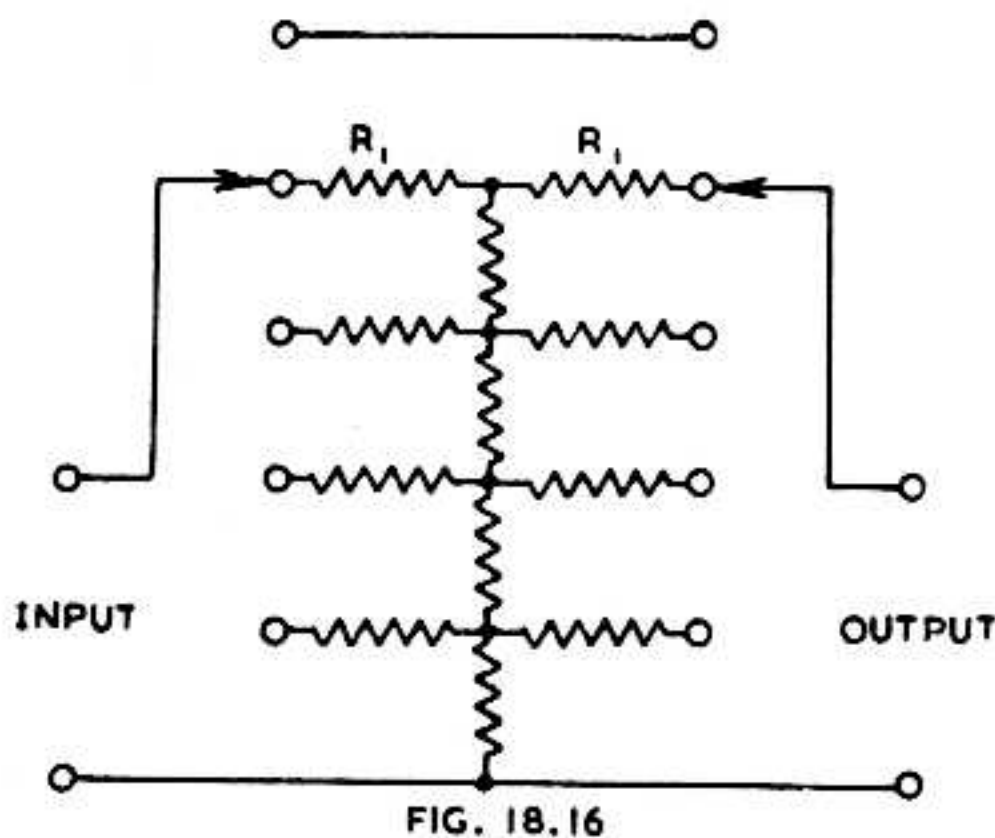
FIG. 18.17

FIG. 18.16

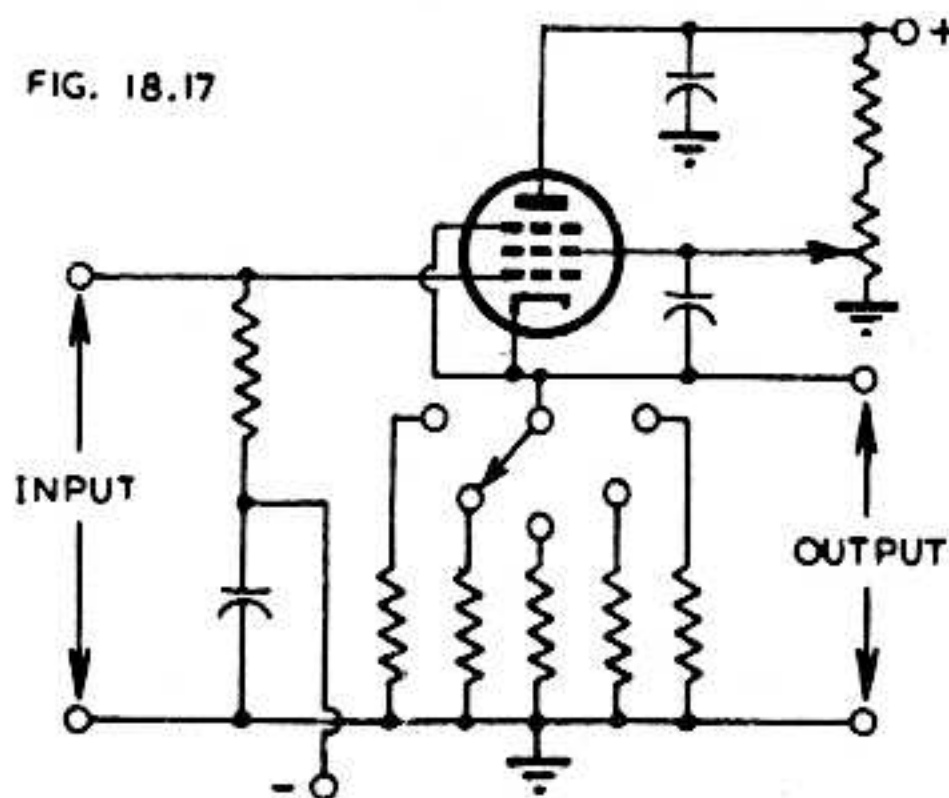*Fig. 18.16. Multiple T section attenuator.*

Fig. 18.17. Electronic attenuator using cathode follower (Ref. C15).

adjustment provided that the input level is not too high. Fixed grid bias must be used. A universal design curve is given in Fig. 18.18 (Ref. C15).

