BBC ENGINEERING TRAINING MANUAL

SOUND AND TELEVISION BROADCASTING
GENERAL PRINCIPLES

K. R. STURLEY, Ph.D., B.Sc., M.I.E.E.

A 'WIRELESS WORLD' BOOK

About this book

This book by Dr. K. R. Sturley, head of the BBC Engineering Training Department, explains the basic principles of sound and television broadcast engineering and operations. It is another of the BBC Engineering Training manuals and was written primarily for new recruits to the BBC Engineering Division.

It is the Corporation's policy of disseminating their specialised knowledge and experience to all interested in sound and television broadcasting, and in line with this policy this book is offered to a wider public.

The introductory chapter deals with basic physical principles and their application to broadcasting. Other chapters follow on sound and television studios, telecine and telerecording. Among other topics covered are apparatus, techniques and procedures; outside television broadcasting, including "Eurovision"; amplitude and V.H.F. modulated transmitters; the problems of conveying the sound and television programme frequencies and communicating between the various studio centres and transmitting centres. The text is amplified by photographs and over two hundred specially drawn line illustrations.

In compiling this book, Dr. K. R. Sturley has had the fullest co-operation from the various specialists in the BBC Engineering Training Department. It should prove invaluable to any one engaged in or responsible for instructing in broadcasting and other forms of radio communication.

382 pages, including 248 diagrams and photographic illustrations.

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General Principles

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CONTENTS

PREFACE

THIS book has been written with the object of providing new recruits to the BBC Engineering Division with the basic principles of sound and television broadcasting engineering and operations. It replaces an earlier manual issued in 1941 to meet the special needs of wartime.

The information is presented at a technical level which allows the book to be readily understood by those having an educational standard equivalent to that of the General Certificate of Education and an active interest in the subject. Throughout the book the author is, in effect, saying ' This is the work that the broadcasting engineer or operator has to do, here is the apparatus he has to use, and this is how he uses it '.

The first chapter deals with the elementary principles of sound, light and electricity and explains their significance in broadcasting engineering.

The second chapter starts the tour of the broadcasting system at the sound studios. It opens with a general explanation of the Simultaneous Broadcasting (S.B.) system, which is the BBC term for the distribution of its various sound programmes to the transmitters. Programme sources—microphones, sound reproducing equipment and Outside Broadcast (O.B.) apparatus—are then defined and described. The equipment used in studios, control rooms and recording rooms is outlined and information is given on operating and test procedures.

Chapter 3 is devoted to Television Studios and the recording and reproduction of television programmes; it follows the same sequence as Chapter 2, describing the television distribution network, cameras and associated equipment, lighting technique, studio equipment, operating and testing, and concludes with an explanation of telerecording and telecine reproduction.

The special problems of Outside Broadcast television are described in Chapter 4. Here again the duties of staff are given in detail and the technical requirements for all types of outside broadcasts are explained, including those for Eurovision.

The first part of Chapter 5, ' The Radio-frequency Transmission of Sound and Vision Programmes ' is concerned with amplitude-modulated sound transmitters radiating on low, medium and high frequencies and it deals with the radiated signal, the carrier-frequency drive, the programme input equipment, the transmitter in all its stages, power supplies, cooling systems, and interlocking circuits. V.H.F. transmitters using frequency modulation are then described in similar sequence, with an explanation of the aerial-combining unit which makes it possible to radiate the output of two or more transmitters, using different carrier frequencies, from a single aerial system. Television transmitters receive similar treatment. Aerials and feeders are described and a section is allocated to propagation at all broadcasting frequencies. The chapter ends with information on the parallel operation of transmitters, automatic monitors, testing equipment, performance tests and frequency checking.

The special problems involved in conveying the sound and vision programme frequencies and of communicating between the various studio and transmitting centres of the BBC are outlined in Chapter 6.

References, many of which are related to BBC Technical Instructions and Training Supplements, are given at the end of each chapter. The Instructions and Training Supplements are written for the use of BBC technical staff but a limited number of copies are available and may be obtained at reasonable cost on application to the Editor, Technical Instructions, Broadcasting House, London, W.1.

In presenting the book for general publication the BBC is continuing its policy of placing the results of its experience in building up and operating a national broadcasting service at the disposal of all those interested in sound and television broadcasting. Although the book is intended primarily for members of the BBC's staff, it is felt that it will be of interest to many others engaged in broadcasting and in other forms of radio communication, and also to those responsible for the training of recruits to these fields.

CHAPTER 1

FUNDAMENTAL PRINCIPLES

1.1 INTRODUCTION

THE operation and maintenance of apparatus used in a broadcasting system requires a wide knowledge of fundamental principles of physics, and this first chapter deals with those principles of sound, light and electricity which are important to the broadcasting engineer and operator. The conversion of sound and light into related electrical waveforms, and the amplification, control and modification of these electrical waveforms so that they are suitable for transmission by a radio-frequency (r.f.) carrier are next considered and then follows a section devoted to the reception, amplification and extraction of the information from the r.f. carrier. The chapter ends with a discussion of the methods for converting the electrical waveform into a directly related sound signal or for using the electrical waveform to reconstitute an image of the original scene on the face of a picture tube in the television receiver.

1.2 PRINCIPLES OF SOUND

The term *sound* can be defined from a purely physical point of view as 'longitudinal vibrations in a medium' but for broadcasting this is inadequate because it ignores what is all-important, the interpretative role of the listener. To meet this need, sound can be defined more accurately as 'longitudinal vibrations, set up in a surrounding medium (gas, liquid or solid) by a vibrating body and producing the sensation of hearing when communicated to the brain by the ear'. The way in which the probable reactions of the listener have to be taken into account in operational procedures is discussed in Chapters 2 and 3. That the surrounding medium is essential for the transmission of sound has been shown by the well-known experiment in which air is withdrawn from a jar containing an electric bell. As a vacuum is approached, the sound from the bell gets weaker and weaker, showing that the air is essential for its transmission. Air is usually the medium through which sound is transmitted, and many examples of a vibrating body producing sound—a tuning fork or a violin string—could be quoted, but it must be noted that the sensation of hearing will not be evoked unless the rate of vibration lies within a range of about 30 to 18 000 vibrations per second. The actual range of vibrations that can be heard cannot however be clearly defined; the range varies considerably among individuals and the upper limit tends to decrease as age increases. The rate of vibration is always referred to as the *frequency* of the sound and is expressed in terms of cycles per second (c/s).

The hearing mechanism can be selective, and is capable of distinguishing one frequency from another when two are sounded consecutively, even if the ratio between the two frequencies is as small as 1·06 (a semitone). It can also be selective in another sense: with training, an individual can concentrate on one instrumental part in an orchestral performance and ignore the others.

Sound is therefore to be thought of as a series of waves emanating from the source of vibration and travelling through the intervening air to the ear. The sound waves consist of a series of compressions and rarefactions; at a compression the pressure is greater than the normal atmospheric pressure and the particles of air are crushed together. The reverse occurs at a rarefaction. A tuning fork generally produces the simplest wave motion, the sinusoidal form, and it sends out a compression wave when the prongs are at their greatest distance apart because the prong has compressed the molecules of air in front of it (Fig. 1.1 (a)). These compressions are propagated outwards from the fork and follow each other at regular intervals and equal distances. The distance between consecutive compressions (AB in Fig. 1.1 (a)) is known as the wavelength (λ) of the sound. In Fig. 1.1 (b) the tuning fork is passing through its rest position and in Fig. 1.1 (c) the molecules of air are being sucked in behind the prongs and the fork is propagating a rarefaction; the distance between consecutive rarefactions (CD in Fig. 1.1 (c)) is the wavelength of the sound, i.e., CD = AB. If the ear is placed at some position such as E, its diaphragm will experience a pressure varying in time above and below the atmospheric pressure, a compression giving a pressure greater and a rarefaction less than atmospheric. The varying pressure causes the diaphragm of the ear to move in and out, and this movement is transmitted by specially shaped bones, called the ossicles, to an inner diaphragm.

The inner diaphragm forms the seal to one end of a spiral-shaped tube filled with fluid, movement of which activates the hearing nerves terminating in a part of the spiral tube called the cochlea. When the hearing nerves are stimulated, electrical impulses are sent to the brain where their significance is interpreted.

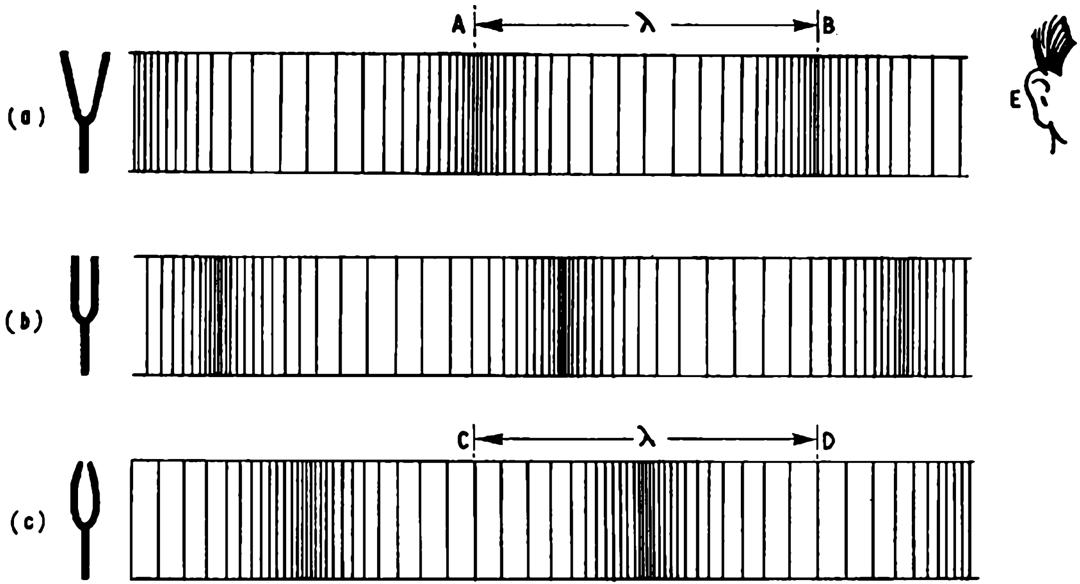


Fig. 1.1. Pressure-distance variations for a tuning fork

If the relationship between the variation of air pressure with time at point E is plotted, a curve similar to that of Fig. 1.2 is obtained. The pressure at time $t = 0$ is assumed to be zero but it could be any value between maximum and minimum depending on when measurement was begun. The interval of time which elapses between two points of equal pressure, e.g., F and G, is known as

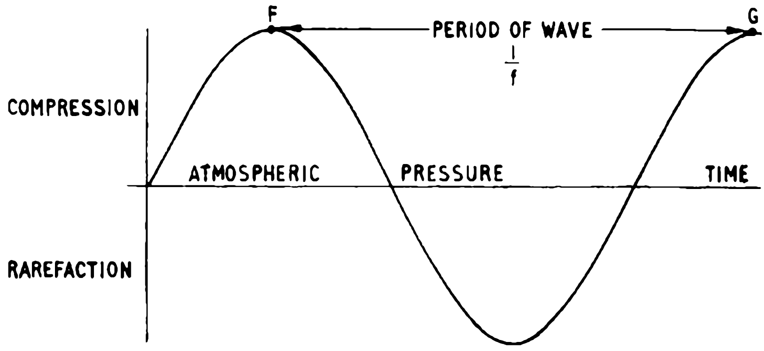


Fig. 1.2. Pressure-time curve of a sinusoidal sound wave

the period of vibration or oscillation (T). This is clearly the reciprocal of frequency, i.e., $T = \dfrac{1}{vibrations/sec}$ or $\dfrac{1}{cycles/sec}$. (The solidus or oblique stroke as used here denotes 'per'.)

During one period of vibration the sound wave advances through the air by one wavelength so that its velocity (v) may be written as

$$v = \frac{distance\ travelled}{time} = \frac{\lambda}{period} = \frac{\lambda}{T};$$

since the frequency $f = \dfrac{1}{period} = \dfrac{1}{T}$

$$v = f\lambda$$

The velocity of sound in air varies with temperature and humidity but is about 1 100 feet per second or 750 m.p.h. Thus the wavelength of a given sound may be calculated from the relation

$$\lambda = v/f; \qquad \text{hence}$$

at a frequency of 30 c/s $\lambda = \dfrac{1\,100}{30} \simeq 37$ ft

and

at a frequency of 15 000 c/s $\lambda = \dfrac{1\,100}{15\,000} \simeq 0{\cdot}074$ ft $\simeq 0{\cdot}9$ in.

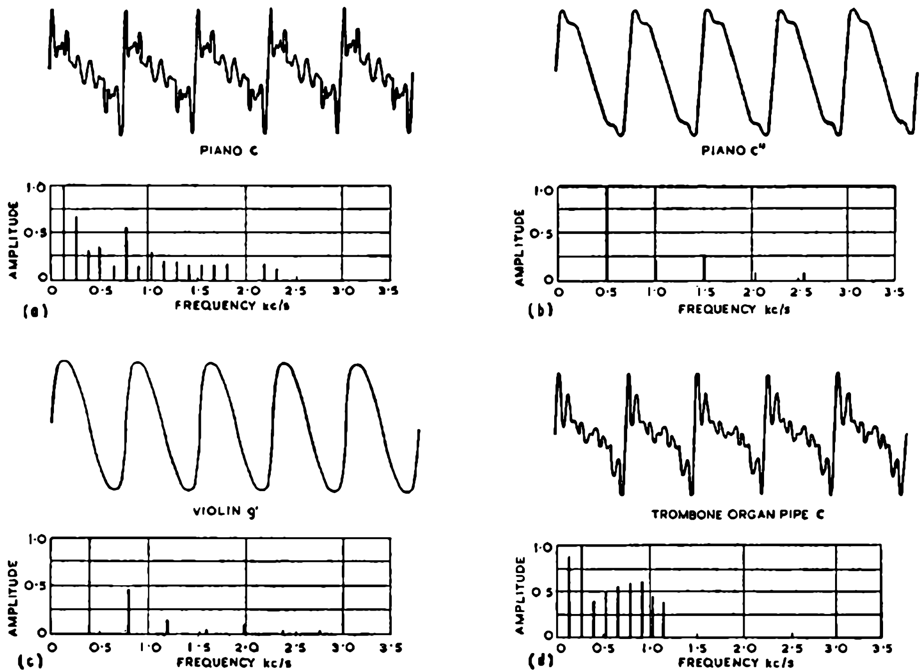


Fig. 1.3. Waveforms of sounds from musical instruments (by courtesy of Harvey Fletcher)

The very large range of wavelengths covered by sound waves makes work on acoustical problems most difficult, because in given circumstances a 30-c/s wave may behave quite differently from a 15 000-c/s wave. For example, an object which is large compared with the wavelength of a given sound will act as an obstacle to the sound and will form a 'shadow' behind itself. Thus a microphone of 3 in. diameter can form an obstacle to sound waves of 15 000 c/s with a wavelength of approximately 1 in., whereas a wave of 30 c/s, which has a wavelength of 37 ft, will act as if the microphone did not exist and will produce no shadow behind it.

1.2.1 *Characteristics of Sounds from Musical Instruments*

Normally sound waves are not just like the simple sinusoidal single-frequency vibration associated with a tuning fork but contain many frequency components of different amplitudes and these add together to produce a very complex waveform. The quality of a musical sound depends on the presence of these other frequencies and their amplitude relationship to the 'fundamental' note. The frequency relationship is often harmonic, i.e., they are simple multiples of the fundamental. Some idea of the complicated waveforms and the relative amplitudes of the component frequencies produced by various musical instruments is given in Fig. 1.3. Figs. 1.3 (a) and 1.3 (b) represent the waveform from a piano note one octave ($f = 128$ c/s) below middle C ($f = 256$ c/s) and one octave ($f = 512$ c/s) above middle C respectively. Fig. 1.3 (c) is from a violin playing G ($f = 384$ c/s) above middle C, and Fig. 1.3 (d) is from a trombone organ pipe playing one octave below middle C.

Fourier has shown that any complicated periodic (repeating) waveform can be built up from a series of harmonically-related waves. Thus if a fundamental and second harmonic are added together as shown in Fig. 1.4 (a) a waveshape is produced very similar to that of the violin playing G as in Fig. 1.3 (c). Similarly the waveform of the piano note one octave above middle C (Fig. 1.3 (b)) can be approached in shape if a second plus a third harmonic is added to the fundamental as shown in Fig. 1.4 (b). It will be obvious that the component frequencies making up any particular sound should not have their amplitudes changed when they pass through the broadcasting system, otherwise the quality of the sound heard in the receiver will not faithfully convey the impression of the instrument to the listener's ear (Section 1.6.5). A chart illustrating the relationship of the fundamental frequencies of the various musical notes of the scale is given in Fig. 1.5, and the range of frequency over which various instruments function is indicated on the same diagram. Though considerable stress has been laid on the significance (to the ear) of the frequency components making up any given sound wave, it is important to note that the ability to recognise the instrument producing the sound

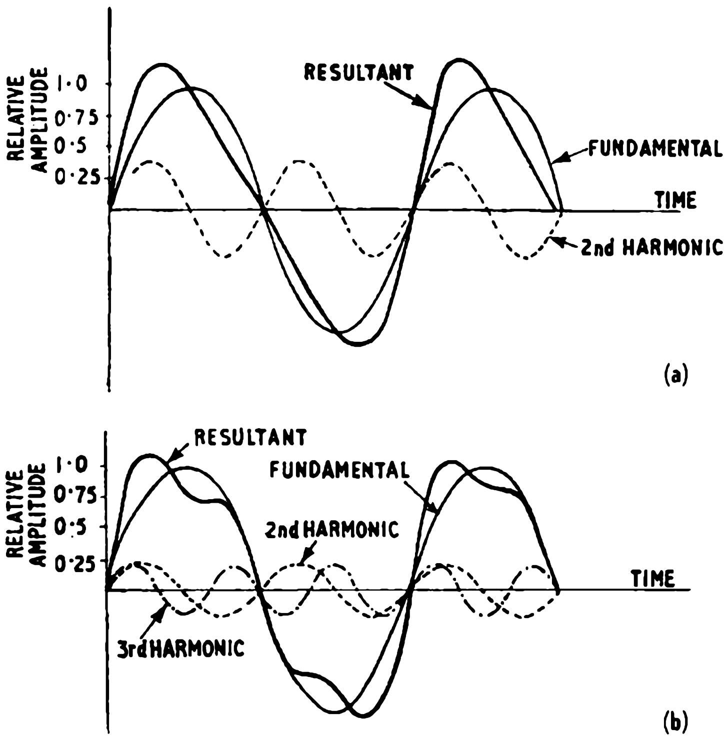


Fig. 1.4. (a) addition of a fundamental and 2nd harmonic; (b) addition of a fundamental and 2nd and 3rd harmonics

depends a very great deal on the rate of rise and decay of the sound, as well as on the frequency components.

1.2.2 *Loudness of Sound*

One of the most important characteristics of sound as judged by the ear is its loudness; if only a single frequency is being produced, the amplitude of its pressure variation gives some indication of its relative loudness. When however the frequency is changed but the amplitude is maintained constant, loudness does not necessarily remain the same. Similarly it is found that the pressure

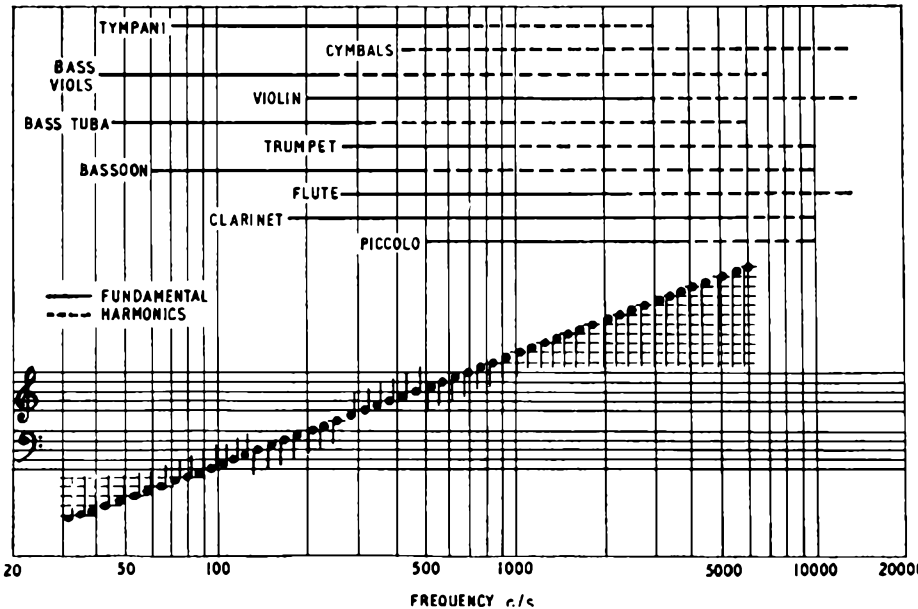


Fig. 1.5. Range of frequencies of musical instruments including the piano (by courtesy of the General Post Office)

required to make a sound just audible varies with its frequency (and with the listener). The sensitivity of the 'average' ear at different frequencies is illustrated by the lowest 'threshold of hearing' curve shown in Fig. 1.6. It will be observed that the ear is most sensitive between 1 000 and 5 000 c/s, the sensitivity falling when the frequency falls below or rises above these values. If the pressure variation of the sound at the ear is increased a point is reached at which pain is the chief sensation and the pressure-frequency relationship for this condition is known as the 'threshold of feeling'.