A circuit using type 6BE6 as a fader-mixer is shown in Fig. 18.18A. This has a voltage gain of 62 from grid 1 input, and 25 from grid 3 input. The distortion for
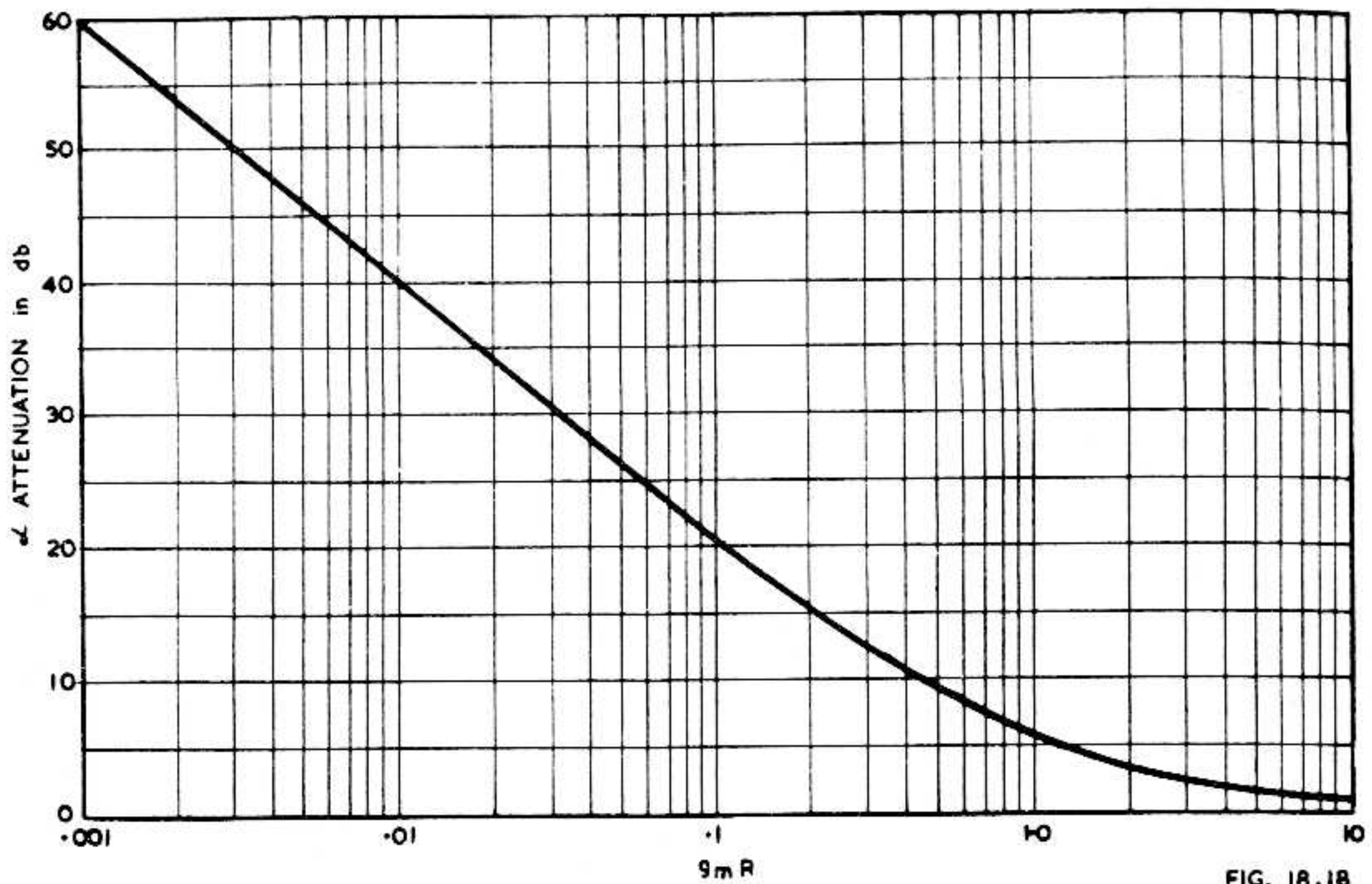
Fig. 18.18. Universal design curve for electronic attenuator (Ref. C15).

an output of 5 volts is 0.19% with input to grid 1, and 1.4% with input to grid 3. A plate load resistor of 50 000 ohms gives lower gain and distortion. For electronic gain control purposes, it is advisable to apply the signal to grid 3 and the control voltage to grid 1 (Ref. C20).
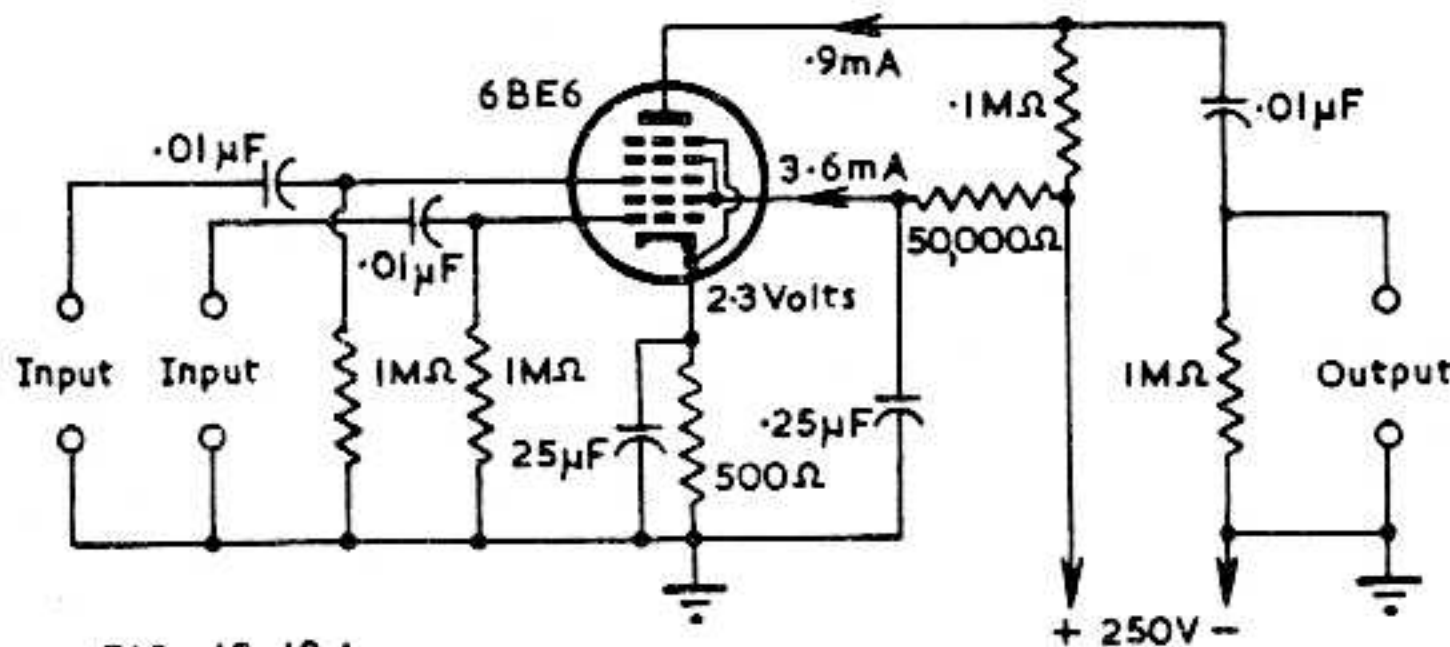

Fig. 18.18A. Fader-mixer circuit using type 6BE6 (Ref. C20).

(vi) Mixers and faders—general

When more than one input source is employed, some form of control is necessary to enable the operator to change from one to the other, or to mix the outputs of two or more sources. A properly designed mixer and fader system enables these objects to be achieved without perceptible jumps.

Mixers (as the complete system will here be called) may be divided into high impedance and low impedance ; constant impedance and non-constant. In addition there are those that have sources at approximately the same level and those with sources having a considerable difference in level. To achieve correct functioning of mixers, it is necessary to provide for the control of the level of individual input sources. Any frequency equalization of input sources is applied prior to the mixer.

(vii) Non-constant impedance mixers and faders

These are commonly used in public address systems, amateur transmitters and other applications which do not require precise adjustment to a predetermined level. The controls are of the continuously variable potentiometer type, and the mixing is usually carried out between a pre-amplifier and a subsequent amplifying stage—under these conditions there is no necessity for maintaining either constant input or output im-

pedance. In some cases the mixing is carried out between the input sources and the grid of the first amplifier stage, and here the load impedance presented to each source must be maintained constant.

The simplest type of fader*, which does not provide mixing, is shown in Fig. 18.19. It is only suitable for high level pickups, or the secondaries of step-up transformers, since the noise from the moving contact is appreciable. The control is a centre-tapped potentiometer with a total resistance $2R$. The value of R should be that recommended for each pickup.