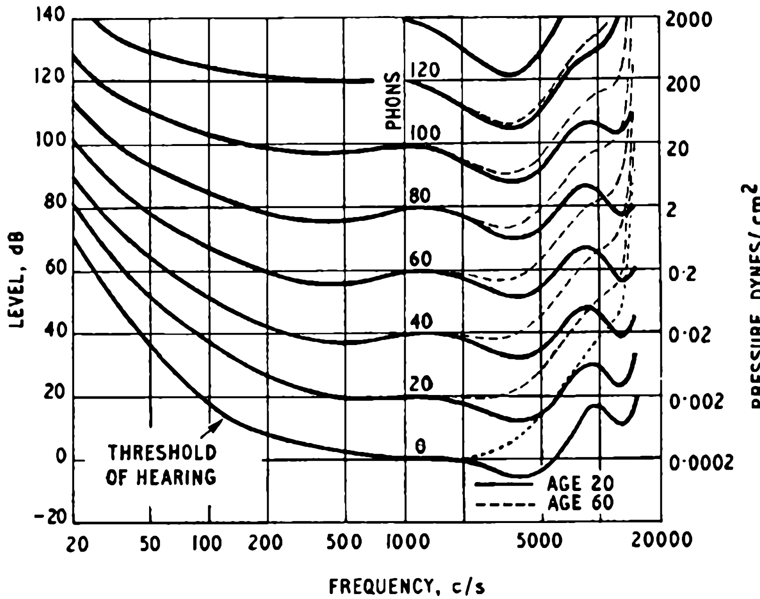


Fig. 1.6. Loudness curves (by courtesy of the National Physical Laboratory)

It is possible to plot a series of intermediate curves joining points of equal loudness as judged by the ear and such curves are indicated in Fig. 1.6.

The variation of loudness with frequency shown by the curves of Fig. 1.6 is very important because it means that the quality of a reproduced musical programme is affected by the average sound pressure at which it is reproduced. Thus a listener who has adjusted his broadcast receiver volume control so that an orchestra is reproduced at an average level of 1 dyne per square centimetre (1 dyne/cm^2) will hear the lower and higher frequency components relative to the middle frequencies louder than the listener who has adjusted his receiver to reproduce the same programme at a level of 0·1 dyne/cm². The unit of loudness is known as the 'phon', and 0 phons represents the threshold of hearing curve. At 1 000 c/s, which is the reference frequency for loudness, the zero reference level for the phon scale is considered to correspond to a pressure of 0·0002 dynes/cm² and at another pressure the reference loudness in phons $= \log_{10} \dfrac{\textit{sound pressure (dynes/cm}^2)}{0{\cdot}0002}$. At any other frequency the loudness cannot be directly related to sound pressure and the note is given the same phon number as the phon number of the 1 000-cycle tone, which appears to the ear equally as loud as the tone at the other frequency. The curves in Fig. 1.6 join points of equal loudness or phon value.

1.3 PRINCIPLES OF LIGHT

Light may be described as 'electromagnetic vibrations capable of inducing visual sensation through the eye'. The terms wavelength, frequency and velocity are applicable but the values are quite different from those of sound. The wavelengths of light vibrations vary between 40 and 75 millionths of a centimetre and their frequencies from 400 million megacycles per second to 750 million megacycles per second. The term 'megacycle' represents 1 million cycles and 'kilocycle' represents 1 thousand cycles so that

1 kilocycle/second (1 kc/s) = 1 000 cycles/second (c/s)

1 megacycle/second (1 Mc/s) = 1 000 000 cycles/second
$= 10^6$ c/s.

Hence light covers a range of frequencies from 4×10^{14} c/s to $7{\cdot}5 \times 10^{14}$ c/s, frequencies which are much greater than those of the electromagnetic waves used for radio transmission. Radio transmission frequencies are approximately from 10 kc/s to 10^5 Mc/s. Light and radio waves travel at a very much greater speed than sound, namely, at a velocity of 186 000 miles/second or 3×10^8 metres/second. It is perhaps easier to appreciate the speed of light by saying that it can travel in one second a distance equal to seven times round the world.

1.3.1 *Characteristics of Colour Sensation*

The sensation of colour produced by light is determined by the wavelength of the vibration. A long-wavelength vibration, about 70 millionths of a centimetre (70×10^{-6} cm, sometimes expressed as 7 000 Ångstroms where 1 Ångstrom $= 10^{-8}$ cm, or as 700 millimicrons where 1 micron $= 10^{-3}$ mm $= 10^{-6}$ metres), produces the sensation of a red colour. A wavelength of about 550 millimicrons, i.e., 55×10^{-6} cm produces a sensation of yellow, a wavelength of 500 mμ produces a sensation of green and a wavelength of 400 mμ causes a sensation of blue.

The eye does not possess the same discriminatory powers as the ear but in fact acts as an integrating or combining device. If presented with light vibrations at different frequencies, it is unable to distinguish between them and interprets the sensation they produce as that of one colour only. Thus if vibrations corresponding to red and green in appropriate amounts are presented to the eye it registers the colour yellow, or if red, green and blue are presented in certain proportions, it sees them as white. This is thought to be due to the presence of three receptors in the eye, and the brightness and colour of a source of light are determined by the intensity of the light and the relative amounts of stimulation it produces in the three receptors. Provided these receptors are stimulated in the same proportions, the eye detects the same colour whatever the frequencies of the visible light involved. The fact that the eye functions in this way is of considerable value in colour television, because it means that the colour in the original scene can be transmitted with the aid of three electrical signals derived from three camera tubes on which have been focused the red, green and blue parts respectively of the image. The image can be reconstituted at the receiver with the aid of three separate picture tubes having red-, green- and blue-glowing phosphors, or their equivalent in one tube. Since the eye possesses a colour-integrating characteristic, it follows that it will sense colours other than those occurring in the visible spectrum. Thus blue and red will be seen as magenta, a colour which does not exist in the spectrum. All the 'purple' shades from blue to red due to mixture of these two colours are non-spectral.

The eye is not equally sensitive to the different colours of the visible spectrum. It has a peak of sensitivity in the yellow-green falling off on either side to blue and red. A curve of eye sensitivity in arbitrary units plotted against wavelengths (in millimicrons—mμ) is shown in Fig. 1.7. A television camera or a photographic film which has a similar sensitivity is said to be 'panchromatic' and this gives a true brightness interpretation of the scene even though colour is missing. Early television cameras possessed excessive sensitivity to red and tended to reproduce all red objects at an exaggerated brightness level.

The three types of receptor sensitive to red, green and blue light are found most thickly concentrated in one small area on the retina of the eye. It is on this area that an individual automatically focuses an image when viewing an object in normal light. Outside this area the colour receptors are spread more thinly and vision depends upon another type of receptor which does not distinguish colour. These receptors are more sensitive to low levels of illumination and account for the improved vision obtained at night by looking slightly to one side of the object to be viewed.

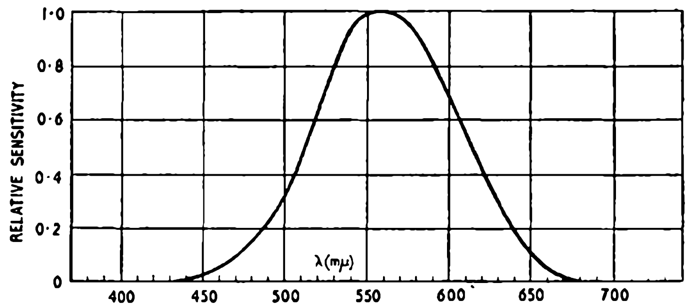


Fig. 1.7. Response of the eye

1.3.2 *The Eye and its Response to Light*

In forming an image on the retina, the eye behaves in much the same way as a camera. It possesses a convex lens but unlike the normal camera lens, the focal length of the eye lens is capable of variation so that objects near or far may be focused at will on the retina where the light stimulates the light-sensitive elements which then send impulses through the optic nerve to the brain. The property of varying the focal length of the lens in the eye is called the 'power of accommodation' and it tends to become seriously reduced with increasing age. The camera achieves this accommodation not by changing the focal length of the lens but by moving the lens away from or towards the film. Normally, in the television camera the position of the lens is fixed but the camera tube is movable, i.e., it is equivalent to moving the position of the film in the camera. The eye possesses a means of controlling the amount of light falling on the retina by using a variable aperture or iris. The opening of the iris is automatically adjusted to suit the brightness of the light, a bright light causing the aperture to close and vice versa. The film or television camera uses the same principle but the aperture is adjusted manually and not automatically, usually by rotating a milled wheel which opens or closes the mechanical iris. The width of scene in focus is measured by the angle that the scene makes or subtends at the eye or camera and this angle is called the angle of view. It is determined by the width of the image surface and the focal length of the lens. The angle of view of the normal eye is about 10° and this means that the eye can see an object subtending an angle of 10° in acceptable focus over the whole of its width. The area in sharp focus is much smaller than this, as can be checked by estimating how many words are in focus when looking at a part of this page. Probably about 3 are sharply defined and this would mean an angle of view of about 4°. If the eye wishes to view in reasonable detail an object subtending an angle greater than 10°, the eye itself must be moved to scan it. A short focal length camera lens can have a much wider angle of view, up to about 40°, but a long focus lens may reduce the angle of view to only about 1° or 2°.

So far only an object in a plane parallel to that of the lens has been considered but this is a condition which will not normally apply to a scene, and objects will be required to be in acceptable focus when they are at different distances from a lens. The actual depth of the scene over which objects are held in reasonable focus is dependent on the focal length of the camera lens and the aperture of the iris, a short focal length and small aperture giving a greater depth of clear focus than the reverse. The ratio of the focal length of a lens to the effective iris aperture is known as the '*f* number' or 'stop number'. For a given lens the greater this is, the greater is the depth of the scene in acceptable focus.

1.3.3 *The Characteristics of Spherical Lenses*

Besides their use in the photographic camera and the television camera, lenses find many applications in television, e.g. in the film scanner, the back projection machine and the teleprompt.

Lens surfaces generally form part of a sphere though aspheric lenses with surfaces which are not spherical may be used for special purposes. There are two basic spherical lenses, the convex and the concave; the convex type is the better known and has the power of converging rays of light passing through it as shown in Fig. 1.8. The line XX′ through the centre of the lens and perpendicular to the plane of the lens is called the axis of the lens. Rays of light, parallel to this axis, are converged by the lens to a point called the 'principal focus' (F), and the distance from the plane of the lens to the principal focus is called the 'focal length'. The focal length of a lens is sometimes quoted in diopters and referred to as the power of the lens, where the power (diopters) is the reciprocal of the focal length in metres. The plane perpendicular to the axis which contains the principal focus F is called the 'focal plane'.

The convex lens may be used to form an image of a distant object, and if the object is at a very considerable distance the image is formed in the focal plane. A nearer object is imaged further away from the lens than the focal plane, and the image distance

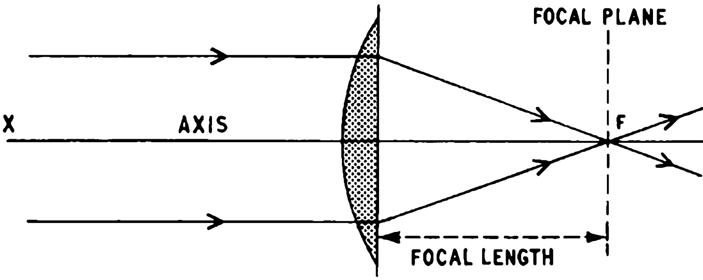


Fig. 1.8. Convex lens

(v) is related to object distance (u) and focal length (f) by the formula

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

The way in which an image is formed by a convex lens is shown in Fig. 1.9. Rays of light travelling parallel to the axis of the lens from point O' on the object are converged towards the principal focus F but those which pass through the centre of the lens continue undeviated and the intersection of these two sets of rays fixes the position of the image II'. The image is inverted and can be seen on a suitable screen placed at that point, hence the term 'real image'.

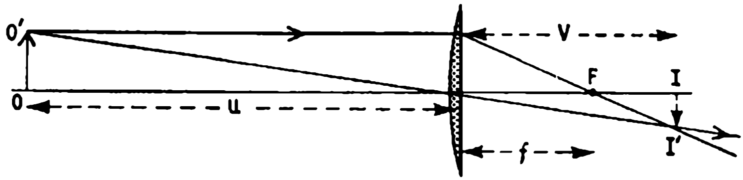


Fig. 1.9. Convex lens showing the position of image and object

It will be clear that the magnification $\frac{II'}{OO'}$, is equal to v/u and that lenses of long focal length give greater magnification than short focus lenses because v is dependent on f.

The spherical concave lens causes rays of light to diverge so that the meaning of focus and focal length is more difficult to appreciate.

The ray diagram of Fig. 1.10 shows how rays parallel to the axis of the lens are diverged and appear to come from F. This point is called the 'virtual' principal focus and its distance from the lens is called the 'focal length'.

When an object OO' is viewed from the right-hand side of the lens, its image will appear to be at II' as shown in Fig. 1.11. A screen placed at II' will not however reveal an image, so that it is termed a 'virtual image' to distinguish it from the real image produced by the convex lens.

When using the lens formula for a concave lens, the focal length f and the power (diopters) are given a negative sign; thus a lens of

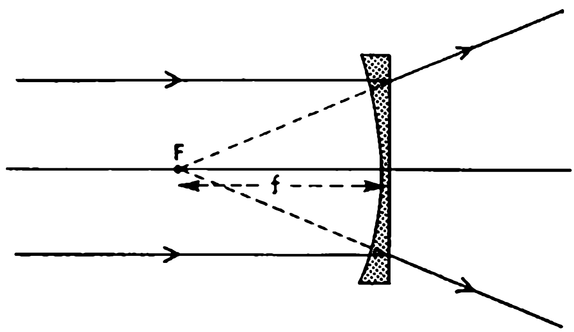


Fig. 1.10. Concave lens

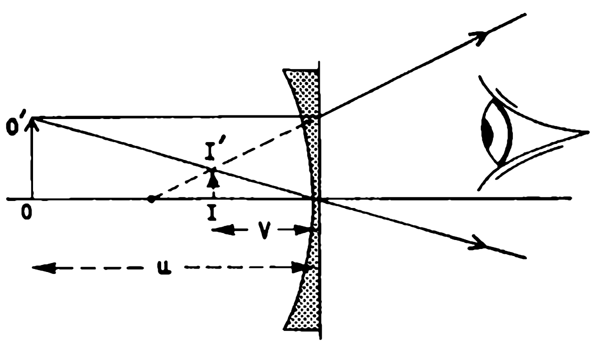


Fig. 1.11. Concave lens showing the position of image and object

-2 diopters is a concave lens of 50 cm focal length (2 diopters $\equiv$focal length of 0·5 m). The chief use of a concave lens is in combination with a convex lens to produce an effective change of focal length. For example if the above concave lens is combined with a $+4$ diopter convex lens (focal length 25 cm) the result is a power of $4 - 2 = +2$ diopters or the equivalent of a single convex lens of 50 cm focal length.

The telephoto lens is an example of this technique and the ray diagram of Fig. 1.12 (a) shows that a parallel beam of light entering the plano convex lens is finally converged to a point image in

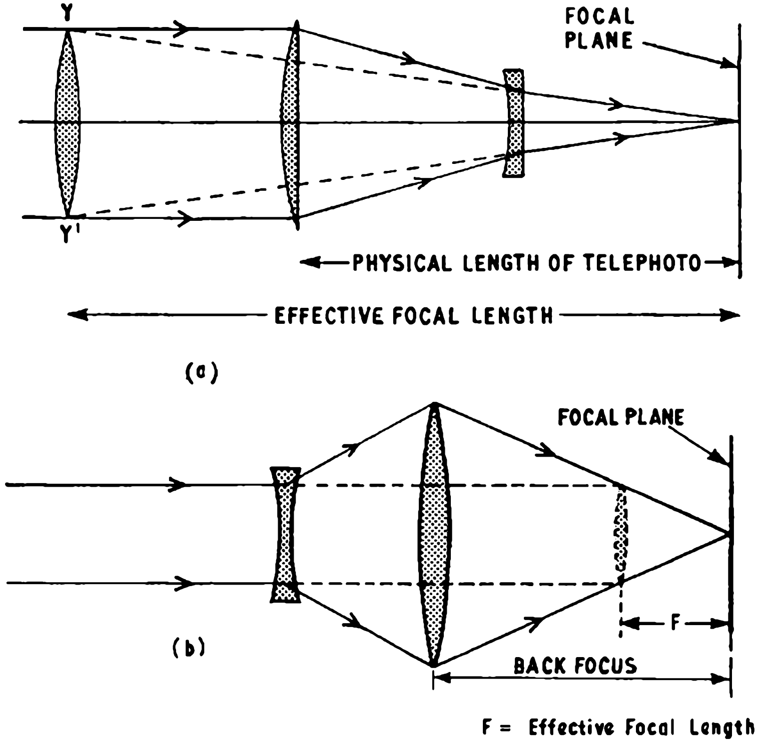


Fig. 1.12. (a) telephoto lens; (b) reverse telephoto lens

the focal plane of the telephoto lens. A single lens producing the same convergence would need to be placed at YY' to achieve the same result. Thus the effect of the single lens is produced by the telephoto lens in a much shorter distance.

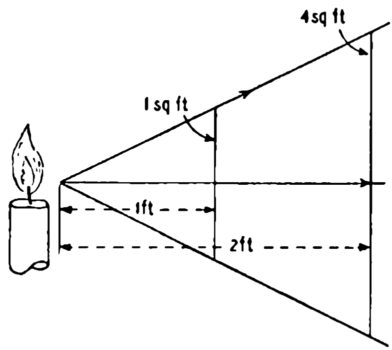
The reverse telephoto lens (Fig. 1.12 (b)) is used when the focal plane must lie further from the rear element than the focal length. This happens when a short focus lens is required to operate with a camera tube having a photo-cathode which must for mechanical reasons lie further from the rear element of the lens than the desired focal length. A reverse telephoto lens gives effectively a long back focus and a short focal length.

1.3.4 *Measurement of Illumination*

Since the sensation of light has to be interpreted by the human eye, it follows that in trying to measure quantity of light or illumination the sensation produced on the retina of the eye must be determined. The electrical signals which are passed along the optic nerve from the retina to the brain cannot easily be intercepted for the purpose of measurement and it is necessary to find some device which will react to light in much the same way as the eye, and will produce an output of some conveniently measurable quantity directly related to the illumination. A photo-electric cell (photo-cell) can convert light into an electrical signal whose amplitude is directly proportional to the brightness of the light, and if a filter is included (having an overall sensitivity (Fig. 1.7) equal to that of the average human eye) between the photo-cell and the source of light, a measurement related to the stimulus received by the brain from the optic nerve is obtained. The units in which the meter associated with the photo-cell is to be calibrated have still to be determined.

In the early days of light measurement a standard candle was used as a light source and under carefully specified conditions of burning, it was defined as a source of 1 candlepower. At a horizontal distance of 1 foot from the candle the rate of flow of light (light flux)

Fig. 1.13. Inverse square law of illumination



is defined as being 1 lumen/square foot. As 1 lumen/ft² corresponds to the illumination of a surface 'one foot from a standard candle', this latter phrase came to be used as an alternative to 1 lumen/ft² and the words 'from a standard' were dropped to give '1 foot-candle'. If the photo-cell is now set up so that the illumination on its surface is 1 foot-candle, the dial of the meter could be calibrated so that the pointer indicated '1'. At two feet from the candle the light which passed through an area of 1 ft² at a distance of 1 ft now passes through 4 ft² (see Fig. 1.13), so that the illumination of a surface 2 ft away is 0·25 foot-candle. By using 2 standard candles as the light source the illumination is doubled at all points. This leads then to a law relating illumination (E foot candles) of a surface by a light source of I candlepower at a distance of d ft as follows:

$$E = I/d^2$$

This is not true when the light strikes the surface obliquely, for then a factor $\cos \varphi$ must be introduced, φ being the angle between the direction of the incident light and the perpendicular to the illuminated surface. The modified relationship is

$$E = \frac{I \cos \varphi}{d^2}$$

The standard candle has been replaced by a light source consisting of one square centimetre of platinum at its melting point, and this corresponds very nearly to 60 old standard candles. The light output is defined as exactly 60 new standard candles or *candelas*; the candela is so nearly equal to the candlepower that for ordinary purposes no distinction need be made between them.

When illumination falls on a surface which is not a mirror, the light tends to be scattered in all directions and such a surface is said to be a 'diffusing surface'. A perfect diffuser, or 'lambert surface', is one which looks equally bright in all directions. The unit of surface brightness is the foot-lambert, which is 1 lumen/ft². The brightness or luminance L of a surface is obviously proportional to the incident illumination and there is a simple formula connecting them, i.e.,

$$L = \rho E$$

where L is the luminance or brightness of the surface in foot-lamberts and ρ, the reflection factor (normally less than 1), is the ratio of the amount of light reflected from the surface to the amount of light falling on it. The amount of light which enters the lens of a camera (television or otherwise) and forms an image on the picture surface is important, and the illumination of this image is proportional to the brightness of the object in foot-lamberts as well as to the effective aperture of the lens. Image illumination is also dependent on the focal length of the lens, because the longer the focal length the bigger is the image and the larger is the area over which the available light is spread. The relation between image illumination and these other factors is given below:

$$E = \frac{\tau L}{4(f/d)^2}$$

where E is the image illumination in foot-candles

L is the scene brightness in foot-lamberts

τ is the transmission factor of the lens system

f is the focal length

d is the effective lens diameter.

The ratio f/d is the f/number of stop number N so that

$$E = \frac{\tau L}{4N^2}$$

It will be noted from the above formula that image illumination is independent of the distance of the scene from the camera or the eye, but image illumination, and therefore electrical signal output from the television camera, is inversely proportional to the square of the stop number; for example changing from a stop number of 4 to 5·6 halves the image illumination E. Each two adjacent stop numbers differ by a ratio $\sqrt{(2)}$ and a normal series of stop numbers is 2, 2·8, 4, 5·6, 8, 11, 16, the iris opening being decreased as stop number is increased. Changing from 4 to 5·6 is known as stopping down one stop whereas action in the reverse direction is known as opening up one stop.

An example of a measuring device for scene luminance is the S.E.I. photometer. The illumination of any point on the image is measured directly in foot-lamberts and such an instrument may be used in determining the stop number at which a given camera should be operated to give the best results.

1.4 FUNDAMENTAL ELECTRICAL PRINCIPLES

Only those fundamental electrical principles which are needed for an understanding of the techniques in broadcasting engineering will be considered here. Matter itself is basically an electrical phenomenon and all atoms are made up of a complex positively-charged nucleus surrounded by a varying number of negatively-charged electrons moving in orbits. A current of electricity consists of large numbers of these electrons freed from their orbits and moving through the relatively vast spaces which exist between the nuclei. In electrical conductors, e.g., metals, electrons are readily detached from their orbits and freely interchanged between nuclei. The application of a unidirectional voltage across the ends of a metallic conductor will cause the electrons to flow towards the positive end and so constitute a current. In an insulator the electrons are not free to move and the application of unidirectional voltage across it will not produce a steady flow of electrons. The electron orbits are distorted or displaced and this momentarily produces a current which, however, quickly dies away. If an alternating voltage is applied across an insulator, an alternating displacement of the orbital electrons occurs and this constitutes an alternating flow of current. This is the principle of the capacitor, which is essentially an insulator between two metal plates; such a device will pass alternating currents relatively freely but will block direct currents.

The electrical characteristics of some materials can be changed by the application of heat or light. Both these phenomena can disturb the electron arrangement and make it easier for electrons to be released. The thermionic valve is an example of the exploitation of this phenomenon. Heating of the filament or cathode of

TABLE 1.1

The M.K.S. System of Units

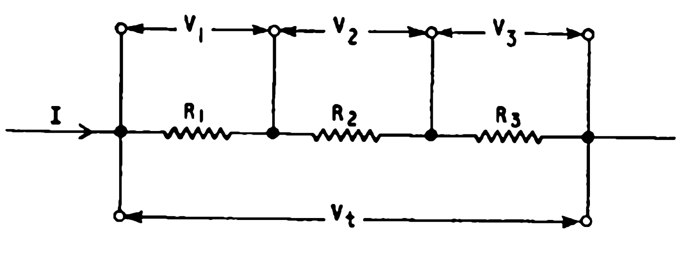
Unit of	*Name of Unit*	*Abbreviation*
length	metre	m
mass	kilogram	kg
time	second	sec
electric current	ampere	A
force	newton	N
work	joule	J
power	watt	W
electrical pressure	volt	V
charge	coulomb	C
magnetic flux	weber	Wb
resistance	ohm	Ω
inductance	henry	H
capacitance	farad	F

the valve causes the electrons to move about more freely, and even to escape from the cathode; and since the air (or gas) inside the valve has been removed to leave a vacuum, the electrons can readily be collected by a positively-biased electrode. The diode valve so produced will only permit the flow of electrons from the heated metal to the positive anode. Electrons cannot flow in the opposite direction. Certain materials will also react in a similar way when light falls on them; thus an electrode coated with the metal caesium when placed in a vacuum will under the action of light emit electrons which can be collected by a positively-biased anode. This is known as 'photo-electric emission' and is the principle upon which the television camera tube operates.

The development of any branch of science ultimately requires measurements to be made and this means fixing the units of measurement. The units now most generally used in electrical engineering are those of the rationalised M.K.S. system based on the ampere and they are given in Table 1.1.

1.4.1 *Electrical Conduction*

As stated above, the application of a potential or voltage to a metal causes the 'free' electrons to stream towards the positive end. The passage of electrons along the wire results in a liberation of energy which appears as heat in the wire and represents a resistance to the free flow of electrons. Long before the electron was discovered Ohm had noted this effect and had enunciated his famous law that 'the ratio of voltage applied across the ends of a conductor to the current which is caused to flow through it, is a constant known as the resistance of the conductor'. Various conditions must be observed in order that Ohm's law may hold and these include constancy of temperature and absence of chemical change.



$$R = R_1 + R_2 + R_3$$

Fig. 1.14. Resistances in series

The law is often stated in the form of expressions such as

$$V = IR, \; I = \frac{V}{R} \quad \text{or} \quad R = \frac{V}{I}$$

where V is the potential difference across the conductor in volts, I is the current in amperes and R is the resistance in ohms. Applying this law to resistors connected in series (Fig. 1.14) shows that their combined resistance equals the sum of the individual resistances. Thus

$$V_t = V_1 + V_2 + V_3$$

i.e.,

$$IR_t = IR_1 + IR_2 + IR_3$$

or

$$R_t = R_1 + R_2 + R_3$$

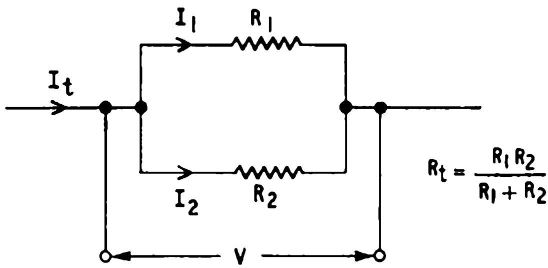


Fig. 1.15. Resistances in parallel

Similarly resistors in parallel (Fig. 1.15) yield an effective resistance R given from

$$I_t = \frac{V}{R_t} = I_1 + I_2 = \frac{V}{R_1} + \frac{V}{R_2}$$

or

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2}$$

The expression $1/R_t$ is known as the conductance and is expressed in mho (ohm backwards). Thus a 10-ohm resistance has a conductance of 0·1 mho. In this way the conductance of a combination of resistors in parallel is seen to be the sum of their individual conductances.

A more convenient method of dealing with two resistors in parallel is to rewrite the formula quoted above as

$$\frac{1}{R_t} = \frac{R_1 + R_2}{R_1 \times R_2}$$

so that

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2} \text{ i.e., } \frac{product}{sum}$$

Since a number of resistances in parallel can be separated into pairs of resistances in parallel, the above formula can always be used.

Thus a 6-Ω resistance in parallel with 3 Ω gives

$$\frac{3 \times 6}{3 + 6} = \frac{18}{9} = 2\Omega$$

and 6-, 3- and 4-Ω resistors in parallel become 2 Ω in parallel with 4 Ω or $\frac{2 \times 4}{6} = 1{\cdot}33\ \Omega$.

Voltage Division. When two resistors are connected in series across a voltage source, a definite fraction of the applied voltage appears across each. In the simple circuit of Fig. 1.16, the voltage V_2 appearing across R_2 is

$$V_2 = V_t \frac{R_2}{R_1 + R_2}$$

If R_1 and R_2 are one continuous resistor with a tapping point anywhere along its length, they constitute a variable potential divider,

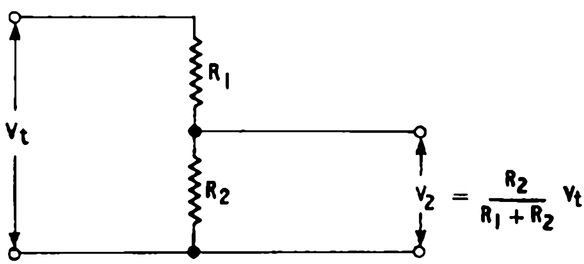


Fig. 1.16. Voltage division

and this is the basis of the simple volume control used in broadcast receivers and the more complicated fader met with in the broadcasting chain itself.

Current Division. Current flowing into two resistors connected in parallel divides so that the current in each resistor is a definite fraction of the total current. Thus the current in R_2 (Fig. 1.17) is

$$I_2 = I_t \frac{R_1}{R_1 + R_2}$$

Similarly

$$I_1 = I_t \frac{R_2}{R_1 + R_2}$$

This principle is involved in the design of shunts for meters measuring current. Only a definite fraction of the current to be measured actually passes through the meter; the rest flows through (i.e., is shunted by) a resistance connected across the meter terminals.

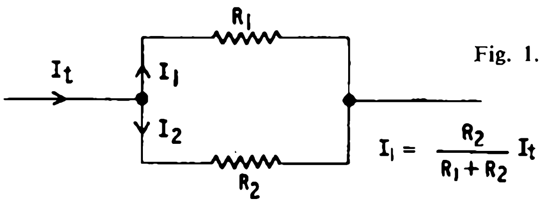


Fig. 1.17. Current division

Power. The power developed in a resistor is the product of the voltage across it and the current flowing in it. As indicated in Table 1.1, the unit is the watt (W), and

$$1 \text{ watt} = 1 \text{ volt} \times 1 \text{ amp}$$

or

$$W = VI$$

Alternative expressions, derived from $V = IR$, are

$$W = I^2R = V^2/R$$

The power developed in a resistor is normally dissipated as heat and the temperature attained is largely determined by the surface area of the resistor. For a fixed temperature rise and a given material, a resistor required to dissipate 5 W must be much larger than one designed for 0·25 W. The material of which the resistor is made will affect the permissible working temperature. Thus a wirewound resistor of a size comparable with a given carbon resistor may be rated to dissipate many more watts because it may be run at a much higher temperature.

A colour code is normally employed to specify the resistance of resistors dissipating 5 W or less: Fig. 1.18 shows the two variations of the colour scheme. Colours marked 1 and 2 in Fig. 1.18 represent the first two digits of the ohmic value. Colour 3 indicates the number of noughts following the first two digits.

Black	Brown	Red	Orange	Yellow	Green	Blue	Violet	Grey	White
0	1	2	3	4	5	6	7	8	9

Examples	1. Yellow	2. Violet	3. Black	= 47 Ω
	1. Blue	2. Grey	3. Yellow	= 680 kΩ

The presence or absence of a fourth colour indicates the percentage tolerance, e.g., 20 per cent tolerance means that the actual resistance lies within ± 20 per cent of the marked value. The tolerance coding is as follows:—

Brown	Red	Orange	Yellow	Gold	Silver	No marking
1%	2%	3%	4%	5%	10%	20%

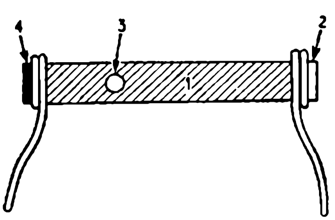
Occasionally a pink band is found on a resistor. This means that it is made of a special compound possessing a highly stable resistance (undergoing little change with variations of temperature or with ageing). To simplify manufacture, a series of 'preferred values' has been evolved, applying to the first two digits of the ohmic value, as follows:—

20% *Tolerance*
10, 15, 22, 33, 47, 68

10% *Tolerance*
As above plus 12, 18, 27, 39, 56, 82

5% *Tolerance*
As above plus 11, 13, 16, 20, 24, 30, 36, 43, 51, 62, 75, 91

Thus, when specifying a resistor whose ohmic value need not be critical, it is usual to select from the 20 per cent series. It is, however, important to appreciate that a given resistor of the 20 per



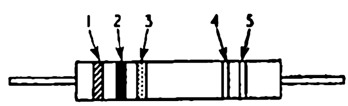


Fig. 1.18. Colour coding of resistors

cent series will not necessarily depart by as much as 20 per cent from its marked value.

1.4.2 *Attenuators*

Control of the sound or vision signal in a broadcasting network generally involves the use of a voltage or potential divider, which is called an attenuator because its action is always to reduce or attenuate the signal. The simple forms of potential dividers or attenuators mentioned earlier are used to control and fade out the vision signal in a television network, but they are less suitable for controlling the audio signal, and modified forms, known as pads (fixed attenuators) and faders (variable attenuators) have been developed.

For example, the simple fader of Fig, 1.19 has the disadvantage that the resistance across the input terminals AB is quite different from that across the output terminals CD. This does not matter

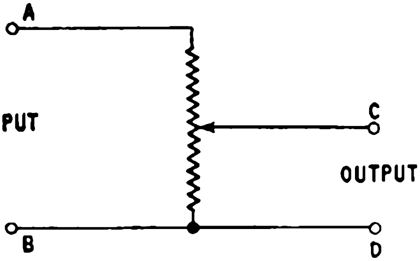


Fig. 1.19. Simple fader

if the output is connected to the grid of a valve offering a very high resistance to the potential divider but it will be important when it is connected to a low load resistance, or to a load which varies with the frequency of the input voltage. The insertion of the attenuator should not change the resistance seen by the input source or the

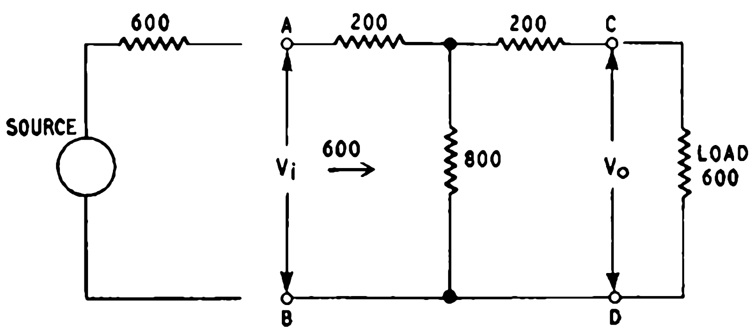


Fig. 1.20. T-type attenuator

output load, otherwise the transmission qualities of the network may be completely changed, so leading to distortion of the signal (Section 1.6.5).

In the sound chain the transmission links are designed so that the signal source and the load have resistances of 600 Ω, and an attenuator pad must present this value to source and output as shown by the example given in Fig. 1.20. A simple investigation reveals that the resistance between terminals A and B and between C and D is 600 Ω, so that the circuit conditions seen by the source and the load are unchanged by the inclusion of the pad. The voltage ratio between the terminals AB and CD can easily be calculated and will be found to be 2 : 1, or 10 volts across AB produces 5 volts across the load terminals. Another pad may be connected in front of the first one as shown in Fig. 1.21, and additional attentuation, giving an overall ratio of 2 × 2 : 1, will be obtained, again leaving the conditions seen by the source and load unchanged. The input resistance which exists across the points AB in Fig. 1.20 when an equal resistance is connected across the output terminals CD is called the *characteristic impedance* of the pad, and it may be found for any given pad by making resistance measurements on it when the output terminals are open- and short-circuited. The resistance between the input terminals AB when the output terminals are open-circuited is 1 000 Ω and is known as the open-circuit resistance (R_{oc}). The short-circuit resistance R_{sc} is the resistance between the same terminals when the output is short-circuited and this is seen to be 360 Ω. The characteristic impedance or resistance R_o is given by the simple relation

$$R_o = \sqrt{(R_{oc}R_{sc})}$$

and in this instance is 600 Ω. This is an important relation and it shows that any pad can be quickly checked to see whether it may be included between a given source and a given load.

1.4.3 *The Decibel*

It is usual to define the attenuation caused by the insertion of an attenuator pad in terms of a logarithmic unit called the decibel rather than in terms of a voltage ratio. The decibel is 1/10 the value of a Bel, which is defined as the logarithm to the base 10 of the ratio of the output power (P_o) to the input power (P_i),

$$1 \text{ Bel} = \log_{10}\frac{P_o}{P_i} \text{ when } \frac{P_o}{P_i} = 10$$

and 1 Bel = 10 decibels (10 dB) so that the attenuation in dB is

$$10 \log_{10}\frac{P_o}{P_i}$$

With the attenuator pad of Fig. 1.20, the input and output powers are measured in the same value of resistance, thus

$$\frac{P_o}{P_i} = \frac{V_o^2/600}{V_i^2/600}$$

and the attenuation of the pad may be written as

$$10 \log_{10} \frac{P_o}{P_i} = 10 \log_{10} \frac{V_o^2}{V_i^2} = 20 \log_{10} \frac{V_o}{V_i} = 20 \log_{10} \tfrac{1}{2}$$

$$= -20 \log_{10} 2 = -6 \text{ dB}$$

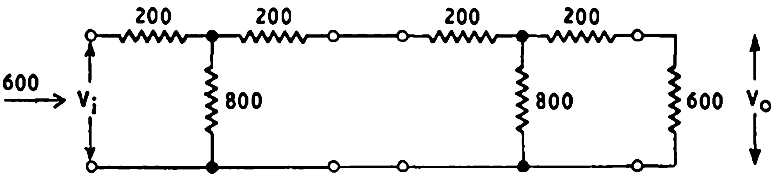


Fig. 1.21. Two T-type networks in tandem

Similarly for the double pad in Fig. 1.21, the attenuation is

$$20 \log_{10} \frac{V_o}{V_i} = 20 \log_{10} \tfrac{1}{4} = -12 \text{ dB}$$

i.e., $-6 + (-6)$ dB

It should be noted that whereas voltage ratios have to be multiplied to obtain the overall ratio, the decibel units are added.

If an amplifier is included in the circuit in place of the attenuator pad (Fig. 1.22) and it has input and output impedances of 600 Ω,

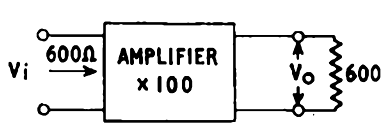


Fig. 1.22. Amplifier between matched loads

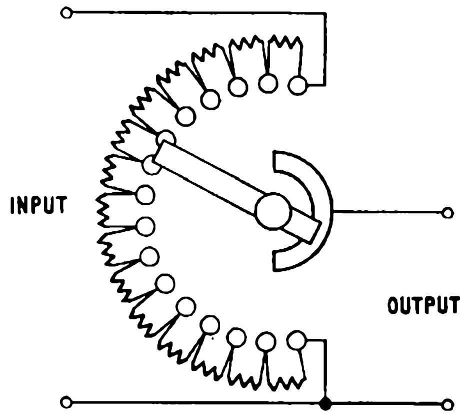
the signal voltage will be increased and the resistance seen by source and load will be unchanged. Assuming the voltage amplification of the inserted amplifier to be 100 the decibel equivalent of this will be

$$20 \log_{10} \frac{V_o}{V_i} = 20 \log_{10} 100 = +40 \text{ dB}$$

Insertion of the attenuator pad (Fig. 1.20) between either the amplifier and source or the amplifier and load reduces the over-all gain of the circuit to $+40 - 6$ dB $= 34$ dB.

Though not strictly permissible, the decibel unit is occasionally applied to voltage ratios when the resistance across which the voltages are developed are not equal. This more particularly occurs in measurements on broadcast receivers and does not so often occur in the broadcast network itself. Since the decibel represents a ratio, it cannot be said to be a unit in exactly the same sense as an inch or a foot, but it can be given greater significance by fixing a definite power level to which the ratio is referred. A power of 1 mW is designated 'zero level' or 0 dB. Thus an output power of 10 mW referred to zero level (1 mW) is written +10 dB, and conversely an output power of −10 dB would represent an output

Fig. 1.23. Stud-type fader



power of 0·1 mW. When 1 mW is absorbed in 600 Ω, there is a voltage of 0·775 volts across the resistance.

The decibel system of notation is used in designating sound intensity (equivalent to electrical power) and sound pressures (equivalent to voltage). Referring to Fig. 1.6 it is quite common to say that the difference between the threshold of hearing and the threshold of pain at 1 000 c/s is approximately 120 dB (pressure ratio of about 10^6 or an intensity ratio of 10^{12}). If the threshold of hearing is taken as the reference level (0 dB) the phon and decibel units have the same numerical values at 1 000 c/s but at other frequencies this is not so. Thus, at 1 000 c/s an intensity of 0·002 dynes/cm^2 $\equiv$ 20 phons $\equiv$ 20 dB from an audibility reference level of 0·0002 dynes/cm^2.

1.4.4 *Faders*

The simplest type of fader, such as that used to control volume in a broadcast receiver, consists of a metal arm sliding over a carbon track. Good electrical contact between a metal arm and a resistance wire or carbon track is not easy to maintain over long periods of use, and for the control of volume in the broadcasting network it is unusual to have a continuously variable contact but to make up the resistance from a large number of small sections, each of which is brought out to brass studs (Fig. 1.23). A wiper arm makes good electrical contact with the studs and satisfactory fader characteristics are maintained over long periods of use. The arm must make contact with a new stud before entirely breaking contact with the previous one, and for sound broadcasting purposes the change in output level from one stud to the next should be so gradual as to be unnoticed by the ear. Generally steps not exceeding 2 dB per stud corresponding to a voltage change of 1·26 are acceptable for control of sound volume, and it is difficult to recognise the variation in signal output produced by rotation of such a fader as anything but continuous. The type of fader shown in Fig. 1.23 is used in the vision signal circuits of a broadcasting network but is not normally used in sound signal circuits because its resistance

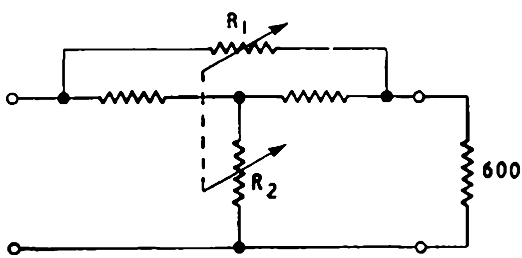


Fig. 1.24. Bridged-T variable attenuator

does not remain constant when the position of the arm is changed. It would be possible to use a T-section pad as shown in Fig. 1.20 with a number of pads connected in series as in Fig. 1.21 and this is the basis of some of the faders employed in broadcasting engineering. A somewhat simpler arrangement using a bridged T network is shown in Fig. 1.24. Providing the square root of the product $R_1 \times R_2$ is equal to 600, the resistance seen by the source and the load remains at 600 Ω. R_1 and R_2 are normally ganged together to maintain the relationship quoted above. When R_1 is large, R_2 is small and attenuation is maximum.

1.4.5 *Inductance*

A direct current flowing through a wire produces a magnetic field in the space surrounding the wire, and the magnetic field is concentrated if the wire is wound in the form of a coil or inductor. The field represents a form of stored energy, which reveals itself if the current through the coil is suddenly stopped; a large voltage then appears across the terminals of the coil and can give a violent shock to anyone holding the ends, even though the original voltage driving the current through the coil is quite low. The induction coil of a motor car is an example of this principle, for although the voltage applied to the coil is only 12, the voltage which can appear across the contact points when they open may be of the order of 250 volts. A voltage is developed in the coil whenever there is any change in the current flowing through it, because this changes the energy stored in the magnetic field. The magnitude of the voltage induced by the change of current is determined by the rate at which current is changing. This may be written as $V =$ *constant* $\times$ *the rate of change of current* $= L \times I/t$ if the current is changing at a steady rate.

L is known as the coefficient of self-induction or simply the inductance, and when the induced voltage is measured in volts and the current change in amperes per second, L is in henrys; thus a current changing at the rate of 1 ampere per second and inducing a voltage of 1 volt means that the coil in which this change occurs has an inductance of 1 henry. Current does not always change linearly with time, and a more general expression is $V = L\mathrm{d}I/\mathrm{d}t$ where $\mathrm{d}I/\mathrm{d}t$ is the calculus method of writing 'the rate of change of current with time'. A negative sign is generally included to indicate that the induced voltage is in a direction which opposes the change of current. If a battery is suddenly connected to a coil of wire possessing resistance, the current does not rise immediately to the value V/R given by Ohm's law. Time is required for the magnetic field to be established and the current rises with time as shown in Fig. 1.25 (a). The curve of exponential shape rises steeply at first and then gradually bends over, slowly approaching the value of current given by Ohm's law, namely, $I = V/R$. It never quite reaches this value, though it can approach very close to it, and in theory it would need an infinite time to reach the value $I = V/R$. If the battery is suddenly removed and replaced by a short-circuit the current does not immediately fall to zero but decreases again exponentially as the magnetic field collapses. This is indicated by the dotted curve in Fig. 1.25 (b).