Fig. 18.20 shows a series network mixer which may be used as a fader, but it has serious drawbacks. Both sides of input source A are above earth, and any hum picked up in this channel is fed without appreciable attenuation to the following grid. Moreover stray capacitances to earth of channel A tend to by-pass the high frequency signal voltages of channel B. This arrangement is not recommended.

A modified series network mixer is shown in Fig. 18.21 in which one side of each channel may be earthed, but a transformer must be used to couple the outputs to the grid. This may be used for fading and mixing.
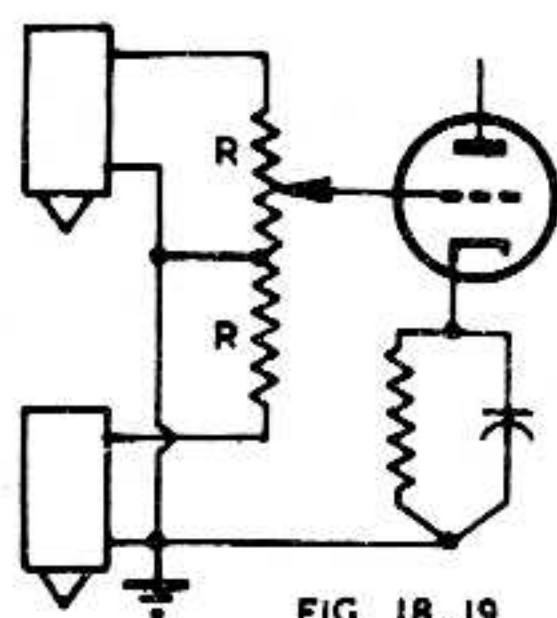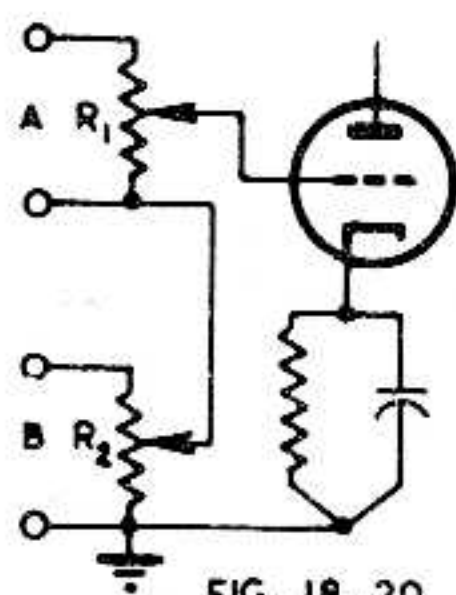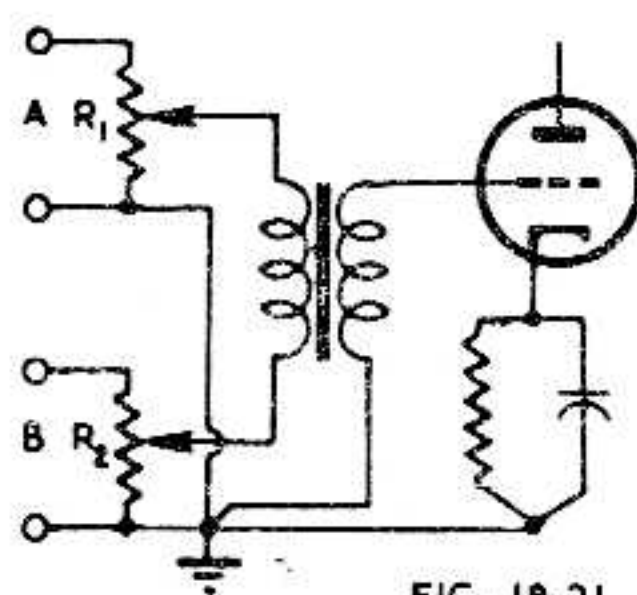

Fig. 18.19. Simple type of fader for two pickups.   Fig. 18.20. Series network mixer.   Fig. 18.21. Modified series network mixer.

The parallel network mixer is shown in Fig. 18.22 where three input sources are provided for, although any number may be used. The value of R_4 may be made equal to or greater than R_1, and similarly with the other channels. If the mixer is connected between two amplifying stages, all resistances may be equal (say 0.5 megohm) and the maximum insertion loss will be 6 db for 2 channels, 9.5 db for 3 channels or 12 db for 4 channels. The insertion loss varies when the controls are moved—the maximum variation in insertion loss caused by any one potentiometer is 2.5 db for two channels but less for more channels. This interaction is less if the source impedance is considerably smaller than the resistances in the mixer, so that triode valves are preferable to pentodes in the preceding stage.
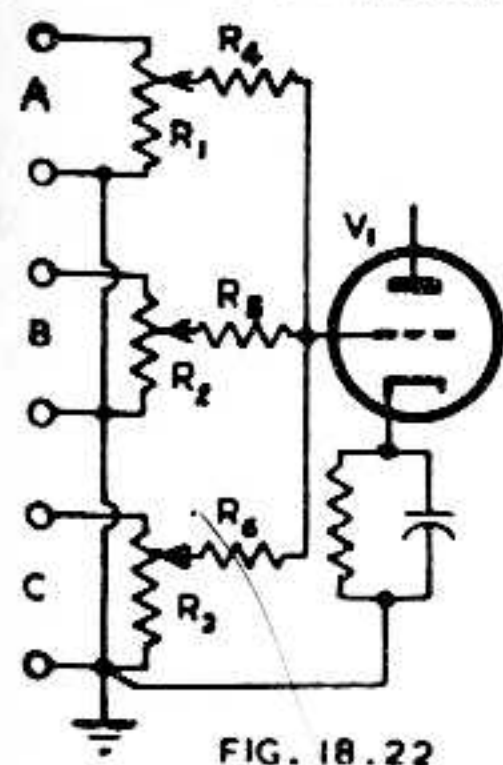

Fig. 18.22. Parallel network mixer.

The circuit of Fig. 18.22 may also be used when the sources are microphones or pickups, but R_1, R_2 and R_3 should be the correct load resistance in each case. The isolating resistors R_4, R_5 and R_6 may be made equal to the highest of the load resistances. This arrangement is only practicable with fairly high source levels, on account of the insertion loss and its effect on the signal-to-noise ratio.

One application of the parallel network mixer is given in Fig. 18.23—this general set-up may be modified to suit any practical case when there is a considerable difference in level between the two sources.

Probably the most popular of all mixing circuits in this class is the method using a common plate load for two or more valves. When two valves are used with a common

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*The word " fader " is here used in the sense of fading out one input source and fading in another. The fading of a single source is here called attenuation. Mixing is the combination of two (or more) sources so that both are amplified simultaneously ; a mixer may however be used also for fading.
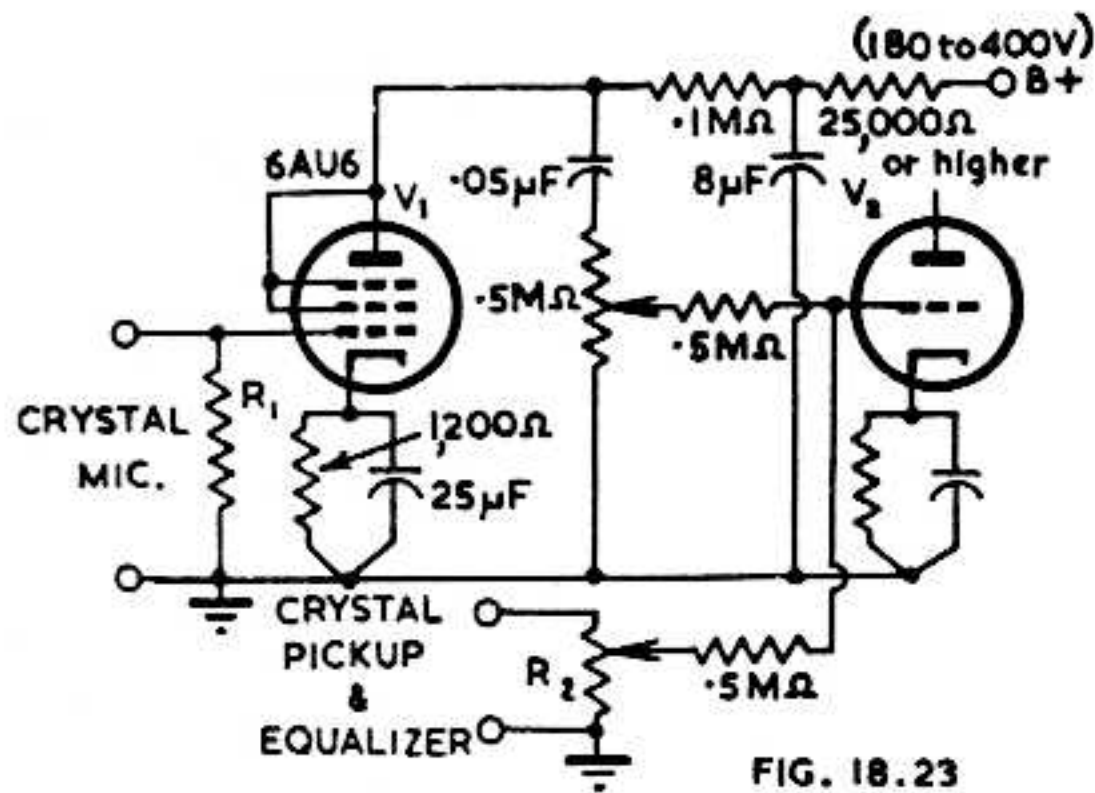
Fig. 18.23. *Complete pre-amplifier incorporating parallel network mixer, for use with high level crystal microphone and crystal pickup.* $R_1 = 1$ to $5M\Omega$; $R_2 = 0.5M\Omega$ or higher. *Gain in* V_1 *is* 30 dbvg.

plate load resistor, the plate resistance of each valve acts as a shunt load on the other, thereby reducing the gain and the output voltage for a limited distortion. With triodes, the gain is equal to the normal gain for a single valve multiplied by $(r_p + R_L)/(r_p + 2R_L)$. If R_L is considerably greater than r_p, the gain is slightly greater than half that for a normal valve. With pentodes, the loss of gain due to shunting is slight, and may be neglected in most calculations. The effect of the shunting on the maximum output voltage is much more severe than on the gain. The output voltage for limited distortion is approximately equal to the normal output voltage multiplied by $r_p/(r_p + R_L)$. If $R_L = 5r_p$ as for a typical triode, then the output voltage is reduced to one fifth of its normal value. For this reason it is suggested that $R_L = 2r_p$ would be more suitable, giving a reduction to one third of the normal value. Here again, the effect on pentodes is small.

One simple but very effective mixer incorporating common plate load mixing is Fig. 18.24. V_1 may be any twin triode, R_L may be determined as outlined above, while the plate supply voltage may be about 250 volts, or higher if a high output voltage is required with low distortion. If desired, a second twin triode with a further two input channels can be added. Alternatively, two r-f pentodes may be used in place of V_1 to provide increased gain. Various combinations may be devised incorporating one or more common plate load mixers with other types of mixers or faders to meet almost any possible requirements. Fig. 18.25 is one example— V_1 and V_2 may be any suitable twin triodes, R_1 pro-

FIG. 18.24

Fig. 18.24. *Simple mixer using twin triode with common plate load resistor.*

vides fading for the two microphones and R_2 is a combined microphone volume control, R_4 and R_5 provide fading and mixing for the pickups while R_3 is a master volume control. V_2 has a common plate load resistor.
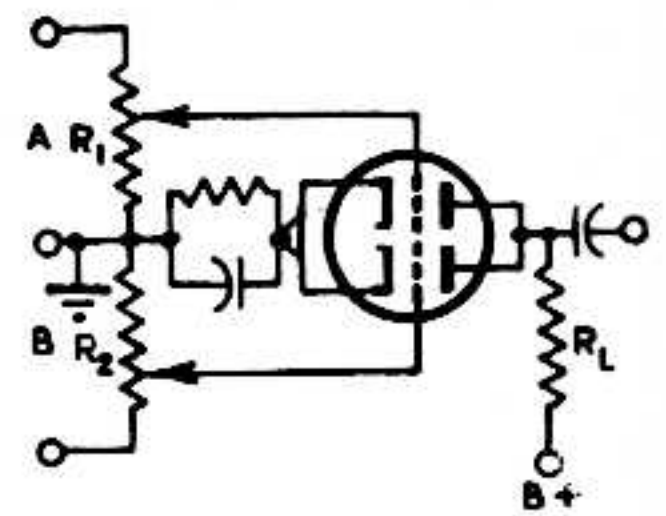
One of the problems with mixers of the common plate load type is the control of volume without introducing noise or circuit complications. This problem may be overcome by the use of 6L7 type valves in which the amplification is controlled by varying the voltage on the third grid (Fig. 18.26). This mixer is intended for use
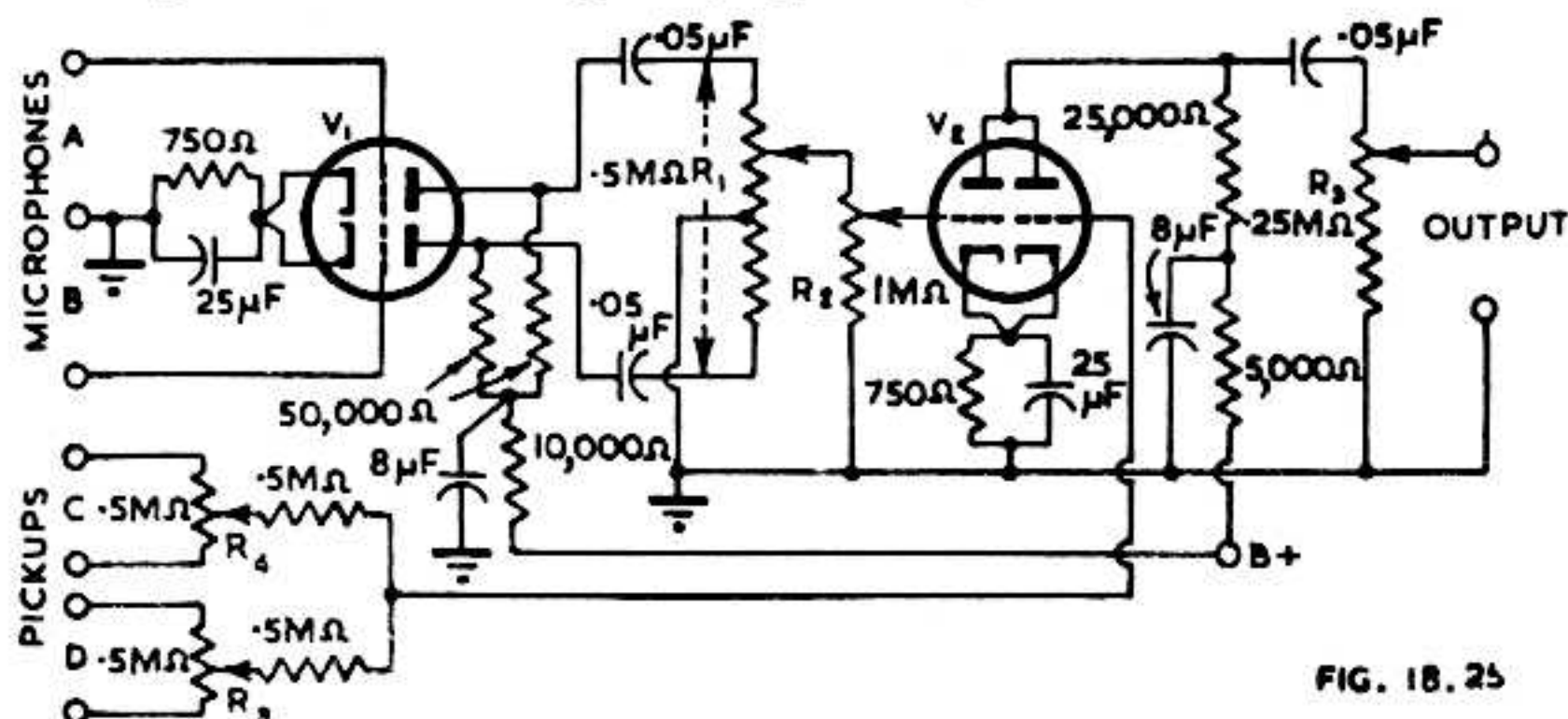