Waveforms other than exponential ones are used in electrical applications and a current waveform commonly encountered in television is the 'saw-tooth'. This is the waveform of the current required in the coils surrounding the neck of a television receiver picture tube in order that the cathode-ray beam shall be appropriately deflected.

Two such saw-tooth currents are required, one to provide the horizontal deflecting magnetic field (controlled by the line synchronising pulse) and one to provide the vertical deflecting field (controlled by the field synchronising pulse). The line deflecting current must be returned quickly to its starting point so as to

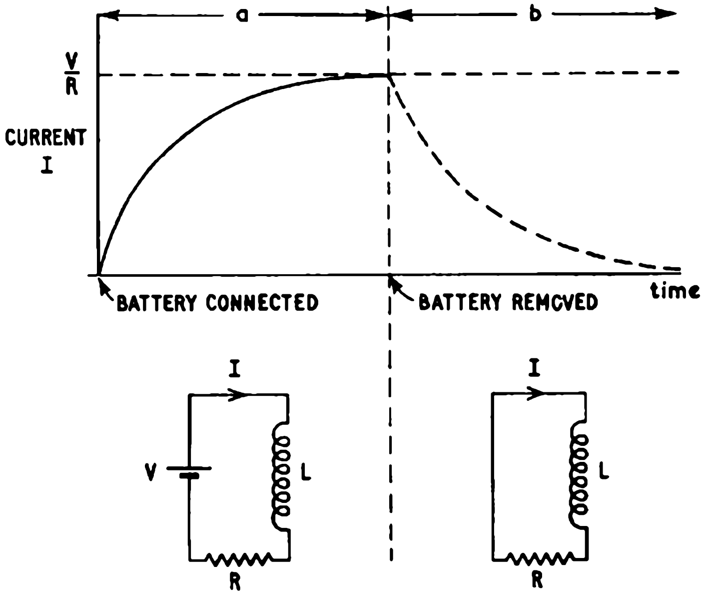


Fig. 1.25. Rise and fall of current in an inductance

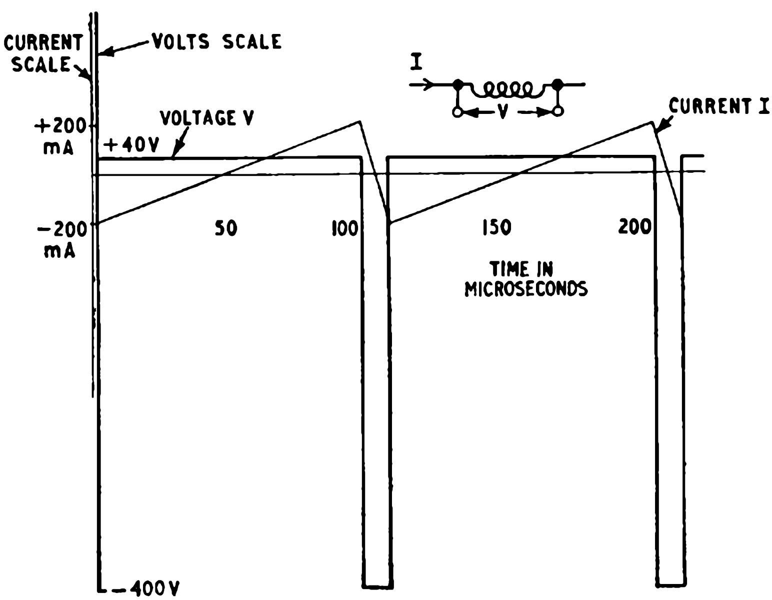


Fig. 1.26. Voltage across a coil carrying a saw-tooth current

allow the next horizontal line to be traced and the current waveshape is similar to that shown in Fig. 1.26. Since the current is varying linearly with time, the voltage waveform will be given by $V = LI/t =$ constant. The voltage waveform across the coils will therefore consist of rectangular pulses as shown in Fig. 1.26. In the television picture tube the current may be changing at the rate of 400 milliamps in 1/10 000th of a second and the inductance of the coils may be of the order of 0·01 of a henry. The induced voltage will therefore be

$$V = LI/t = \frac{0{\cdot}01 \times 400/1\,000}{1/10\,000} = 40 \text{ volts}$$

so that during the forward horizontal movement a constant voltage of 40 volts appears across the coil. During the flyback period

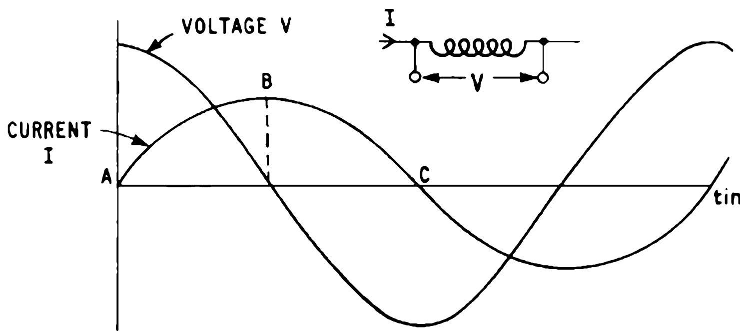


Fig. 1.27. The voltage across a coil is sinusoidal when a sinusoidal current is flowing through it

which takes place in approximately 1/10th of the time of the forward stroke the voltage induced will be ten times greater at 400 volts. The voltage will therefore go to —400 volts. If the current through a coil has a sinusoidal waveform, the induced voltage will also be sinusoidal in shape but its peaks will occur a quarter of a cycle out of phase with the current change. For example, the current at A in Fig. 1.27 is changing in a positive direction most rapidly as it passes through zero so that the voltage appearing across the terminals of the coil will be at its maximum positive value. Similarly when the current is maximum at B its rate of change is momentarily zero and the voltage across the terminals will be zero. At C the current is again changing at its maximum rate in a negative direction so that the voltage across the terminals will be at the maximum negative value. The voltage is said to lead the current by 90 degrees, i.e., by one quarter of a cycle.

If a sinusoidal voltage is applied to a resistance, the current and voltage rise together as shown in Fig. 1.28, because at every point on the cycle Ohm's law applies and the ratio of the voltage to the current is the resistance.

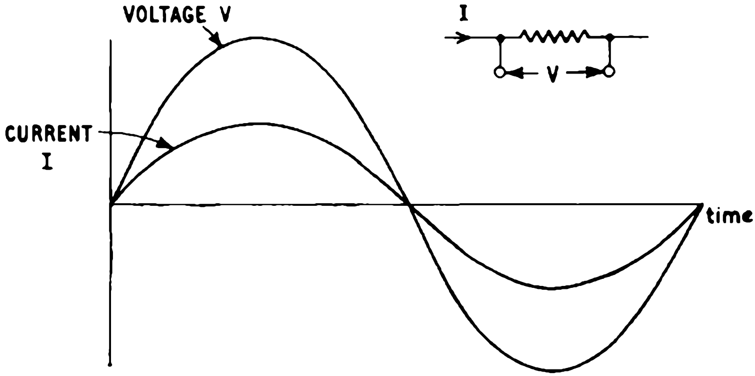


Fig. 1.28. Voltage across a resistance when a sinusoidal current is flowing through it

For the coil the ratio of the voltage at its maximum or peak value to the current at its maximum or peak value is called the inductive reactance. The voltage-current relationship in the resistance can be represented vectorially as two vectors in line with each other as shown in Fig. 1.29 (a), whereas the voltage and current for the inductive reactance are at 90 degrees to each other as shown in Fig. 1.29 (b), the voltage being in advance of, or leading the current. Inductive reactance ($2\pi fL$ often designated X_L) is directly proportional to frequency and is zero at zero frequency (d.c.). In practice, a coil always has some resistance so that the voltage appearing across it is never exactly at 90 degrees to the current but leads it by some angle less than 90 degrees as shown in Fig. 1.29 (c). The voltage has two components IR and IX_L at right angles to each other. The ratio of the peak value of voltage to the peak current is called the impedance and impedance implies the presence of resistance and reactance. Alternating voltages and currents measured by normal measuring instruments usually give the root-mean-square value which is directly proportional in a sinusoidal wave to the peak or r.m.s. $= 0{\cdot}707$ peak. Thus a mains voltage of 230 volts measured by a meter represents a r.m.s. value and the peak value of voltage is $230/0{\cdot}707 = 230\sqrt{2} \simeq 350$ volts.

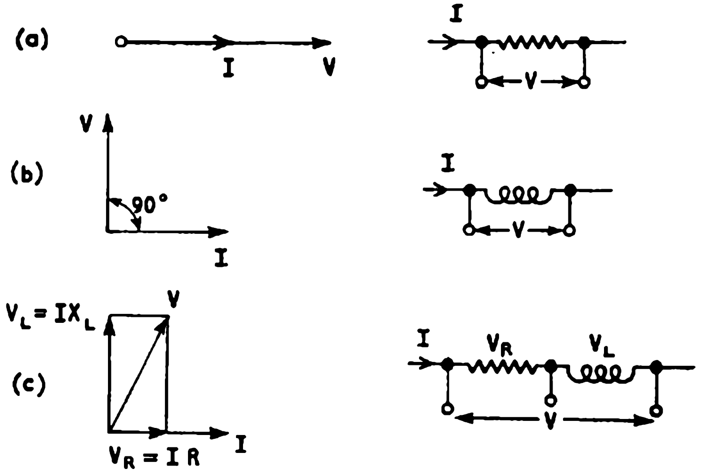


Fig. 1.29. Voltage and current vector relationships for (a) resistance, (b) inductance, (c) inductance and resistance

1.4.6 *The Transformer*

A component which is a development from the coil and is very much used in broadcasting is the transformer. It consists of two coils, one known as the primary and the other as the secondary. The two coils are coupled together so that when a current flows in the first coil a magnetic field is set up and this magnetic field threads the other coil. When the current is varying (alternating) the magnetic field does the same and this induces in the second coil an electromotive force (e.m.f.) which is directly proportional to the rate of change of the magnetic flux.

At low frequencies an iron core is used to increase the magnetic field between the two coils and under these circumstances the ratio of the primary to the secondary voltage is the ratio of the primary to the secondary turns. Thus a transformer having a ratio of primary to secondary turns of 1 : 5 and a primary voltage of 1 volt produces a secondary voltage of 5 volts. Since it steps up the voltage from primary to secondary it is known as a step-up transformer. A step-down transformer is represented by one having fewer secondary than primary turns, for example a 25 : 1 primary-to-secondary turns ratio on a step-down transformer means an output voltage of 0·04 for 1 volt input.

For operation at frequencies less than about 50 kc/s the iron core is usually made up of thin laminations of iron sheet insulated from each other. The core must be laminated because the changing magnetic flux will induce voltages in the iron itself and the currents which result cause an undesirable power loss. At much higher frequencies the circulating currents become even more troublesome and lamination is not enough; the iron core has to be divided up into very small particles or no core may be used.

Apart from it use as a voltage step-up or step-down device, the transformer may be employed for coupling balanced lines (neither side earthed) to unbalanced lines (one side earthed) and for changing a resistance (or impedance) value to some other specified value. An example of its use as a voltage step-up device occurs at a generating station where a generator output at, say, 11 000 volts may be stepped up to 275 000 volts before transmission via the grid system. In a broadcast receiving set, however, a transformer is often employed to step-down the mains voltage of 230 to about 6·3 volts for supplying power to the valve heaters. An illustration of the use of the transformer as a matching device is afforded by the transformer from the output valve of a broadcast receiver to the loudspeaker. The output valve requires a load of about 6 000 Ω and the normal speech coil is of the order of 3 Ω. A transformer will enable the speech coil load to be raised to the value which the valve requires if the turns ratio is suitably selected. The relationship between resistance and turns is simple and worth deriving.

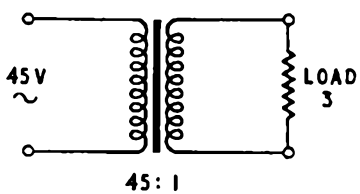


Fig. 1.30. Matching transformer

Consider the transformer shown in Fig. 1.30 with a 3-Ω resistance connected across its secondary winding. If the primary voltage is 45 volts, the secondary voltage will be 1 volt because the step-down is 45 : 1 and the power developed in the output load 3 Ω will be $V^2/R = 1/3$ watt. If the power loss in the transformer itself can be neglected (its efficiency is usually greater than 90 per cent) the power input to the primary must also be 1/3 watt. The 45-volt input is therefore required to provide 1/3 watt, which means that the input current will be $1/(3 \times 45)$. Dividing the input voltage by this gives a resistance at the primary of $45^2 \times 3$, i.e., 6 075 Ω, i.e., the resistance (or impedance) ratio is the square of the turns ratio, and the larger impedance occurs across the winding with the greater number of turns.

Transformers may also be used to connect lines balanced with respect to earth to the input of an amplifier, one side of which is earthed. Thus General Post Office (P.O.) lines used to carry sound broadcasting programmes from studio centres to transmitters are usually 'balanced' pairs with respect to earth because this confers a large measure of immunity from interference by stray magnetic

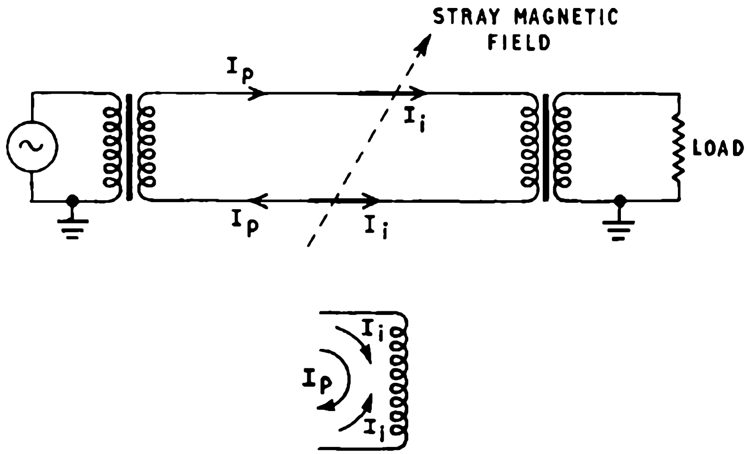


Fig. 1.31. Example of a balance/unbalance connection

fields which may link with the wires. As shown in Fig. 1.31, these fields induce interference currents I_i in the wires in the same direction and they cancel each other in a transformer with a balanced winding to earth. The programme currents I_p are in opposite directions and do not cancel in the transformer. The other winding of the transformer need not be balanced to earth but may have one side earthed as in Fig. 1.31.

1.4.7 *Capacitance*

The other important property of an electrical circuit is capacitance. Two metal plates separated from one another by an insulator which may be a solid, liquid, or gas can constitute a capacitor. If a direct voltage is connected across the metal plates, a current passes momentarily, because electrons are attracted to the positive plate and repelled from the negative and the orbital electrons in the insulator have their orbits distorted. The capacitor, like the inductor (coil), stores energy but in this case the energy is in the form of an electric field. This energy can be shown to exist by disconnecting the battery and joining the two plates by a lead, when a spark occurs. A capacitor connected to a source of direct voltage is said to acquire a charge, and the total charge, the units of which are coulombs, is given by the product of the current which flows multiplied by the time during which the current is flowing. The

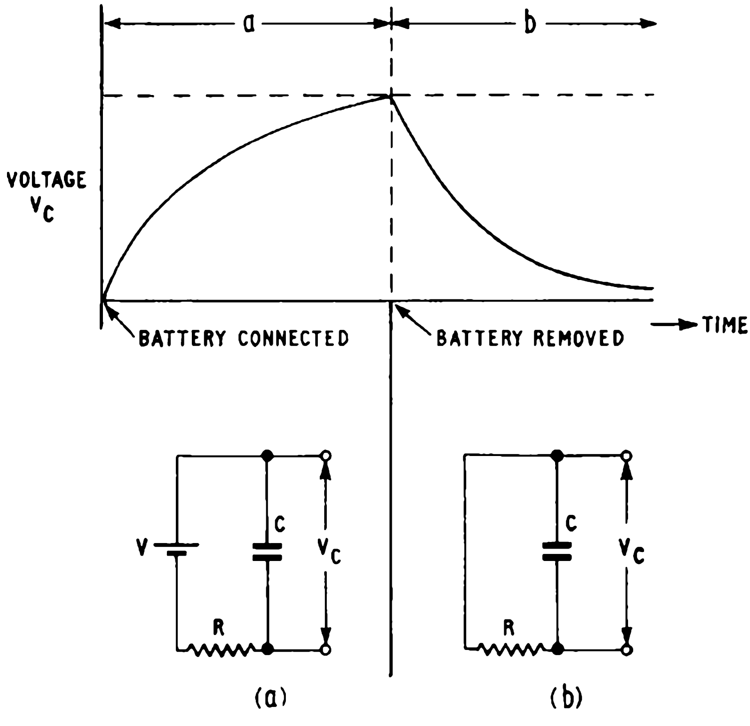


Fig. 1.32. Rise and fall of a voltage across a capacitor

charge is related to the voltage applied to the plates by the expression $Q/V = C$ or $Q = VC$ where Q is the charge received by the capacitor, V is the voltage providing the charge and C is the capacitance of the capacitor. The unit of capacitance is the farad (F) but as this unit is very large the microfarad (μF) which is one millionth of a farad and the picofarad (pF) which is one million millionth of a farad are more commonly used. 1 coulomb of charge is gained by a capacitance when 1 ampere flows into it for 1 second. If the capacitor has a capacitance of 1 farad the voltage required to produce a charge of 1 coulomb will bc 1 volt. The expression for chargc

$Q = VC$ can be made more general by writing rate of change of $Q = C \times$ *rate of change of* V or using the calculus notation $\frac{dQ}{dt} = C \times \frac{dV}{dt}$. But dQ/dt is the current so that

$$I = \frac{C \times dV}{dt}$$

which is an expression very similar to that which exists between the voltage across a coil and the rate of change of current through it, i.e., $V = L dI/dt$.

If now a voltage V be applied to a capacitance C through a resistance R the voltage across the capacitance will not rise immediately to V but will rise in an exponential manner as shown in Fig. 1.32 (a). The shape of the voltage rise is identical to the shape of the current rise in a coil (Fig. 1.25). Similarly, if the battery is replaced by a short-circuit (Fig. 1.32 (b)) the voltage across the capacitance will fall exponentially just as current did in the coil. In fact the voltage across a capacitor acts in a similar way to the current in an inductor.

Consider next a sinusoidal voltage waveform applied across a capacitance; the current waveform through it is also sinusoidal and is given by $C \times$ *the rate of change of the voltage waveform.* Thus when the voltage is at zero and rising positively at its greatest rate (point A, Fig. 1.33) current will be maximum. At its peak B where

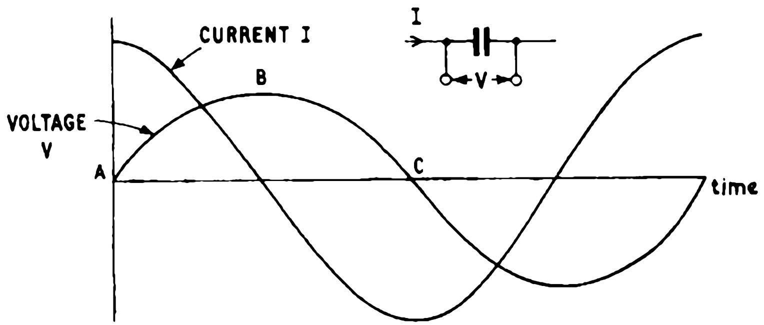


Fig. 1.33. Voltage and current waveforms for a capacitance

the voltage is momentarily not changing the current will be zero. Similarly at C where the voltage is changing at its greatest rate in a negative direction, current will be maximum and negative. The ratio of maximum voltage to maximum current is known as the *capacitive reactance*, and is equal to $1/2\pi fC$, i.e., the reactance of a capacitor decreases as the supply frequency increases. The current maximum occurs 90 degrees before the voltage maximum and this condition is represented by current and voltage vectors at 90 degrees to each other, the current leading on the voltage as in Fig. 1.34.

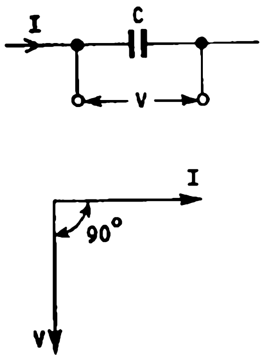


Fig. 1.34. Voltage and current vector relationships for a capacitance

1.5 CONVERSION OF SOUND AND LIGHT INTO ELECTRICAL IMPULSES

1.5.1 *Conversion of Sound Waves into Electrical Waves*

The conversion of sound waveforms into electrical waveforms involves the transfer of sound energy into electrical energy with the aid of a microphone, which may employ any one of the following principles:

(1) the variation of resistance of carbon granules when subjected to varying pressure;

(2) the voltage generated in a conductor which is made to move in a magnetic field;

(3) the voltage generated by a conductor which is made to move in an electric field; and

(4) the voltage generated by the variation in pressure on crystals of certain substances such as Rochelle Salt.

The earliest microphone invented by Alexander Bell was of the carbon granule type and it consisted of a diaphragm behind which were loosely-packed carbon granules. A battery was used to supply a current in a transverse direction through the granules and when a compression wave caused the diaphragm to press on the granules the resistance fell and the current increased. Conversely when a rarefaction caused the diaphragm to be sucked out, the pressure on the carbon granules was reduced, their resistance increased and the flow of current decreased. The output from this microphone consisted of a direct current with a superimposed alternating current having a shape corresponding approximately to the variations of the pressure in the sound wave. A transformer was used to separate the alternating component of current corresponding to the sound wave from the direct current.

Examples of the second type of microphone are the moving-coil and ribbon microphones. When a conductor moves in a magnetic

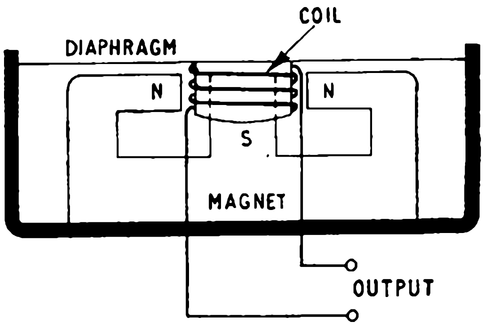


Fig. 1.35. Moving-coil microphone

field an e.m.f. is developed in the conductor and it is proportional to the velocity (u) of movement of the conductor, to its length (l) in the magnetic field, and to the magnetic flux density (B), so that the expression for voltage becomes $V = Blu$ volts where u is in metres per second, l in metres and B in webers per square metre.