FIG. 18.25

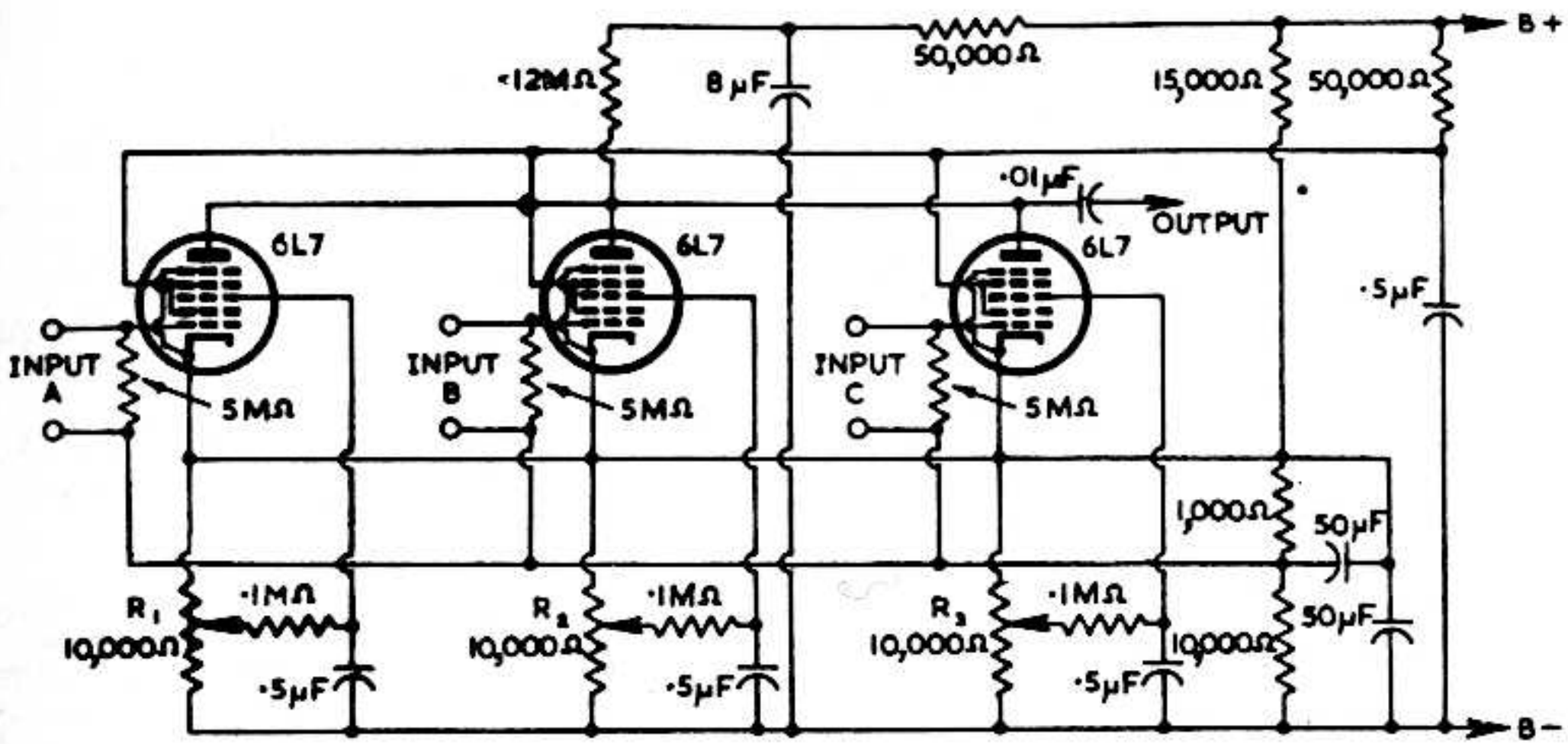Fig. 18.25. *Mixer for two microphones and two pickups. Values of resistors are for* $V_1 = V_2 = 6SN7\text{-}GT.$

Fig. 18.26. Three channel mixer with electronic volume control (Ref. C4).

with three high-level crystal microphones ; the volume controls operate on d.c. and may therefore be placed some distance from the mixer (Ref. C4).

References to non-constant impedance mixers : C3, C4, D10.

(viii) Constant impedance mixers and faders

Constant impedance* attenuators may be used to provide both attenuation and mixing, and are widely used in studio equipment. In such equipment they usually work out of and into 600 (sometimes 500) or 150 (sometimes 200) ohm circuits.