The construction of a typical moving-coil microphone is shown in Fig. 1.35. The coil is attached to the centre of a diaphragm which is pushed in or pulled out by the compressions and rarefactions of the sound wave. A voltage, proportional to the movement of the centre of the diaphragm, is developed in the coil due to its motion in the surrounding magnetic field, and with careful design the waveshape of the electrical voltage produced will be an almost exact copy of the pressure wave of the sound.

The ribbon microphone (Fig. 1.36) consists of a single ribbon conductor suspended between the poles of a permanent magnet and actuated by the difference between the sound-wave pressure at the front and at the back of the ribbon. The problem with all types of microphones is to obtain an electrical output which is directly proportional to the sound-wave variations, because each microphone tends to have mechanical resonances which make the response at the various sound frequencies unequal. The moving-coil microphone has special arrangements to damp out this effect and the ribbon microphone uses a duralumin ribbon which has a resonance frequency well below the lowest sound-wave frequency.

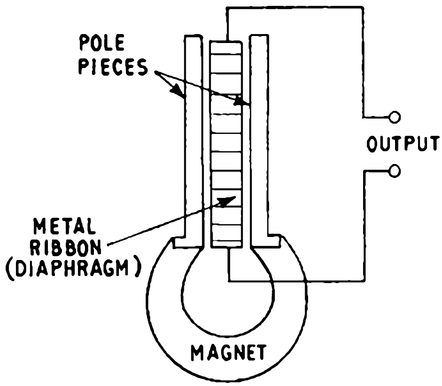


Fig. 1.36. Ribbon microphone

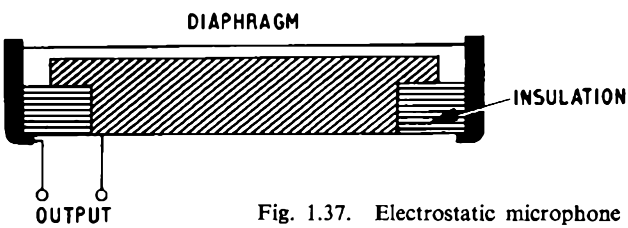


Fig. 1.37. Electrostatic microphone

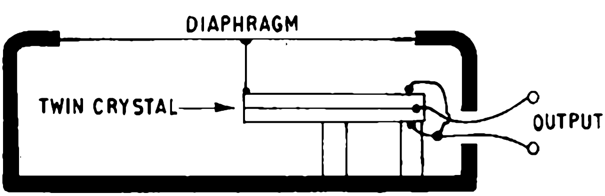


Fig. 1.38. Crystal microphone

The electrostatic microphone is an example of a microphone which depends on the movement of a conductor in an electric field. The diaphragm of the microphone is either a thin sheet of metal or is of plastic material with a conducting film and it forms one plate of a capacitor, the other plate being placed parallel to and immediately behind the diaphragm (see Fig. 1.37). A polarising positive or negative potential is applied to the diaphragm and variations in capacitance between it and the other parallel plate occur when the diaphragm is moved in and out by the sound waves. The quantity of charge Q may be considered as a constant determined by the polarising voltage so that the voltage change produced across the two plates is inversely proportional to the change in capacitance due to the movement of the diaphragm.

An illustration of the crystal microphone which depends on piezo-electric action is given in Fig. 1.38. The sound wave is used to cause a mechanical compression and extension of the crystal and this deformation causes an e.m.f. to appear across the faces of the crystal.

1.5.2 *Conversion of Variations in Light Intensity into Electrical Signals*

The problem of obtaining electrical signals corresponding to the vision content of a television programme is quite different from that involved in obtaining electrical signals corresponding to the sound content of the programme. The sound-wave pressures are directly converted into electrical waveforms whose frequencies are the same as those making up the original sound waves, and at the receiver a loudspeaker is employed to convert the electrical waves back to a sound waveform corresponding as nearly as possible with that of the sound actuating the microphone. In conveying the vision content the frequencies of the electrical signal are in no way related to the frequencies of the light emitted from the scene and the signal is merely used to control the brightness of the output of a light generator (the picture tube) contained in the vision receiver. The electrical vision signal is therefore only acting as a control signal, whose amplitude is directly proportional to the light intensity emitted from the particular part of the scene then being transmitted.

Reference has been made in Section 1.4 to the fact that when light falls on certain substances it causes electrons to be released. The term photo-electron is applied to such electrons to indicate the releasing agent, and they differ in no way from electrons released by the application of heat. A positively-charged plate (anode) placed close to the electron-emitting surface (called the photo-cathode) allows the electrons to be collected and their quantity measured. A photo-electric cell or photo-cell (Fig. 1.39) consists of an anode and a photo-cathode enclosed in an evacuated glass envelope. For certain purposes when sensitivity to light is all-important the vacuum may be replaced by rare gases at low pressure.

Variation in the light intensity on the photo-cathode causes variation in the electron emission and hence a variation in anode current. If this current is passed through a resistance, a voltage proportional to the intensity of the light falling on the cell will appear across the resistance. A single photo-cell would be useless for producing the television control signal unless special arrangements were made to present it sequentially with light from small areas of the scene.

Suppose however that a large number of photo-cells are employed and each has focused on it the light from a very small area of the

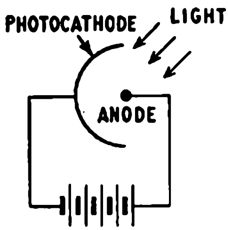


Fig. 1.39. Photo-electric cell

scene; then the output from each cell will be proportional to the average light intensity focused on it, and if these are switched sequentially there will be a series of electrical control signals whose amplitudes are proportional to the light intensities of each small area of the scene. This series of signals may be used to control the brightness of the light generator at the receiver to build up an image of the original scene. The earliest television cameras operated in this way. A mosaic of very small photo-cells was formed on a mica sheet on which was focused the image of the scene. Sequential switching was provided by an electron beam which was deflected quickly horizontally and relatively slowly vertically so as to scan the whole area of photo-cells. As the electron beam in the camera tube scanned from side to side and up and down, the camera output varied in accordance with the light intensity falling on the area under the scanning beam.

When there is considerable detail and contrast in the transmitted picture the camera output (the picture signal) varies rapidly and there may be an appreciable change of output amplitude in as short a time as one-third of a microsecond. The amplifier circuits following the camera tube must thus be able to deal satisfactorily with this rapid change which involves frequencies up to 3 Mc/s.

At the receiver the picture tube uses a similar beam of electrons and this beam is maintained in synchronism with the scanning beam in the camera tube. The density of electrons in the beam is controlled by the transmitted vision signal amplitude and when the beam strikes the fluorescent screen on the end of the picture tube a reconstituted image of the original scene will be built up. This reconstruction process is dealt with more fully in Section 1.9 and it is sufficient here to note the need for synchronising signals to keep the horizontal and vertical deflecting systems for the receiver picture tube in synchronism with those of the camera tube. Two such synchronising signals are required, one for horizontal deflection known as the *line* synchronising pulse and the other for vertical deflection known as the *field* synchronising pulse. These together with the picture signal constitute the television waveform.

1.5.3 *The Television Waveform*

In dealing with the television waveform the system used for broadcasting in the United Kingdom on Bands I and III will be considered first; this will be followed by some details of the West European 625-line system. The electron beams in both camera and receiver make one scan from top to bottom in 1/50 sec and during this time the beam is deflected from left to right a total of $202\frac{1}{2}$ times. In two vertical scans or 'fields' 405 horizontal scans or lines are accomplished and these are necessary to produce a complete picture. It can be readily shown that the $202\frac{1}{2}$ lines of the first

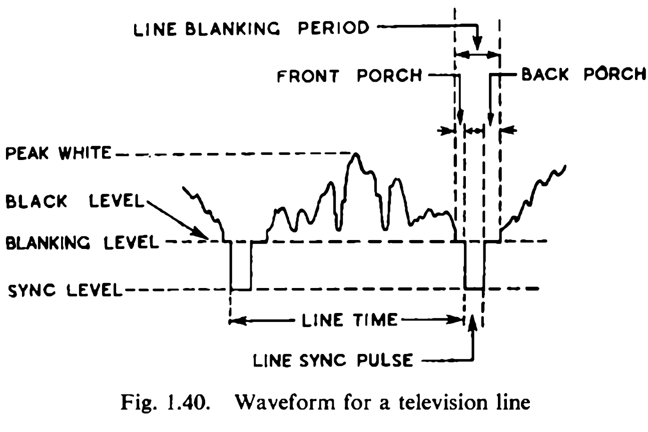


Fig. 1.40. Waveform for a television line

field are automatically interlaced with the $202\frac{1}{2}$ lines of the second field and the resultant picture suffers less from flicker than would a sequential 405-line system. Thus there are 25 complete pictures per second, 50 fields per second and $202\frac{1}{2} \times 50 = 10\,125$ lines per second. Details of a typical waveform for a single line of the British television system are given in Fig. 1.40.

The time taken for the spot on the picture tube to complete a line scan and return ready to start the next line is 1/10 125 sec or about 98 microseconds. Not all this time is available for the transmission of picture information as allowance must be made for the flyback time of the 'spot' returning from right to left. During flyback the beam must be cut off and picture information is suppressed or blanked off for 18 microseconds; during this line blanking period the line synchronising pulse is introduced. The line pulse has a duration of 9 microseconds and its purpose is to initiate line flyback and keep the line scans of the receiver in exact synchronism with those of the camera. Before the line synchronising pulse there is a short period of blanking lasting for about 2 microseconds and called *front porch*. This pause allows the picture suppression to become completely effective in the receiver circuits and prevents picture information from interfering with the leading edge of the line pulse performing the synchronising. Following the end of the line pulse, there is a further time interval during which the picture signal remains blanked out. This is known as *back porch*. It allows adequate time for flyback and is also used for maintaining correct black level in the studio and television transmitter circuits. If zero voltage is considered to be that voltage corresponding to the bottom of the synchronising pulses, *blanking level*, which is the same as black level, corresponds to 30 per cent of the total voltage reached at peak-white level. In some television systems black level is slightly higher than blanking level, the difference between the two being known as pedestal. In the BBC system pedestal is rarely used so that black level is also blanking level.

This ratio of 70 : 30 picture-to-synchronising pulse voltages has been so chosen that when noise or interference is present, unacceptable picture quality occurs at about the same time as failure of synchronisation. Fig. 1.41 (a) and (b) shows what happens at the end of a field when the picture information is suppressed for 14 lines. During this time, line synchronising pulses must be maintained and field synchronising pulses inserted. Field synchronisation is effected by a train of eight broad pulses 40 microseconds wide separated by about 10 microseconds return to blanking level. Two broad pulses occur during each line and the leading edge of every other broad pulse initiates line flyback. Because odd fields (1, 3, 5) end halfway through a line and the interlacing even fields end with a complete line the video waveforms differ for even and odd fields and this is illustrated in Figs. 1.41 (a) and (b). After the 8 field-synchronising pulses have been transmitted, field blanking continues for 10 lines interrupted only by the line synchronising pulses, and this allows ample time for the field flyback to be effected.

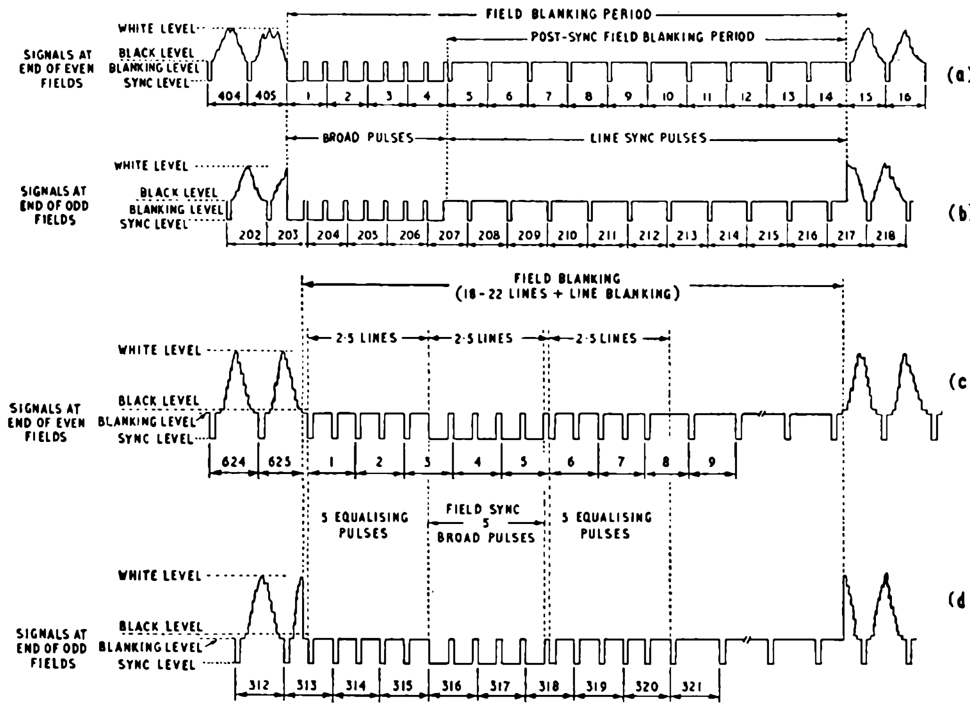


Fig. 1.41. Television waveform for odd and even fields. (a) and (b) 405 lines; (c) and (d) 625 lines

Lines are numbered as they occur so that for field 1 they number from 1 to 202½ and for field 2 from 202½ to 405.

The calculation of video bandwidth required to deal with the frequency spectrum of the British Television waveform is shown elsewhere[1] to be about 3 Mc/s.

The West European 625-line system, the waveform for which is shown in Fig. 1.41 (c) and (d), differs in a number of important aspects from the British system not least of which is the use of 625 lines instead of 405. Table 1.2 summarises some of the important parameters of each system.

TABLE 1.2

Comparison of 405- and 625-Line Television Systems

Parameters	*British*	*West European*
Number of lines	405	625
Video bandwidth (Mc/s)	3	5
Modulation	Positive	Negative
Line frequency (c/s)	10 125	15 625
Field frequency (c/s)	50	50
Picture frequency	25	25
Black level as % of peak carrier ..	30	75
Sound modulation	a.m.	f.m.
Field blanking	14 lines	25 lines
Field sync	4 lines	3 lines
Pre-equalising pulse	—	3 lines
Post-equalising pulse	—	3 lines
Line period (microseconds) ..	98·7	64
Line sync pulse (microseconds) ..	9	6
Line blanking (microseconds) ..	18	12
Active lines	377	575

Calculation of the bandwidth required by the West European 625-line system for equal horizontal and vertical definition yields about 7 Mc/s but some loss of horizontal definition is acceptable and a vision bandwidth of 5 Mc/s is usually satisfactory. The vision carrier is amplitude-modulated using negative modulation (see Section 5.4.1 and Fig. 5.26 (b)), whereas f.m. sound is employed.

The vision and sound signals are amplified together in the i.f. amplifier (there is no separation at the frequency changer as in receivers for the U.K. system) and they are only separated after detection, when the sound signal appears as a frequency-modulated transmission at a carrier frequency of 5·5 Mc/s, the difference frequency between vision and sound carriers. This system is referred to as 'inter-carrier sound'. The vision output (0–5 Mc/s) at the detector is passed to the video amplifier via a low-pass filter which removes the sound signal. The latter is applied to an amplifier-limiter tuned to 5·5 Mc/s and a frequency-to-amplitude converter.

The use of the six half-line equalising pulses before and after the field synchronising pulses (Fig. 1.41 (c) and (d)) allows the use of a simple integrator for field time base synchronisation in the receiver and prevents the derived synchronising pulse from being affected by odd or even field conditions.

1.6 AMPLIFICATION OF ELECTRICAL SIGNALS

Electrical signals may be amplified with the aid of a number of different devices but the most important are the thermionic valve and the transistor.

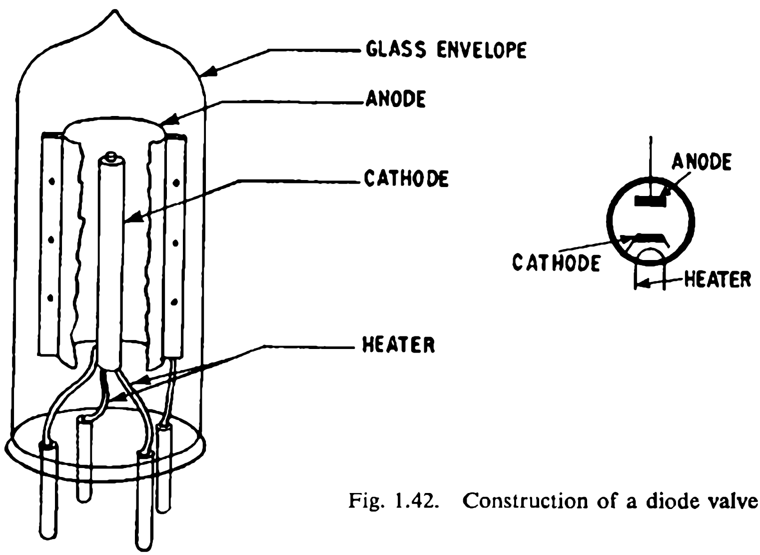


Fig. 1.42. Construction of a diode valve

1.6.1 *The Diode Valve*

The thermionic valve amplifier has developed from the diode valve which has the simplest electrode system, consisting of a heated cathode and an anode contained in an evacuated glass or metal envelope (Fig. 1.42). When the anode is made positive with respect to the cathode the electrons emitted by the heated cathode are collected and current flows through the valve. When the anode is negative with respect to the cathode electrons are repelled towards the cathode and no current can flow through the valve. This action led to the use of the word 'valve' by John Ambrose Fleming, who discovered the diode in 1904.

If an alternating voltage is applied between the anode and cathode of a diode valve, current flows during positive half-cycles only, and the valve is said to be a rectifier when it is used in this way to convert alternating current into direct current. Fig. 1.43 (a) shows a simple half-wave rectifier for providing a d.c. supply at about 250 volts from the 50 c/s mains supply. The first capacitor C_1 is known as the reservoir capacitor and may have a value from 8 to 32 microfarads. The provision of this large value of capacitance in compact form is made practicable by using the electrolytic type of capacitor. On each positive cycle C_1 is charged to B (Fig. 1.43 (b)) almost to the peak value of the applied a.c. voltage ($1{\cdot}414 \times$ the r.m.s. value) and then the diode ceases to conduct and C_1 discharges through the load until its voltage is overtaken at D on the next

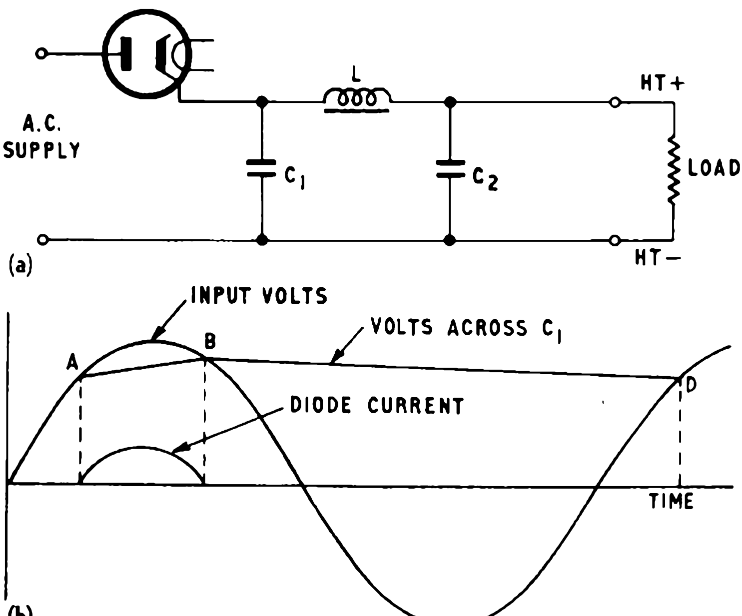


Fig. 1.43. (a) half-wave rectifier; (b) voltage waveform

positive cycle and the diode conducts again. The variation in voltage across C_1 depends on the d.c. current taken by the load; the greater this is the greater is the fall from B to D. The inductance L and capacitance C_2 act as a smoothing circuit to reduce appreciably the ripple voltage appearing across the load. The inductance has a high impedance to alternating current and a low resistance to direct current; the capacitance C_2 functions in the reverse way.

More efficient rectification and smoothing is achieved by using a double diode as shown in Fig. 1.44. The two diodes are usually

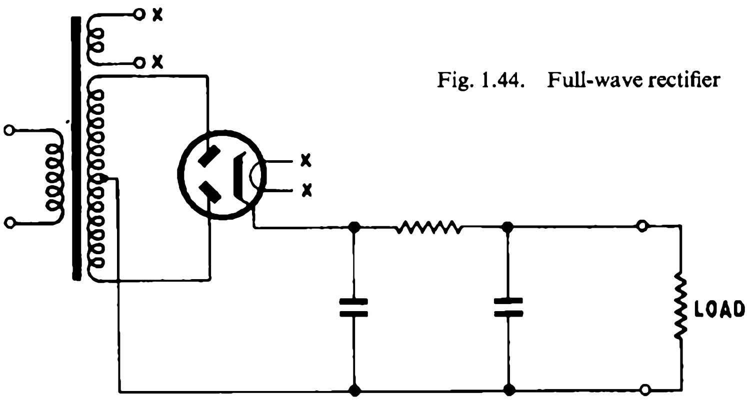


Fig. 1.44. Full-wave rectifier

enclosed in the same envelope and may share a common cathode. A mains transformer with centre-tapped secondary is required and conduction occurs during both half cycles of the input waveform, the current flow from the cathode pulsating at twice the frequency of the half-wave circuit. This circuit using the double diode is often known as a 'full-wave' rectifying circuit although in fact it consists of two half-wave rectifiers working from two supplies in antiphase. For this reason the circuit is more correctly termed a biphase half-wave rectifying circuit. For many applications the smoothing choke is replaced by a resistor as shown in Fig. 1.44. The resistor is cheaper, saves space and does not pick up hum from the mains transformer field. The d.c. output voltage variation with load current is generally greater with resistance smoothing.

The circuit shown in Fig. 1.45 with four diodes (normally metal rectifiers) connected in a bridge form is more correctly designated a full-wave rectifier. When A is positive with respect to B current flows from A through diode 2 to the load and on through diode 3 to B. When B is positive with respect to A diodes 2 and 3 are non-conducting and 1 and 4 take current which passes through the load in the same direction as when diodes 2 and 3 were conducting. The diode is essentially a non-linear device, i.e., the wave shape of its output voltage is quite different from that of the input, and it may be used for any purpose which requires non-linear operation, such as mixing, frequency changing or detecting amplitude-modulated signals (see Section 1.8.1).

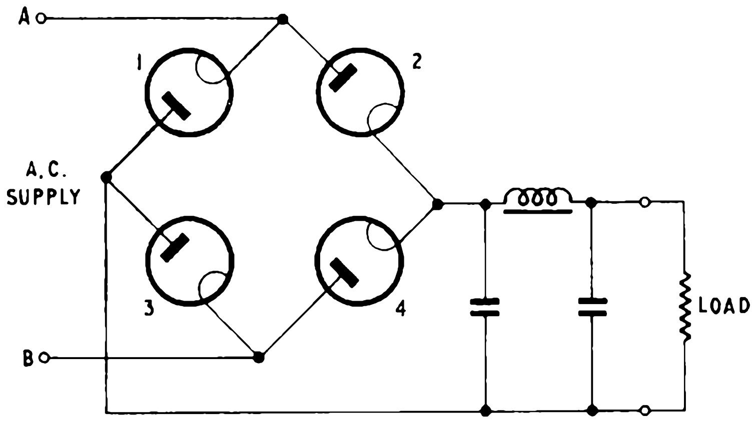


Fig. 1.45. Bridge rectifier

1.6.2 *The Triode Valve*

The triode valve was discovered by Lee de Forest in 1907. A wire mesh interposed between cathode and anode, much nearer to the cathode than to the anode, allows the electron current to be controlled by the application of a relatively small voltage to the mesh or grid. This valve is called a triode because it has three electrodes—cathode, grid and anode—and its diagrammatic representation is as shown in Fig. 1.46 (a). When used as an amplifier, a d.c. voltage positive with respect to the cathode is required between anode and cathode; an alternating voltage applied to the grid then causes an alternating current to flow through the valve. The mutual conductance (g_m) is the parameter which indicates how sensitive the valve current is to changes in voltage on the grid, and typical values for receiving valves range from about 2 to 10 milliamperes (of anode current) per volt (applied to grid). Thus an alternating grid voltage of one volt peak-to-peak which causes a variation in the anode current of 6 mA peak-to-peak indicates a g_m of 6 mA/V. Typical curves showing the relationship between grid voltage and anode current are given in Fig. 1.46 (b). As a general rule electrons should not be collected by the control grid because this means that current flows between the grid and cathode and constitutes an undesirable load on the input circuit supplying the voltage to be amplified. To prevent electron collection, a negative bias voltage is applied between grid and cathode and it must be of sufficient value to prevent the positive peaks of any applied signal from carrying the grid positive with respect to the cathode. At the same time the negative signal peaks must not take the grid so far negative that anode current is cut off.

By connecting a resistance, the anode load resistance, between the anode and its d.c. voltage source, the varying valve current causes a varying voltage to appear across this resistance, and this voltage is an amplified version of the voltage applied to the grid if the anode load resistance is large; a typical value is 20 kΩ. The output from the amplifier is taken via a capacitor or a transformer so that the d.c. voltage present at the anode is absent from the output terminals. The circuit of a simple triode amplifier for audio-frequency signals is indicated in Fig. 1.47.

The most usual method of using the triode valve is with the cathode as a common point for input and output signals as in

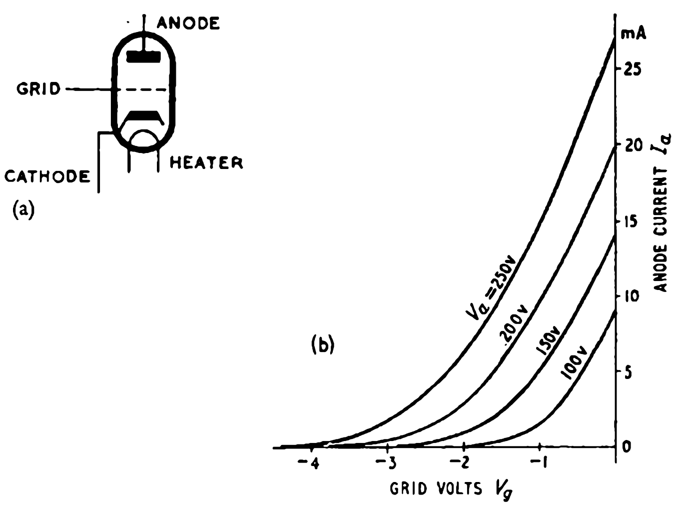


Fig. 1.46. (a) triode symbol; (b) $I_a V_g$ characteristics for a triode valve

Fig. 1.47. Two other circuit configurations are possible and each has its particular advantages for certain purposes.

One is the circuit known as the 'cathode follower' when the anode is earthed to a.c. by means of a large capacitor between anode and earth. The input signal is then connected effectively between grid and anode (earth), and the output appears between cathode and anode (Fig. 1.48). It is called a cathode follower because the output is in phase with the input, i.e., the cathode voltage follows the grid voltage in phase. The input impedance

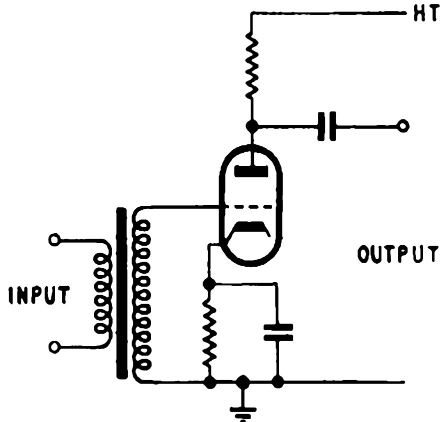


Fig. 1.47. Triode amplifier

of this circuit is very high (many megohms) and its output impedance is very low (a few hundred ohms) although its voltage gain is less than 1. It is therefore used most commonly as a matching device where a high impedance source provides power in a low impedance load, e.g., it has been used for this purpose to link an electrostatic

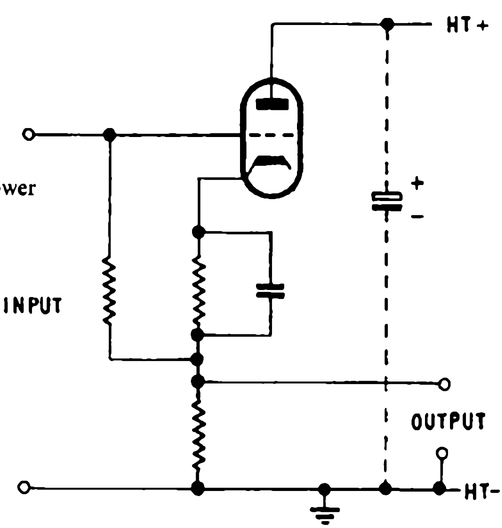


Fig. 1.48. Cathode follower

microphone to a long microphone cable which behaves as a large shunt capacitance.

The second circuit is known as the 'earthed-grid' or 'grounded-grid' amplifier and as its name implies the grid is the common terminal between input and output signals (Fig. 1.49). In this application the grid acts as a screen between input and output circuits, and very much reduces the capacitance coupling between them, thus overcoming some of the disadvantages attendant on using the triode as an amplifier of high-frequency signals. The earthed-grid amplifier gives useful amplification up to and beyond 1 000 Mc/s and introduces less noise than does the pentode because it has no screen electrode to add its own quota of random variation to the electron stream.

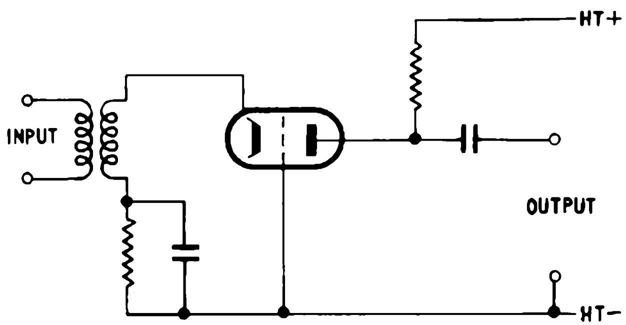


Fig. 1.49. Earthed-grid amplifier

1.6.3 *The Pentode Valve*

As mentioned above, capacitance between the grid and the anode of a triode causes undesirable coupling which makes this valve unsuitable for high-frequency amplification when used in its normal earthed- or common-cathode connection. An additional grid known as the 'screen grid' can be interposed between the signal control grid and the anode to reduce the capacitance between anode and grid. It must be given a positive voltage equal to about two thirds of the anode d.c. voltage and it is earthed to signal frequencies by a large capacitor. Such a valve is known as a 'tetrode' and with its aid high-frequency amplification can be successfully achieved. An undesirable feature of the screen grid is that it collects any secondary electrons 'knocked' out of the anode by the main electron stream whenever the anode voltage falls below that of the screen as it may well do when amplifying a signal. An additional grid (called the 'suppressor grid' and held at cathode potential—

in fact it is often internally connected to the cathode) is introduced between screen and anode to prevent the secondary electrons emitted from the anode from returning to the screen.

The pentode valve (Fig. 1.50) gives greater amplification than the earthed-grid triode and this explains why it is so much used for low-power r.f. amplification. Radio-frequency transmitter stages

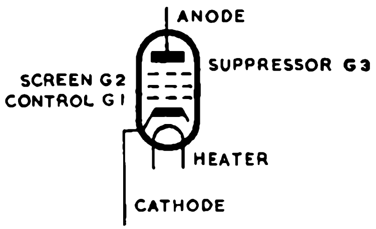


Fig. 1.50. Pentode valve

for reasons mainly connected with efficiency and cooling generally use triodes as amplifiers but a special circuit is employed to neutralise the effects of interelectrode capacitance.

1.6.4 *The Transistor*

Thermionic valves depend for their action on the control of electrons in vacuum by voltages applied to control grids. In transistors the controlled electrons exist within the crystals of the

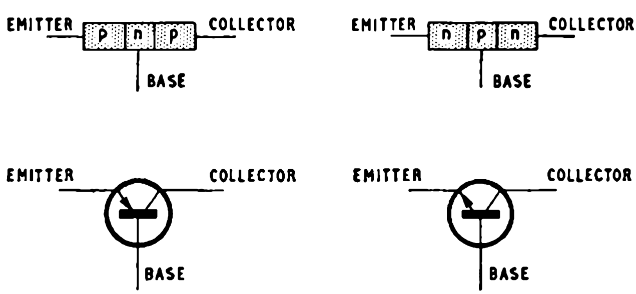


Fig. 1.51. Construction of a transistor

germanium and silicon elements from which transistors are made. Zones are created within the crystals of these substances by the introduction of minute and carefully controlled traces of other elements such as arsenic and indium. A zone doped with arsenic contains free electrons and is referred to as an n-type zone (n for negative). A zone which is doped with indium behaves as though it contained free 'positive charges' and is referred to as a p-type zone (p for positive).

A transistor generally consists of three such zones which may be p-n-p or n-p-n. In each case the first zone is called the 'emitter', the second the 'base' and the third the 'collector' (Fig. 1.51). Such a device acts in a very similar way to a triode valve, the emitter being analogous to the cathode, the base to the grid and the collector to the anode.

Thus the transistor connected in common-emitter (Fig. 1.52) behaves very similarly to the triode valve in common- or earthed-cathode. In common-base connection the situation is very similar to the earthed-grid valve amplifier and higher frequency operation is possible than with the common-emitter connection. In common-collector connection the voltage gain is less than unity but high

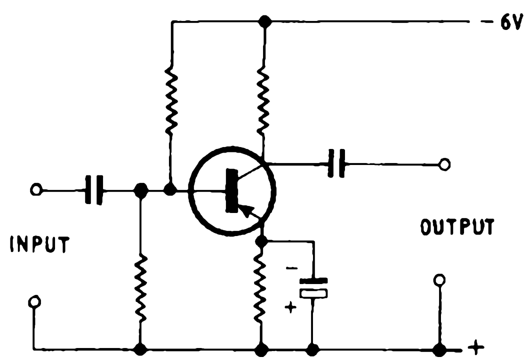


Fig. 1.52. Transistor amplifier

input and low output impedances are achieved as with the cathode-follower valve.

The input impedance of the transistor in common-emitter differs considerably from that of the triode valve and is of the order of 1 500 to 2 000 ohms. This presents difficulties of circuit design peculiar to the transistor; so does the influence which temperature has on the amplifying properties of the device, though the application of negative feedback can stabilise gain and very much reduce its dependence on temperature.

Operating voltages also differ considerably from those for the thermionic valve and are of the order of 3 to 50 volts. A transistorised receiver can operate perfectly well from a small 6-volt battery for a long period. This is principally because no heater supplies are required and efficiency is high. Since the transistor was first introduced in 1948 progress has been extremely rapid and transistor devices now exist capable of amplifying up to 1 000 Mc/s and of controlling large d.c. and a.c. powers.

1.6.5 *Distortion of the Sound Programme Signal*

Sound waves leaving the listener's loudspeaker should be exactly the same as those which are received by the studio microphone but for a number of reasons this does not happen. First there is the deliberate and necessary compression of the dynamic range of the sound carried out by the broadcasting operator. A large symphony orchestra may produce a volume variation of as much as 60 dB (10^6 to 1) between a fortissimo and pianissimo passage but the broadcasting chain can only accept a variation of about 25 dB (300 to 1) if the soft passage is not to be obscured by the inherent noise level of the system or the loud passage is to be prevented from overloading the apparatus.

There are four other types of distortion that can occur in the sound broadcasting chain and they are termed non-linearity distortion, attenuation, phase and delay distortion. The microphone itself (if large in size) can cause distortion of the sound field in which it is placed and its conversion characteristics may produce distortion. The studio equipment, lines, transmitting apparatus and the listener's own receiver, especially the loudspeaker, are all potential distorting devices.

Non-linearity Distortion. Non-linear distortion arises when the instantaneous output amplitude is not directly proportional to the instantaneous input amplitude and it produces harmonics of the frequencies making up the input wave. An incorrectly biased or overloaded valve is a common source of this type of distortion and Fig. 1.53 (a) shows the effect of overbias. The resultant output current waveshape is peaked at the top and flattened at the bottom, and in Fig. 1.53 (b) the result of adding a second harmonic wave to the fundamental wave in the right time relationship is shown to be a waveshape similar to that of the output current of the valve. Fig. 1.53 (c) shows what happens when a valve is correctly biased but overloaded; the wave is flattened at the top and bottom and can be synthesised from a third harmonic and a fundamental (Fig. 1.53 (d)). Non-linear distortion produces sum-and-difference frequencies as well as harmonics from the component input frequencies and their effect on the reproduced sound from the receiver is often far worse than that of the harmonics. Harmonic frequencies, of the form nf, where n is a whole number, generally cause a change in the quality and timbre of a note. On the other hand the sum and difference frequencies (known as intermodulation products and of the form $mf_1 \pm nf_2 \pm pf_3$) will usually be unrelated in any simple way to the component frequencies and will sound discordant and very unpleasant.

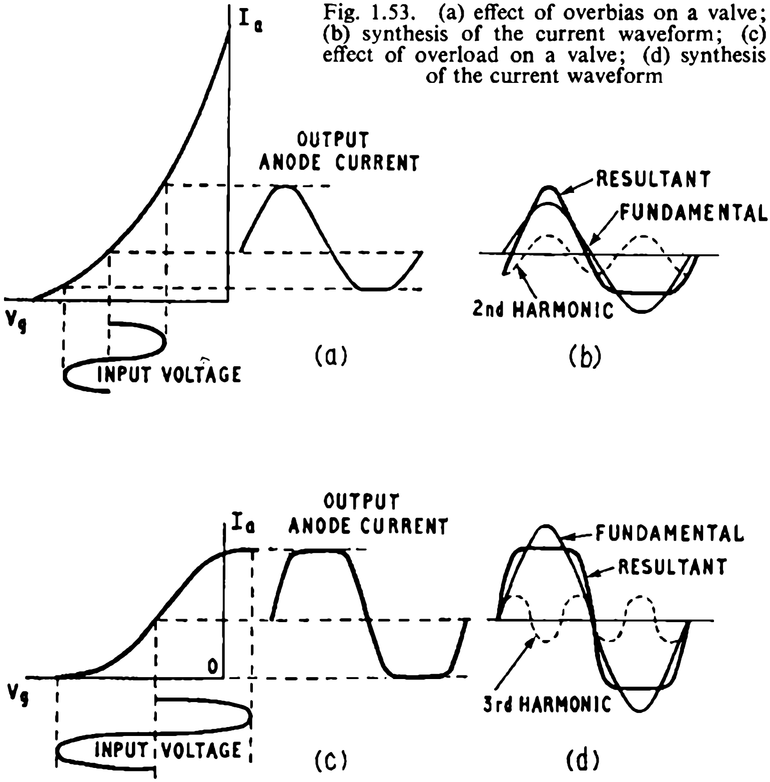


Fig. 1.53. (a) effect of overbias on a valve; (b) synthesis of the current waveform; (c) effect of overload on a valve; (d) synthesis of the current waveform

Attenuation Distortion. A complex sound from a musical instrument is shown in Section 1.2.1 to consist of a fundamental frequency and its harmonics and it is essential that the broadcasting chain should preserve their original amplitude relationship. When this is not done, attenuation distortion is said to occur because constant amplification is not maintained over the sound frequency range and some frequency components are attenuated in relation to other frequency components.

Unavoidable attenuation distortion can be corrected by including circuits, called equalisers, which have an inverse attenuation characteristic, i.e., a loss of high frequencies is corrected by a circuit which

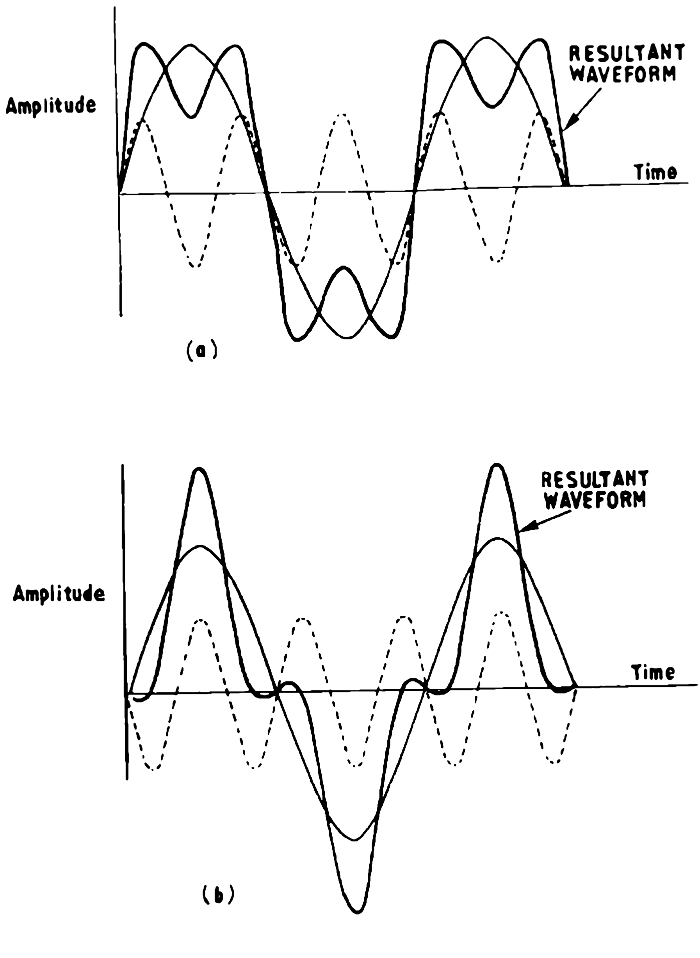


Fig. 1.54. (a) fundamental with a 3rd harmonic starting in phase; (b) fundamental with a 3rd harmonic starting out of phase

attenuates the low frequencies in such a way that the overall response is constant over the range of frequencies it is desired to transmit. Equalisation may be required at the end of a programme line linking a studio centre with a transmitter, and after a disk reproducing head or certain types of microphones.

Phase Distortion. When the component frequencies of a sound programme are passed through an amplifier in the broadcasting chain their relative phase relationships may be altered. Fig. 1.54 (b) shows the effect on the original waveshape (Fig. 1.54 (a)) of altering the phase of the third harmonic frequency by 180°. The ear is unable to recognise any audible difference between the two composite waveshapes, and this type of distortion can generally be said to have no significance in sound broadcasting. The causes of a relative phase change are reactances in the circuit, such as the primary of a transformer, which affects the low-frequency components, or stray capacitance, which affects the high-frequency components. Phase lag or lead is discussed in Sections 1.4.5 and 1.4.7.

Delay Distortion. Delay distortion is said to occur when the time taken for a wave to travel from the input to the output of a system is not the same for all its frequency components. If the time delay difference is large (several milliseconds) the effect on sound quality can be quite noticeable, particularly on transient waves. Distortion of this kind can occur on very long programme lines.

1.6.6 *Distortion of the Picture Signal**

In television, the picture signal, like the sound signal, must be kept within certain limits determined by noise and overload and the lighting supervisor and vision control operator generally aim to keep the contrast range within about 40 to 1 (Section 3.3.3.) Non-linear distortion of the picture signal can be tolerated because its main effect is to alter the contrast ratio of the whites or blacks or both. The light output of the picture tube in the receiver is not linearly related to the electrical vision signal, and it tends to crush the contrast ratio of the blacks and 'open out' the contrast ratio of the whites. The picture signal has to be predistorted to compensate; the predistortion is called gamma correction (Section 1.9.2.). Apart from the necessary gamma correction the shape of the picture waveform must be preserved throughout the system by

* In accordance with British Standard 204:1960, *picture signal* implies the signal which conveys the picture information as generated by the scanning device; *video signal* is the combined picture and synchronising signal; *vision signal* is the signal produced by the modulation of the carrier by the video signal.

having a flat frequency response (no attenuation distortion) over a range from about 20 c/s to 3 Mc/s and the relative phase shift must be zero or proportional to the frequency of the component being considered, i.e., a 10° phase shift at the fundamental frequency must become a 20° phase shift at the second harmonic. The importance of keeping phase distortion to a minimum is clearly shown by Fig. 1.54 (a) and (b). The component amplitudes are the same but the relative phase shift of the third harmonic produces an output picture signal completely different from the input. Delay distortion must also be as small as possible; it is zero when the phase shift is proportional to frequency because 10° of the fundamental component in terms of time is the same as 20° of the second harmonic because

$$\textit{time delay} = \frac{10^\circ}{360^\circ \times f} = \frac{20^\circ}{360^\circ \times 2f}$$

Delay distortion and phase distortion are in effect facets of the same type of distortion and attenuation distortion is often closely related to phase distortion. It is quite common not to separate these three types of distortion when the video signal (picture plus synchronising) is being discussed but to use an all-embracing title such as waveform distortion.