The constant impedance attenuators may be of the T, bridged T, Π, ladder, bridge, or any other form, together with their balanced equivalents. They may be arranged in parallel, series, series-parallel or bridge circuits.
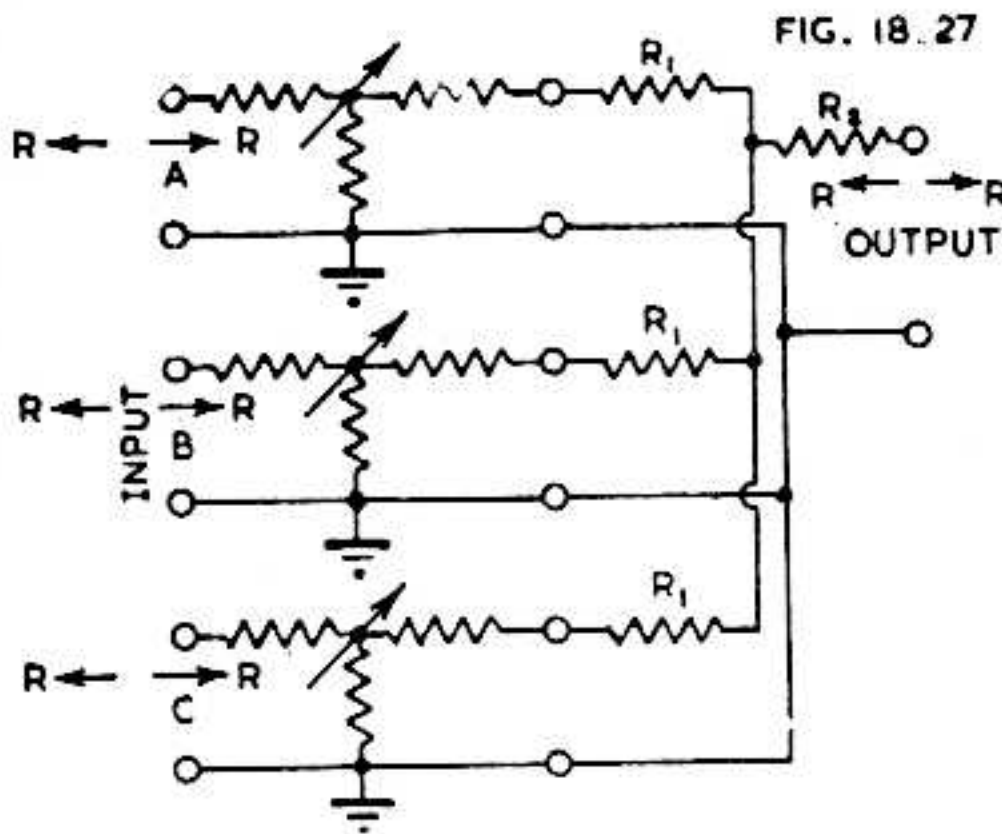

Fig. 18.27. Constant impedance mixer using three T type attenuators in parallel.

(A) Parallel type mixers

Fig. 18.27 shows a three channel mixer using T type attenuators in parallel—the same principle may be applied for any number of channels. Since the attenuators are of the constant impedance type with input and output impedances R, and the mixer output is loaded by the same impedance R, in this case $R_1 = R_2 = \frac{1}{2}R$ and the mixing loss is 9.5 db. In the general case

$R_1 = R_2 = R(n - 1)/(n + 1)$ and Mixing loss $= 20 \log_{10} n$

where n is the number of channels. Values are tabulated below :

$n =$	2	3	4	5	6
$R_1 = R_2 =$	$(1/3)R$	$\frac{1}{2}R$	$(3/5)R$	$(2/3)R$	$(5/7)R$
Mixing loss	6.02	9.54	12.04	14.0	15.56 db.

An alternative form omits R_2 and thereby obtains lower mixing losses, but the output impedance of the mixer and hence the input impedance of the master attenuator will be R_L instead of R_1, the values being given below :

*Constant impedance indicates that both the input impedance and the looking-backwards output resistance are maintained constant under all conditions.

$$R_1 = R(n - 1)/n \qquad\qquad R_2 = 0$$
$$R_L = R(2n - 1)/n^2 \qquad\qquad \text{Mixing loss} = 10 \log_{10} (2n - 1)$$

n	$=$	2	3	4	5	6
R_1	$=$	0.50R	0.67R	0.75R	0.80R	0.83R
R_L	$=$	0.75R	0.56R	0.44R	0.36R	0.31R
Mixing loss	$=$	4.77	6.99	8.45	9.54	10.41 db.

If it is desired to maintain all input and output impedances constant and equal to R, it will be necessary to insert a matching transformer or to add a matching pad, the latter introducing loss.

FIG. 18.28

(B) Series type mixers

Fig. 18.28 shows a three channel mixer using T type attenuators in series. Only one of the channels can be earthed, so that there tends to be some cross-talk although this may be kept low by good design. The output impedance at terminals D is given by R_D where $R_D = Rn^2/(2n - 1)$, and the mixing loss up to terminals D is $10 \log_{10}$
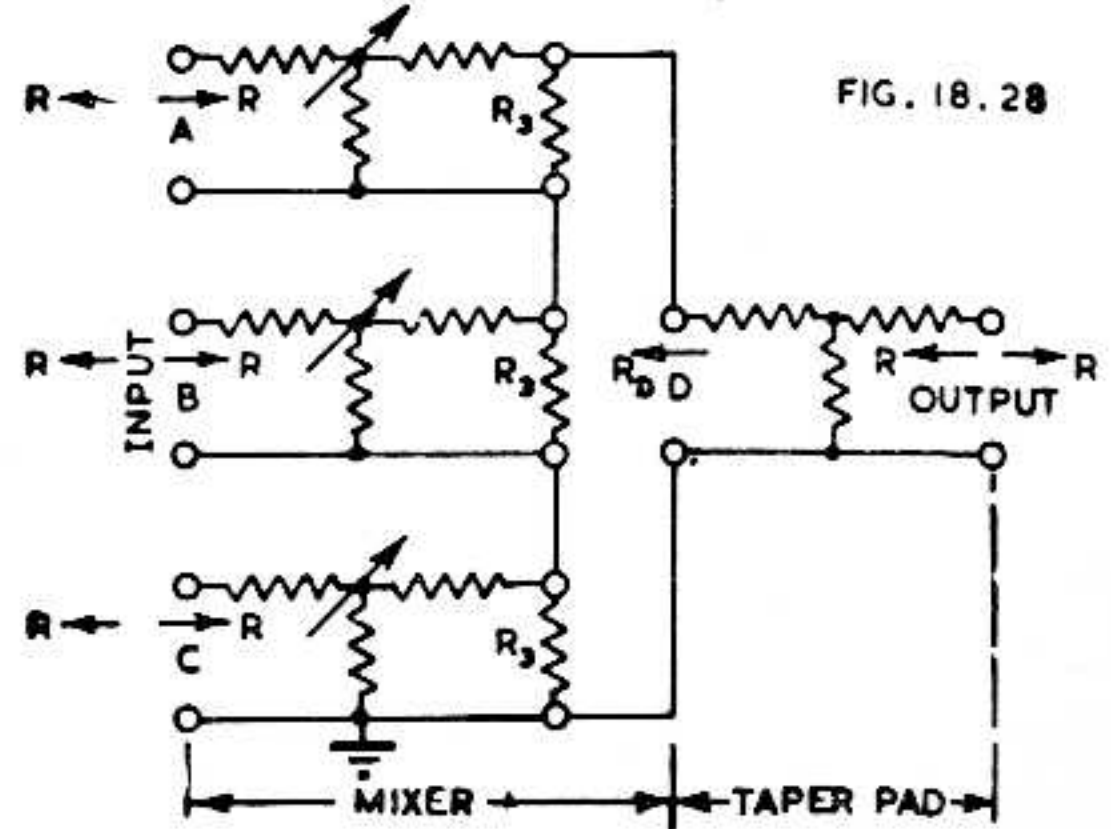
Fig. 18.28. Constant impedance mixer using three T type attenuators in series.