1.6.7 *Negative Feedback*

Negative feedback is employed in audio- and radio-frequency amplifiers to reduce distortion, hum and noise produced in the amplifier, and to make the gain of the amplifier less dependent on valve performance.

A portion of the output of the amplifier, the feedback fraction, is 'fed' back to the input in reverse phase so that it subtracts from the input signal. The input to the first valve of the amplifier is therefore the difference between the signal input and the feedback fraction. Thus if the amplification of the amplifier falls, the feedback is less and the input to the first valve is increased, partially offsetting the reduction in amplification.

When distortion such as the flattening of the top of the input wave is produced by the amplifier, the feedback fraction is similarly flattened and when subtracted from the input signal, produces a peaked signal between the input terminals of the amplifier, the peaked part occurring where the amplifier flattens and this tends to restore the correct waveform. Fig. 1.55 illustrates this; the difference voltage V_{CD} is in effect predistorted in the opposite sense to the distortion produced by the amplifier so that after amplification the output is much nearer the sine wave input V_{AB} than was the case without feedback. Hum or noise produced in the amplifier is also fed back to the input in reverse phase and partially cancels that in the amplifier to reduce the output of hum and noise in the same proportion as the distortion is reduced.

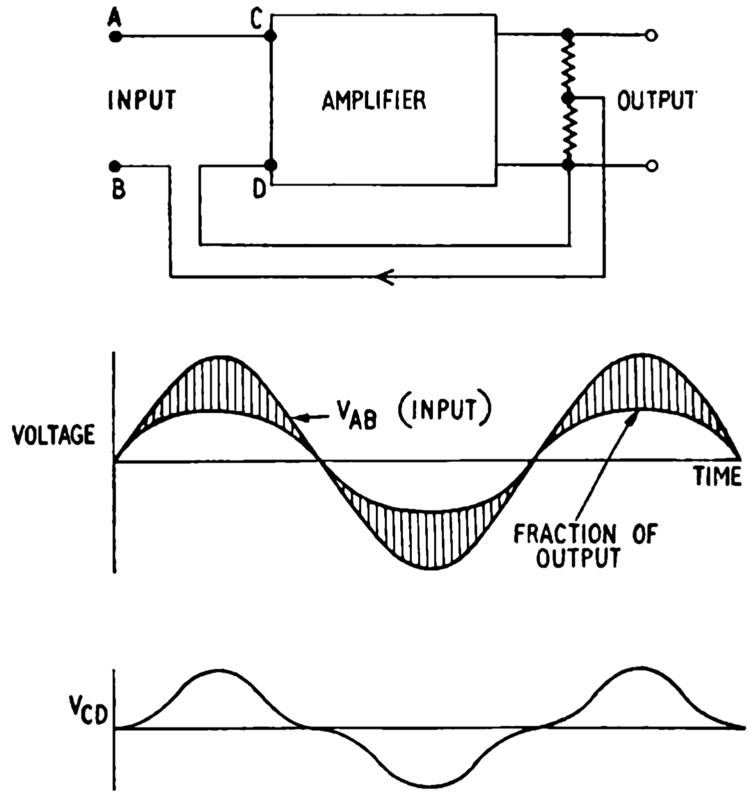


Fig. 1.55. Action of negative feedback

1.7 RADIO FREQUENCY BROADCAST TRANSMISSION

From the technical point of view broadcasting involves the sending out (transmission) of sound or vision programmes in such a manner that with suitable receiving apparatus any one programme can easily be selected and can be heard or viewed without interference from other programmes. The only satisfactory means of achieving this is by using radio-frequency carriers to transmit the programmes. The carriers use frequencies within internationally-agreed frequency ranges and at present there are four important broadcasting bands:

low-frequency from 150 kc/s to 285 kc/s, medium-frequency from 525 kc/s to 1 605 kc/s, high-frequency selected bands in the range from 6 to 26 Mc/s and very-high-frequency (v.h.f.) in which three bands are at present used for broadcasting in the United Kingdom, namely, Band I, 41–68 Mc/s (television), Band 2, 87·5 to 100 Mc/s (frequency-modulated sound), Band 3, 174 to 216 Mc/s (television).

There are three main elements in any transmitter installation, the carrier-frequency generator, the modulator and the aerial. A detailed treatment of these essential parts is given in Chapter 5 and it is only necessary at this stage to outline their functions.

1.7.1 *The Carrier-frequency Generator*

The carrier-frequency generator consists of a valve amplifier, some form of positive feedback between its output and input, and a frequency-controlling network. An example of a simple triode oscillator, which will produce a radio-frequency voltage, is shown in Fig. 1.56. The frequency-controlling network is L and C in the anode circuit, and positive feedback of energy into the grid circuit is provided by the coil L_1 coupled to the anode coil L. The direction of the winding L_1 should be such that a positive voltage is developed at G by increasing anode current in the tuned circuit.

The CR circuit in the grid provides grid-bias voltage which becomes more negative when the oscillation amplitude increases and vice

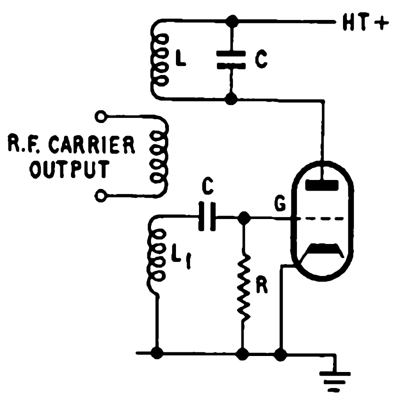
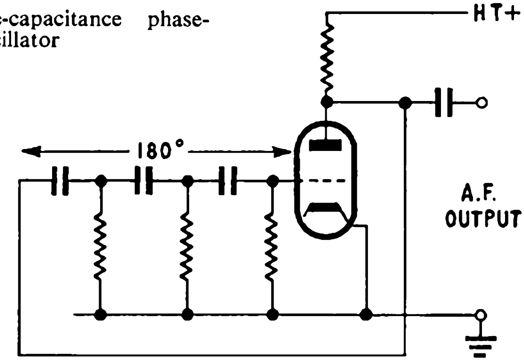


Fig. 1.56. Triode oscillator

versa. It therefore tends to maintain the level of oscillation constant. The degree of coupling between L and L_1 is a determining factor in the oscillation amplitude; generally the greater this is the greater is the amplitude. If the coupling is not tight enough the voltage fed back will not be sufficient for the valve to make up the resistance losses in the tuned circuit, and oscillation will not be built up.

There are other tuned-circuit possibilities, e.g., L and C may be placed in the grid and L_1 in the anode. The tuned-circuit oscillator is used as the source of carrier frequency in high-frequency transmitters which have to make planned carrier-frequency changes. The quartz crystal is generally used as the frequency-controlling

Fig. 1.57. Resistance-capacitance phase-shift oscillator



device in fixed carrier-frequency transmitters on low-, medium- and very-high-frequency ranges because its frequency is very stable, a stability of 1 part in 10^7 c/s being easily maintained over long periods. The carrier-frequency generator is always followed by a series of r.f. amplifying stages which bring the carrier amplitude up to the value (usually from 5 to 10 kV) required for high-power broadcasting.

In v.h.f. transmitters the carrier-frequency generator almost always operates at a much lower frequency than is finally required. Its output is then applied to non-linear r.f. stages which have circuits tuned to harmonics of the carrier frequency. A sufficient number of multiplier stages is connected in cascade to provide the final carrier frequency. Suppose that a final frequency of 90 Mc/s is desired; the initial carrier frequency might very well be at 5 Mc/s and followed by 3 multiplier stages ($3 \times 3 \times 2$) giving a total multiplication of 18. After multiplication the final carrier is amplified to its required value.

It is interesting to note that oscillators can be produced with RC networks as their frequency-controlling device. An example of an oscillator generating audio frequency is given in Fig. 1.57. It is known as the 'phase-shift oscillator' for at its oscillation frequency there is a phase shift of 180° between its anode output voltage and the grid input voltage. This gives the desired increasing positive voltage at the grid with increasing anode current. The phase-shift oscillator is never used as a carrier-frequency generator but it is employed as a source of audio frequencies in testing sound broadcasting apparatus.

1.7.2 *Modulation of a Transmitter*

A carrier frequency possesses two fundamental characteristics which may be controlled by the sound or vision programmes.

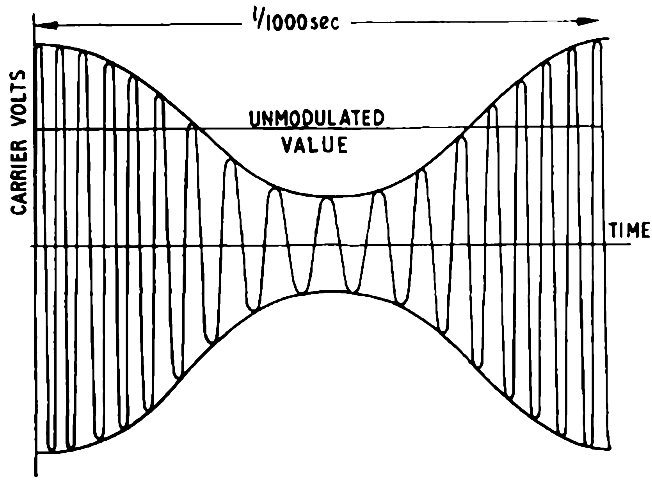


Fig. 1.58. Amplitude-modulated carrier wave

These characteristics are amplitude and wavelength, and either is capable of being modulated, i.e., varied. Consider first amplitude modulation and assume that the modulating signal is the simplest, a 1 000-c/s sinusoidal voltage.

Amplitude Modulation. When a r.f. carrier amplitude is modulated by 1 000-c/s tone, its amplitude is made to vary above and below the unmodulated value in 1/1 000 second, and this results in an envelope variation similar in shape to the amplitude of the modulating frequency (Fig. 1.58). The carrier amplitude variation must of course be directly proportional to the modulating amplitude, and this means that the modulating signal must be amplified up to a maximum value of the order of the final carrier amplitude, i.e., from 5 to 10 kV. The final a.f. amplifier stage dealing with the modulating signal will therefore be comparable with that of the carrier-modulated amplifier.

Before modulation the transmitter sends out one radio frequency only, i.e., the carrier frequency (f_c c/s) but when modulated by 1 000-c/s tone, an additional frequency appears on either side of the carrier frequency and spaced from it by 1 000 c/s, i.e., at $(f_c + f_m)$ and $(f_c - f_m)$ c/s where f_m is the modulating frequency. When a sound programme is being transmitted, each component frequency produces two side frequencies, and to transmit the full range of audio frequencies requires a frequency band of twice the maximum audio frequency. Thus if 10 kc/s is regarded as the highest wanted audio frequency the transmitted signal will require a frequency band of 20 kc/s. The internationally-agreed medium-frequency range provides an available frequency band of approximately 1 000 kc/s so that if every transmitter is to be provided with its own band no more than 1 000/20 = 50 can be accommodated. In fact about 10 times that number are trying to use the medium-frequency band in Europe, and though attempts are made to place far apart those transmitters whose carrier frequencies are almost equal, it is perhaps not surprising that reception is chaotic after nightfall when ionospheric conditions favour the long distance transmission of rays sent out at an angle to the ground.

Modulation of a sound transmitter is normally achieved by using the output from the final a.f. amplifier effectively to vary the h.t. supply to the final carrier-frequency amplifier. This is done by inserting the secondary of the a.f. output transformer between the h.t. and the h.t. end of the carrier frequency-tuned circuit. With a vision transmitter the vision signal is used to vary the grid bias of the carrier amplifier stage. This reduces appreciably the modulation power required and non-linearity of the $I_a V_g$ characteristic of the carrier amplifier valve can be taken into account by predistorting the vision signal. (Section 5.4.6.)

Frequency Modulation. The other carrier characteristic capable of being varied is wavelength, i.e., frequency, and an example of frequency modulation of a v.h.f. 90 Mc/s carrier by a 1 000-c/s note of two different amplitudes is shown in Fig. 1.59 (a) and (b). The carrier frequency varies above and below its unmodulated value, 90 Mc/s, by an amount which is directly proportional to the modulation amplitude. The frequency variation of the carrier is known as the deviation frequency, signified by f_d, and its internationally-agreed maximum value is ± 75 kc/s. In Fig. 1.59 (b) it is assumed that the maximum 1 000-c/s modulating voltage is applied so deviating the carrier by ± 75 kc/s. When the modulating voltage is reduced to 1/10 of this value the deviation frequency falls to $\pm 7 \cdot 5$ kc/s. The rate at which the carrier frequency is deviated is determined by the modulation frequency as shown in Fig. 1.59 (a) and (b). Frequency modulation produces more than one pair of side frequencies for every modulation frequency, and the band taken up by a f.m. transmission is approximately twice the sum of the maximum modulation and deviation frequencies. Thus if it is assumed that maximum $f_m = 10$ kc/s and $f_d = 75$ kc/s, the frequency band required is approximately $2(85) = 170$ kc/s. This type of modulation is used for the BBC v.h.f. broadcasting of sound programmes and also on radio links for the vision signal.

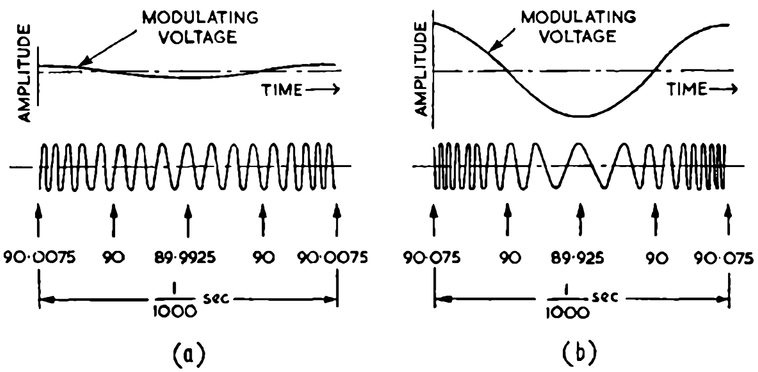


Fig. 1.59. Frequency-modulated carrier wave: (a) 10% of maximum modulation; (b) maximum modulation

The chief advantage of frequency-modulated transmission is that noise and electrical interference can be very much reduced at the receiver in comparison with an amplitude-modulated transmission. Noise and interference mainly cause an amplitude change and it is very difficult to discriminate against it when an a.m. signal is being received. In a f.m. receiver it is possible to do so because the modulation produces no amplitude change; by including in a f.m. receiver a limiter stage (an amplifier which squares the signal waveshape and allows only a constant amplitude signal to appear at its output) it is possible to eliminate nearly completely the noise without in any way affecting the programme content of the signal.

Modulation of the frequency of a carrier is effected by varying the L or C of its tuned oscillatory circuit. A simple and easy way of achieving this would be to use an electrostatic microphone in parallel with the tuned circuit. Sound pressure variations of the diaphragm cause a change in capacitance which is directly proportional to the pressure change. Such a scheme would be impracticable in broadcasting because the microphone and transmitter cannot be brought sufficiently close together. In fact the voltage produced from the microphone is used to control the gain of a valve placed across the oscillator tuned circuit and so connected that it acts as a variable inductance or capacitance. The valve is termed a variable-reactance valve (Section 5.3.3).

Since modulation of frequency involves no amplitude change, the modulating device requires very little power to operate it. There is no need for a high-power a.f. amplifier so that the space occupied by the transmitter installation and the cost of the equipment are very much reduced. Furthermore the initial carrier may be modulated before being multiplied up to its final value. Multiplication of the carrier also multiplies the deviation frequency in the same proportion and the effective modulation content is increased at the same time, e.g.,

$$18(5\ \text{Mc/s} \pm 4{\cdot}166\ \text{kc/s}) = 90\ \text{Mc/s} \pm 75\ \text{kc/s}.$$

Multiplication of an a.m. carrier is not possible because it would cause distortion of the modulation envelope; distortion of amplitude is of no consequence with a frequency-modulated carrier.

1.7.3 *The Transmitting Aerial*

To provide a broadcasting service the power developed in the last stage of the transmitter must be transferred to an aerial capable of sending out radio-frequency waves into space. The aerial may take almost any form; thus there is the T-shaped system for low frequencies, the vertical omnidirectional mast radiator for medium frequencies, the horizontal directional system for high frequencies, and the array of stacked dipoles or the tubular slotted aerial at the top of a high mast for vision and f.m. sound in the v.h.f. range. Coupling between the transmitter and aerial must give maximum power transfer to the aerial and for local broadcasting the aerial should send out maximum energy horizontally and generally in all horizontal directions equally. For overseas high-frequency broadcasting use is made of the ionosphere, and maximum energy is projected upwards at an angle of about 10° to the ground in the direction of the region for which the programme is intended. Section 5.5 gives details of the various types of aerial used for broadcast transmission purposes.

Before leaving the subject of aerials the meaning of the terms vertically and horizontally polarised as applied to radio waves must be explained. There are two components to a radiated carrier wave, namely, electric and magnetic, and they operate in planes at right angles to each other. The reference plane is always that of the electric field, and in a vertically-polarised wave the plane of the electric field is vertical and that of the magnetic field horizontal. Such a field pattern is produced from a vertical straight wire

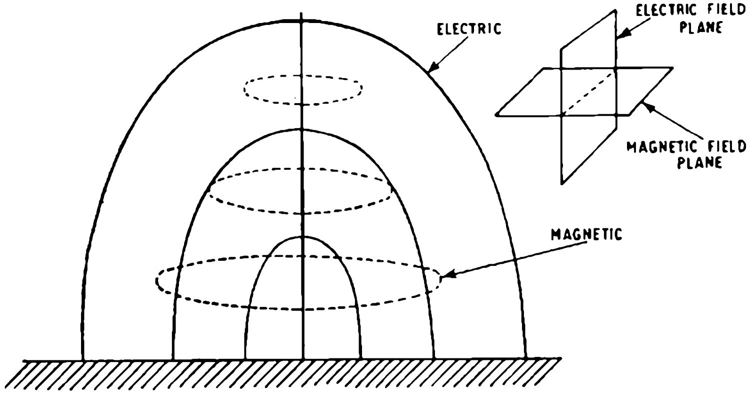


Fig. 1.60. Electric and magnetic field for a vertical aerial

or mast transmitting aerial, and medium-frequency transmissions are normally vertically polarised. The two fields produced by a vertical aerial are shown in Fig. 1.60. The electric field (full lines) except at the surface of the aerial is represented by straight lines at right angles to the ground and the magnetic field is represented by concentric circles round the aerial. In a horizontally-polarised wave the plane of the electric field is horizontal and that of the magnetic field vertical. This type of field pattern is obtained from a horizontal wire aerial and the BBC's high-frequency broadcast transmissions are provided in this way. The BBC f.m. transmissions in the v.h.f. band are also horizontally-polarised and for the high-power transmitters are obtained from a vertical-slot-aerial system.

1.8 THE RECEPTION AND REPRODUCTION OF SOUND PROGRAMMES

The reception and reproduction of a sound programme involve a process which is the exact reverse of that of broadcast transmission. The modulated carrier is picked up on an aerial and is amplified and applied to a detector, which reverses the modulation process and extracts the audio-frequency signal. The detector is followed by an a.f. amplifier whose output is supplied to a loudspeaker which reverses the microphone process and converts the electrical audio-frequency signals into sound waves.

1.8.1 *Receiver for a.m. Transmissions*

A generalised schematic of a receiver for a.m. reception is given in Fig. 1.61. The type of aerial used depends on the frequency-range which is being selected. For low and medium frequencies a vertical wire erected on the roof and connected by a shielded lead-in cable to the receiver will give the best signal-to-noise ratio, but in areas of very high field-strength the programme will be receivable when only a short length of wire is connected to the aerial terminal of the receiver; noise and interference will however tend to be troublesome. Most high-frequency transmitting aerials are placed horizontally so that in theory the receiving aerial should be horizontal. During the passage of the wave through the ionosphere its plane is usually twisted and the vertical aerial used for low and medium frequencies will probably give an adequate signal.