$(2n - 1)$, where n is the number of channels. Values are tabulated below :

n	$=$	2	3	4	5	6
R_3	$=$	2.00	1.50	1.33	1.25	1.20
R_D	$=$	1.33	1.80	2.29	2.78	3.27
Mixing loss	$=$	4.77	6.99	8.45	9.54	10.41 db.

If this mixer is followed by a transformer there is no further loss, but if it is followed by a taper pad as in Fig. 18.28 there must be added the loss in the taper pad, the value of which is given by

$$N = 20 \log_{10} (R_Z + \sqrt{R_Z{}^2 - 1}) \text{ decibels}$$

where $R_Z{}^2$ = impedance ratio (greater than unity)
$$= n^2/(2n - 1).$$

n	$=$	2	3	4	5	6
impedance ratio	$=$	1.33	1.80	2.29	2.78	3.27
loss in pad (N)	$=$	4.77	6.99	8.45	9.54	10.41 db.

(C) Series-parallel type mixers

Fig. 18.29 shows a four channel mixer using T type attenuators in series-parallel. The input and output are both balanced. The values of R_4 and R_0 are given by

$$R_4 = R(n - 3)/n \text{ and } R_0 = 4R(2n - 3)/n^2$$

where n is the total number of input channels.

If n	$=$	4	6	8
then R_4	$=$	0.25R	0.5R	0.625R
R_0	$=$	1.25R	R	0.75R
and loss in mixer	$=$	7.0	9.5	11.1 db.

With six channels, the output resistance is equal to R and the taper pad will not be required. In other cases its loss should be added to that in the mixer.

(D) Bridge type mixers

Fig. 18.30 shows a bridge type mixer with four input channels. This can only be earthed at one point, but is otherwise satisfactory for four input sources. The output resistance is equal to R, so that no taper pad or matching transformer is required— the mixing loss is 6 db, which is less than that of any other 4 channel resistance mixer.

(E) Coil mixing (Ref. C18)

Coil mixing refers to the use of a special transformer (Fig. 18.31). The loss is the theoretical minimum and is given by $10 \log_{10} n$ where n is the number of input sources —it is 6 db when $n = 4$. The value of R_6 is given by

$$R_6 = \tfrac{1}{2}R(n - 1)$$

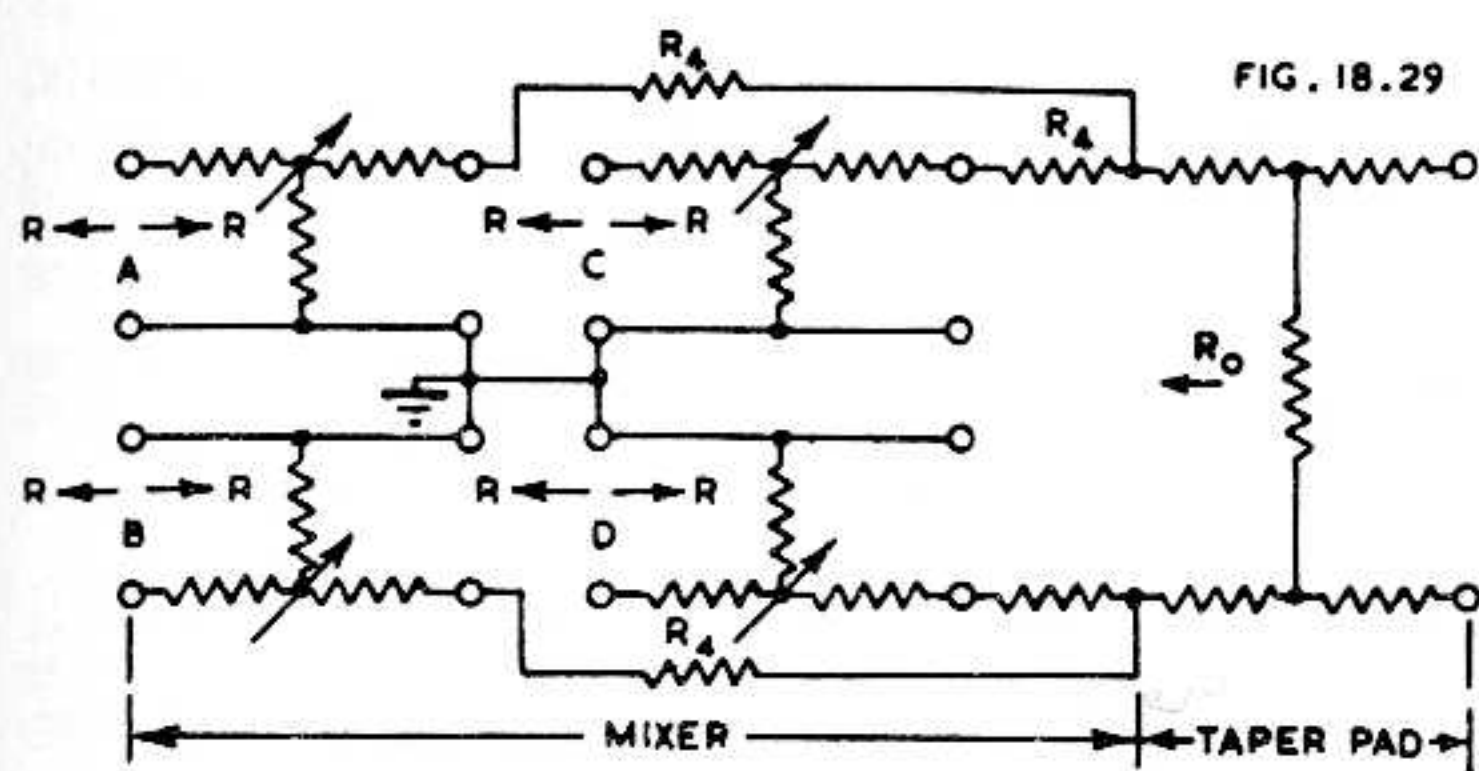and is equal to R when $n = 4$. The secondary transformer impedance is equal to nR.

Fig. 18.29. *Constant impedance mixer using four T type attenuators in series-parallel.*

Coil mixing appears to be very little used.

(F) Choice of mixer circuit

The parallel circuit has the very important advantage that one terminal of all (unbalanced) attenuators can be earthed.   Other circuits in which one or more attenuators are above earth nearly always suffer from cross-talk and variation of frequency response at high attenuations.   There are thus two features on which the choice of a mixer circuit must be based—the earthing of all attenuators, and minimum mixing loss. Many engineers insist on the earthing even at the expense of increased mixing loss in some cases.

Fig. 18.30. *Constant impedance mixer using four T type attenuators in bridge connection.*
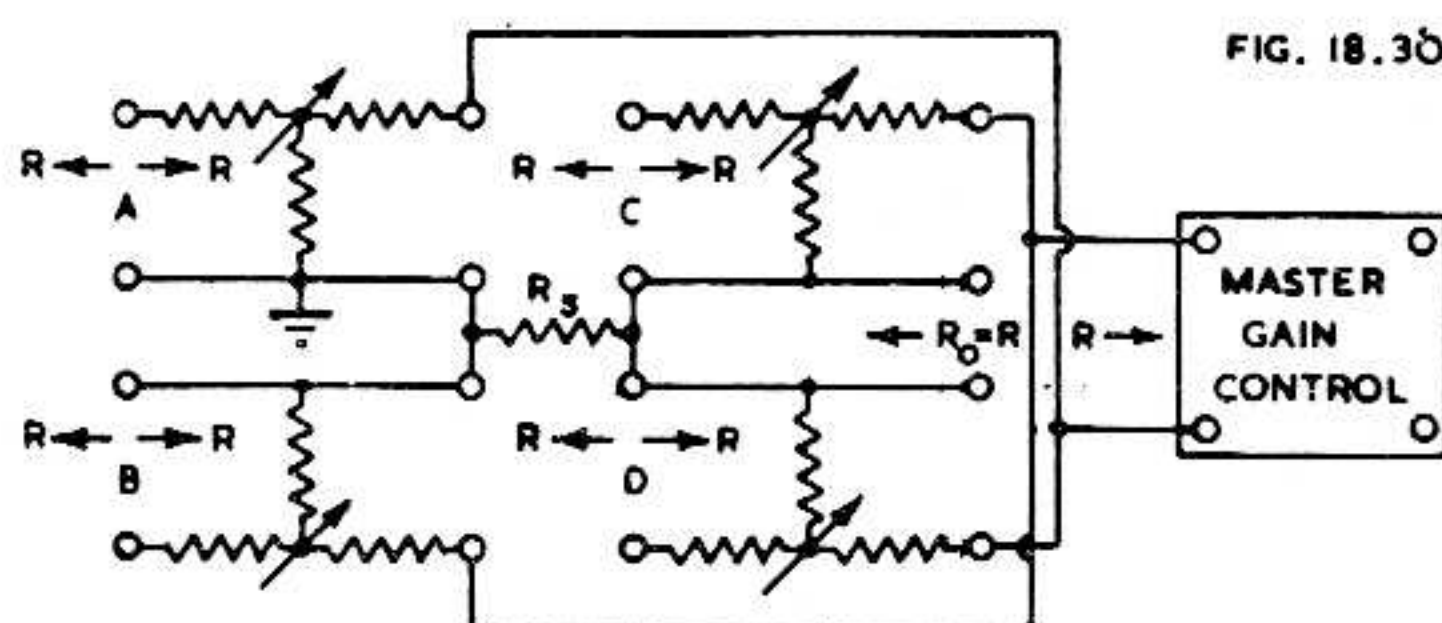
The following comments are based solely on minimum mixing loss, and are therefore to be applied with discretion—

1. When the impedance of the input circuit is required to be higher than that of the output circuit, a parallel mixer should be used.
2. When the impedance of the output circuit is required to be higher than that of the input circuit, a series or coil type mixer should be used.
3. When the input and output circuits are required to be nearly the same impedance, a series-parallel or bridge type mixer should be used.

References to constant impedance mixers : C1, C2, C3, C12 (parts 7 and 8), C16, C18, D10, D11.

(G) Precautions with studio type mixing systems

Under any possible operating conditions, the level at any stage should be kept at least 6 db and preferably 10 db above the critical pre-amplifier level of − 60 vu.

With mixer controls turned right off, and a normal level applied to each input in turn, the ratio of " leakage " at 10 000 c/s to normal programme level should be better than 70 db.

Cross-talk between two different circuits may be reduced by using twisted leads for all speech circuits with an electrostatic screen around each pair.
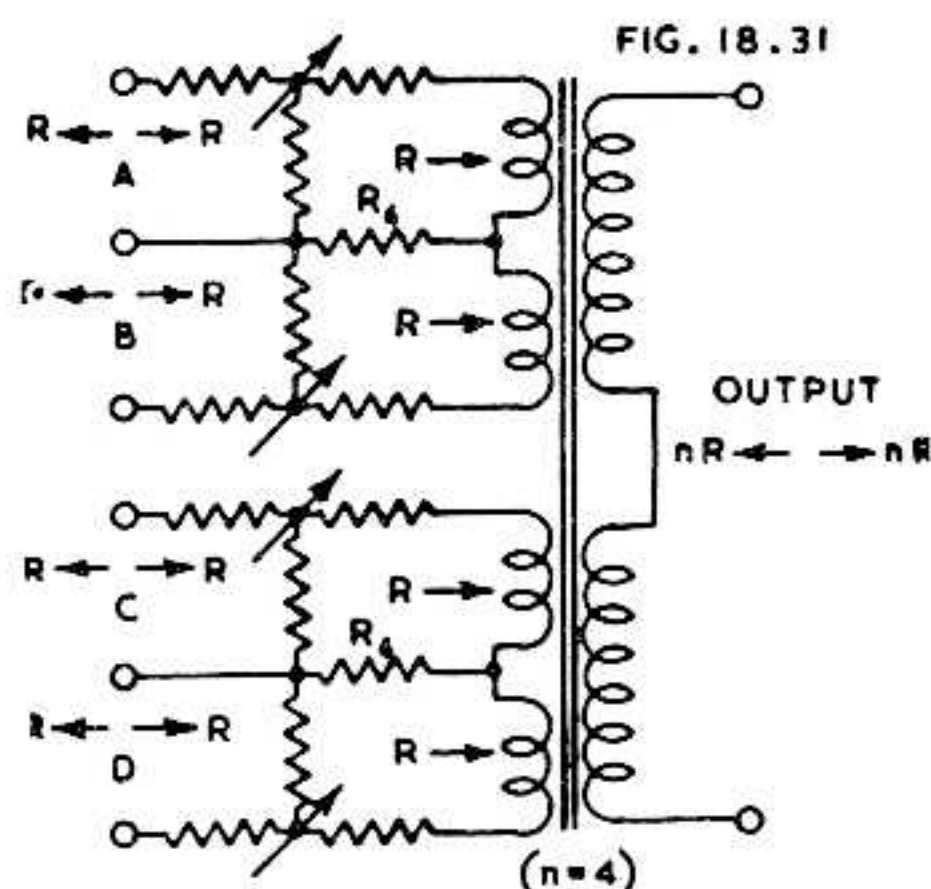

Fig. 18.31. *Constant impedance mixer using coil mixing with four input sources.*

Where there are long circuits between pre-amplifier outputs and mixer outputs, it is usually considered wise to use balanced transformer inputs to avoid the possibility of cross-talk or noise affecting the programme.

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