When a receiver is a link in an important high-frequency communication, chain 'diversity reception' may be employed. This means that several aerials of special design are used at separate sites and their outputs are so combined that whichever aerial is providing the greatest signal voltage takes over and suppresses the outputs from the others. The r.f. amplifier stage following the aerial is essential for communication receivers because it improves

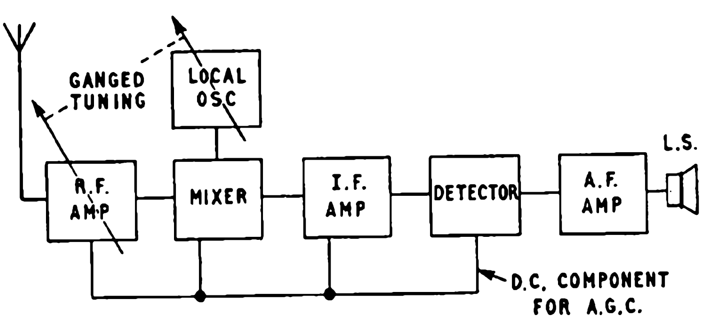


Fig. 1.61. Schematic diagram of a receiver for amplitude modulation

signal-to-noise ratio on weak signals; it is rare to find it incorporated in receivers for broadcast reception and the first stage is the mixer or frequency changer which, with the aid of a local oscillator, changes the selected incoming carrier frequency to a frequency known as the 'intermediate frequency' (about 465 kc/s). The principle by which an incoming modulated carrier is converted to a fixed intermediate frequency carrier with the same modulation is known as the 'superheterodyne' principle. Further amplification occurs in the i.f. amplifier and finally the modulated i.f. signal is applied to a diode detector which, when the carrier is unmodulated, functions in an exactly similar way to the half-wave rectifier described in Section

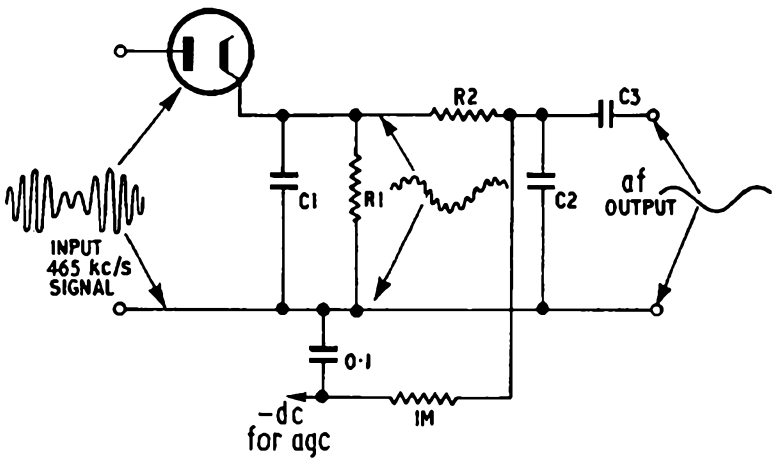


Fig. 1.62. Detector circuit for amplitude-modulated signals

1.6.1, i.e., it produces a d.c. output voltage almost equal to the peak value of the carrier. When the carrier is modulated its amplitude varies up and down and the d.c. voltage follows it, provided the time constant (R_1C_1) of the load circuit (Fig. 1.62) is short enough to allow the output voltage to fall from one i.f. carrier peak to a value less than the succeeding i.f. peak. This means that every i.f. wave must take the diode into conduction, and the output voltage will consist of a d.c. voltage, an a.f. voltage (practically equal to the i.f. carrier envelope voltage) with a superimposed i.f. ripple voltage. The i.f. ripple can be removed by the simple R_2C_2 filter and the d.c. can be stopped by the coupling capacitor C_3 to the a.f. amplifier. Typical values for the components are $C_1 = C_2 = 100$ pF, $C_3 = 0{\cdot}01$ μF, $R_1 = 250$ kΩ, $R_2 = 100$ kΩ. Since the diode detector produces a d.c. voltage proportional to the i.f. carrier voltage, it will be clear that a negative voltage similarly derived could be used to bias the r.f., mixer and i.f. stages to reduce their gain and reduce the output voltage increase for a given input voltage increase. The required negative voltage can be obtained by reversing the diode connections in

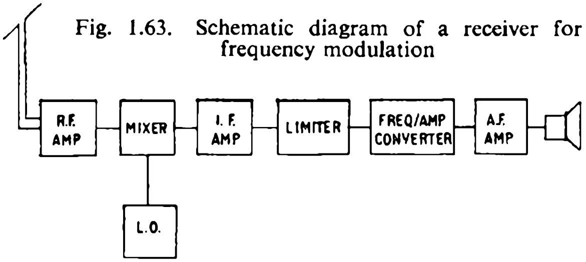
Fig. 1.62. This system of partially stabilising output voltage is known as automatic gain control (a.g.c.) and it is a great help in combating fading and preventing overload when tuning from a weak to a strong transmission. An a.f. amplifier (RC-coupled) and an a.f. output valve with transformer-coupling to the speech coil of the loudspeaker normally follow the diode detector. Before discussing the features of the loudspeaker the features of the f.m. receiver will be outlined.

1.8.2 *Receiver for f.m. Transmissions*

Carrier frequencies using frequency modulation for conveying the sound programme operate in the v.h.f. range and this fact modifies the design of the aerial and r.f. stage. In addition the f.m. receiver requires two other features (Fig. 1.63), namely, a limiter stage to remove any amplitude modulation caused by noise and interference, and a frequency-to-amplitude converter to change the modulation content back to an amplitude variation.

The dipole aerial, consisting of two wires one-quarter of a wavelength long ($\frac{1}{4}\ \lambda$), is normally used in the reception of v.h.f. transmissions and it may be given a directional pick-up by including a reflector, a single wire slightly greater than $\frac{1}{2}\ \lambda$ behind the aerial (away from the transmitter), and a director (less than $\frac{1}{2}\ \lambda$ long) in front. The plane of the v.h.f. transmission is horizontal so that the receiving aerial must be horizontal. For v.h.f. reception a r.f. amplifier stage is essential between the aerial and mixer in order that good signal-to-noise ratio may be maintained even for weak signals (from 50 to 100 microvolts). It is also of considerable value

Fig. 1.63. Schematic diagram of a receiver for frequency modulation



in preventing break-through of the local oscillator output into the aerial, from which it might be transmitted to cause local interference.

The mixer, local oscillator and i.f. amplifier are similar to those for an a.m. transmission except that a much wider pass-band (about 180 kc/s) is required and the intermediate frequency is much higher at 10·7 Mc/s. The amplitude-limiter is in effect a signal-

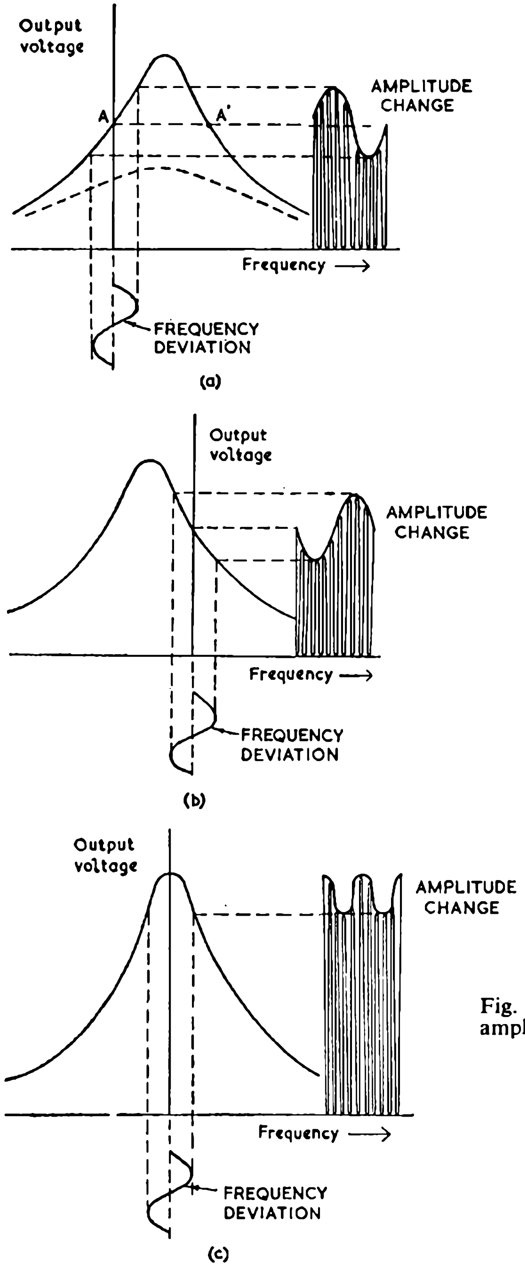


Fig. 1.64. Frequency-to-amplitude conversion using an off-tuned circuit

squaring stage which removes all amplitude modulation due to noise and interference. The valve has a short grid base, takes grid current and has a saturated anode-current characteristic. The frequency-modulated signal must be converted to an amplitude-modulated signal before it can be detected and this is achieved by using an off-tuned circuit (or its equivalent) with the f.m. carrier placed on the side of its selectivity curve where the amplitude of the voltage developed across the tuned circuit is proportional to frequency. The f.m. wave is thus given an amplitude modulation which is proportional to the frequency deviation of the carrier as shown in Fig. 1.64. The combined frequency- and amplitude-modulated wave is applied to a diode detector which extracts the audio-frequency amplitude variation and ignores the frequency variation. Either side of the selectivity curve may be used, the change from one side to the other effecting a 180° phase change in the envelope. Normal practice is to use two oppositely tuned circuits (or their equivalent) producing two amplitude-modulated outputs whose envelopes are 180° out of phase. Each is detected by a diode and the outputs from the diodes are connected in push-pull so that they add to give an a.f. output twice that from one diode. The phase-discriminator frequency-to-amplitude converter uses this principle though the two-tuned-circuit effect is achieved by special connections between two coupled tuned circuits. A more popular type of frequency-to-amplitude converter, the 'ratio detector', does not connect the diodes in this way because they are used as variable damping devices (as well as detectors) to secure a measure of limiting action. The stages from the detector onwards are identical with those for an a.m. receiver.

1.8.3 *The Loudspeaker*

The aim of the broadcasting engineer and technician is to produce a carrier-wave modulation content which in waveshape is a faithful copy of the original sound wave being picked up by the microphone, and the designer of broadcast receivers must share this aim within the limits set by economic considerations. The most important link in the complete chain is the loudspeaker, and as its conversion process is the reverse of that performed by the microphone, it would appear that there could be as many types of loudspeaker movement as there are of microphones. In fact only the moving-coil loudspeaker has been fully exploited commercially though the electrostatic loudspeaker, which operates like an electrostatic microphone in reverse, shows signs of becoming a competitor.

The moving-coil loudspeaker consists of a specially-shaped permanent magnet with pole pieces producing a strong magnetic field across an annular gap in which the speech coil is located as shown in Fig. 1.65. The coil is free to move in the annular gap and is secured to the base of a paper or metal cone. Audio-frequency currents in the speech coil cause it to move backwards and forwards in the gap and this movement is transmitted to the air by the cone.

The electrostatic loudspeaker consists of two perforated metal plates with a third plate midway between them. This third plate

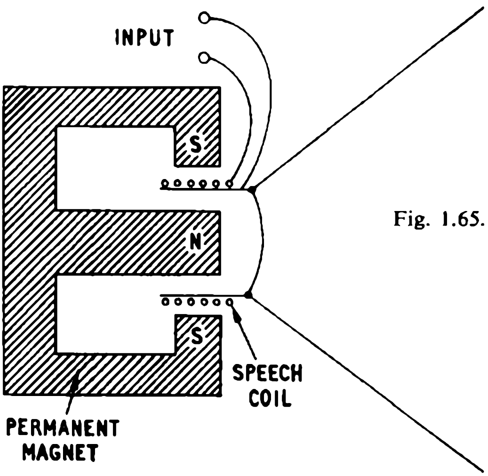


Fig. 1.65. Moving-coil loudspeaker

is usually a thin plastic sheet whose surface is coated with a metallic powder to make it slightly conducting. It is connected through a high resistance to a d.c. voltage source. Application of the audio-frequency signal in the form of a push-pull voltage to the two outer plates causes the plastic diaphragm to vibrate and produce sound waves.

1.9 THE RECEPTION AND REPRODUCTION OF VISION PROGRAMMES

1.9.1 *The Television Receiver*

The superheterodyne principle is employed in television reception and a schematic diagram of the television receiver is shown in Fig. 1.66. The incoming sound and vision signal, occupying a bandwidth of about 4 Mc/s, is picked up by a dipole (plus reflector) aerial system mounted as high as possible, the signal being conveyed to the receiver by means of a coaxial feeder. There is usually one stage of r.f. amplification before the frequency-changer in whose anode circuit are two tuned circuits arranged to select and separate the vision from the sound part of the programme. Two separate i.f. amplifiers are provided: the amplifier for the a.m. sound is identical with that described in 1.8.1, and the amplifier for the vision signal at an i.f. of about 35 Mc/s only differs from the sound i.f. amplifier because it has a much greater pass-band (about 3 Mc/s). The vision i.f. amplifier usually contains rejection circuits to prevent any breakthrough from the sound programme. The vision detector is a diode but since it has to detect vision frequencies up to 3 Mc/s, the time constant of its RC load circuit must be very much less than that of the sound detector load. The load resistance is normally about 3 000 ohms and the capacitance (mainly made up of strays) about 10 picofarads.

The output from the vision detector is amplified by a video amplifier having a frequency response up to 3 Mc/s and is then connected to the grid or cathode of the picture tube. Direct coupling is generally employed between vision detector and video amplifier because the d.c. content of the vision signal should be applied to the grid of the picture tube. A limiter is generally included to prevent large-amplitude impulsive-interference spikes occurring and taking the vision signal beyond peak-white. When this happens large white defocused spots appear on the picture.

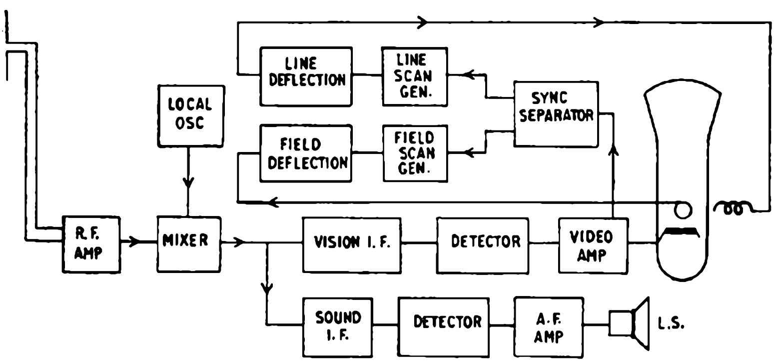


Fig. 1.66. Schematic diagram of a television receiver

The vision signal from the video amplifier is also taken to a synchronising separator stage where the synchronising signals are separated from the picture signals and from each other. The field and line synchronising signals lock the field and line-scan generators which in turn provide the input to the deflection amplifiers. The current outputs (saw-tooth in shape) from the latter are finally taken to the field and line deflecting coils which deflect the electron beam in the picture tube and allow the image to be built up on the screen.

1.9.2 *The Picture Tube*

The picture tube may employ electrostatic or magnetic focusing of the electron beam but magnetic deflection is always employed. When magnetic focusing is used the electrode structure can be quite simple and it generally consists of a heated cathode, supplying the electrons for the beam, a grid to control the number of electrons in the beam and hence its brightness at the screen, and a final anode at a voltage from 10 to 20 kV to accelerate the electrons. A form of tetrode construction with magnetic focusing is illustrated in Fig. 1.67; the deflecting coils are on the neck just below the flare and the final anode is continued almost up to the screen by a conducting coating on the inside of the tube. A permanent magnet surrounds the neck of the tube and produces an axial field inside; this brings the electron beam to a sharp spot focus at the fluorescent screen. The beam intensity is varied by variation of the voltage between grid and cathode of the picture tube. Electrostatic focusing is now more often employed and a pentode form of construction is used with two auxiliary anodes, at low d.c. voltages, before the final anode. Fig. 1.68 shows a typical beam-current/grid-voltage characteristic; since light output is proportional to beam current, it follows that the brightness-voltage characteristic will be similar. It is clear that this characteristic is not linear and the curve tends to a power law relationship of

$$\textit{Brightness} \propto I_b \propto V_g^{2\cdot 5}$$

In light terminology the system is said to possess a gamma of 2·5, and in order to approach a faithful reproduction of the original scene it would be necessary to have a gamma of 0·4 from the transmitter. This gives the following relationship between the transmitted picture voltage V_t and the brightness of the original scene

$$V_t \propto (\textit{Scene brightness})^{\frac{1}{2}}$$

so that

$$\textit{Image brightness} \propto V_g^2 \propto V_t^2[(\textit{Scene brightness})^{\frac{1}{2}}]^2 \propto \textit{Scene brightness}$$

Modern camera-tube characteristics generally have a gamma of about unity and a gamma-correcting amplifier is inserted in the vision channel before the transmitter. Control of the d.c. component of picture-tube voltage varies the average illumination of the image on the screen. When no picture is being transmitted the 'brightness' control knob on the receiver is set just to cut off the beam and prevent the normal rectangular image due to the deflecting coils being seen. The correct aspect ratio (3 vertical to 4 horizontal) of this rectangle, which should just fill the screen, is achieved by

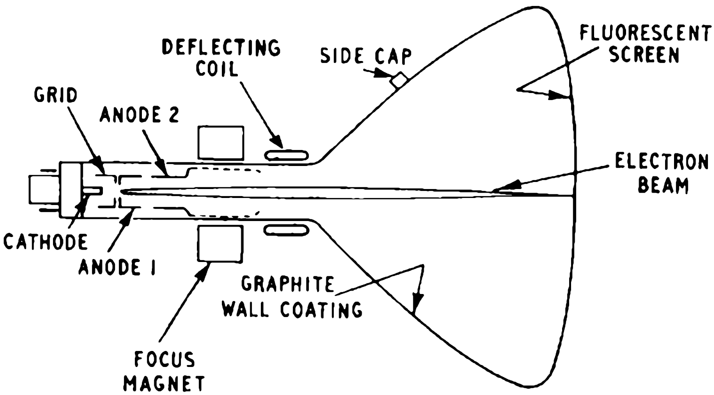


Fig. 1.67. Television picture tube

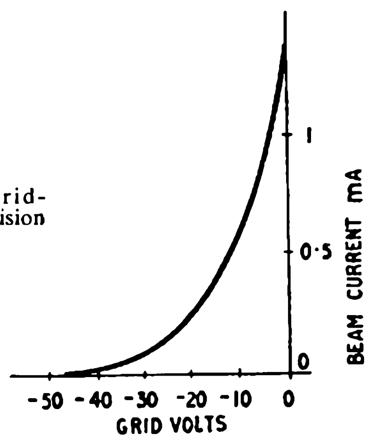


Fig. 1.68. Brightness-grid-voltage curve for a television picture tube

adjustment of the currents to the field and line deflecting coils. The a.c. component of the picture signal determines the contrast ratio of a given image and it is normally controlled in the receiver by adjusting the gain of the r.f. and i.f. amplifiers. The e.h.t. supply for the anode of the picture tube is normally obtained from the line-deflection amplifier. The rapid collapse of current on the flyback of the line scan produces high peak voltages in the windings of the line-output auto-transformer. A small diode rectifier converts these voltage pulses into a d.c. voltage, of the order of 15 kV or greater, for application to the anode of the picture tube. Failure of the line-scan generator means that no e.h.t. is generated.

REFERENCES

1. Amos, S. W. and Birkinshaw D. C., 'Television Engineering', BBC Engineering Training Manual, Vol. 1, p. 27, Iliffe Books Ltd., 1960.

CHAPTER 2

SOUND STUDIOS AND RECORDING

2.1 INTRODUCTION

To one unfamiliar with the techniques of broadcasting, the problems of providing and transmitting a sound programme would not appear to be unduly complicated provided a microphone, an amplifier, a transmitter and an aerial were available. In practice the operation of a co-ordinated service requires a very much more complicated technique involving the smooth transition from one programme source to another, the insertion of special effects, the control of programme volume so that overload of apparatus is prevented without destroying artistic values, the monitoring of programme quality, the recording and reproduction of programmes and the provision of a communication system to aid supervision and monitoring. These and all the other problems associated with getting a sound programme 'on the air' are discussed in this chapter, which for convenience is divided into three main sections dealing with:

1. General administrative problems and the duties of staff who are responsible for the operation and maintenance of control room, studio and recording apparatus for the Sound Service.

2. The apparatus contained at Studio Centres in the control rooms, recording suites and the studios themselves.

3. The tests and operational procedures which have to be followed to ensure that the Service functions efficiently and provides all reasonable facilities.

The communication system is a specialised activity and forms the subject of Chapter 6 but some reference will be made to it in this chapter also.

2.2 THE WORK OF STAFF MANNING THE STUDIO CENTRE

A schematic diagram of the operating positions in the sound broadcasting chain from the studio to the transmitting aerial is given in Fig. 2.1. The diagram is representative of the essential parts only and it could be considerably more complicated than shown. The programme may come from a number of sources, e.g. (1) a BBC Sound studio, (2) an external source such as a concert hall or a sports stadium, (3) play-back, from the recording suite, of a programme that has been previously recorded, (4) from overseas via Continental Trunks, Radio Terminal or Transatlantic Terminal. Each item is usually called a contribution.

The paths of the programme contributions can be traced from Fig. 2.1. The contribution from the artist or artists is controlled in

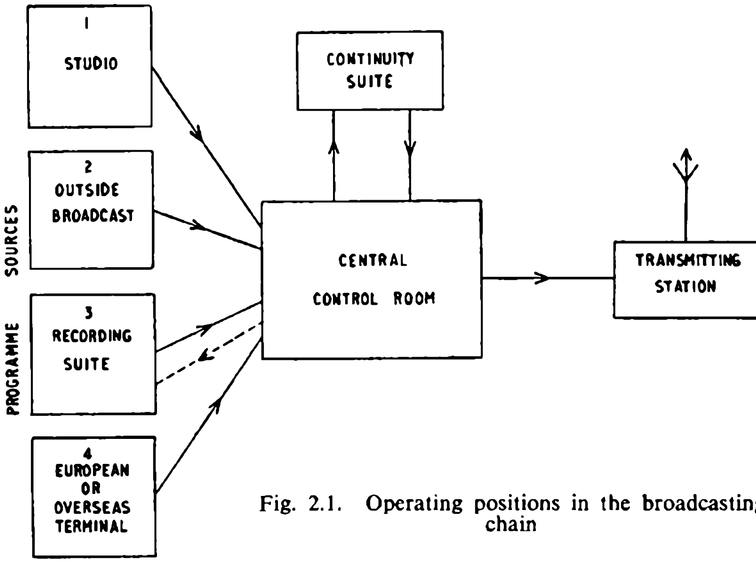


Fig. 2.1. Operating positions in the broadcasting chain

volume by the studio manager in the studio control cubicle alongside the studio. The studio manager is also responsible for ensuring that the various component sounds forming the programme are correctly balanced with respect to each other. This implies that microphones are so placed as to (a) maintain the correct relationship between the volume of sounds from different sources within their range, and (b) ensure a proper ratio between the direct sound from the artist or instrument and the indirect sound reflected from room boundaries, walls, floor and ceiling. Control of volume of programme must be exercised because the studio apparatus, and more particularly the transmitter, must not be subjected to excessive voltages, otherwise distortion and possibly damage may result. In addition the volume must not be so low that it is masked by the unwanted noise which is always present in the broadcasting chain from the microphone to the listener. The volume range within which the studio manager should work is about 24 dB, giving a power ratio between loudest and softest sounds of 250 : 1. This is often referred to as the 'dynamic range'. When special effects have to be inserted in the programme the studio manager may have an assistant to operate gramophone turntables if the effects have been recorded or to make appropriate 'live' noises, such as the closing of a door, walking up steps, walking across gravel, etc.

When a contribution is required from some outside event or concert, Outside Broadcast (O.B.) apparatus must be taken to that point and set up by the O.B. engineer, who decides on the placing of the microphone and controls the volume of the outgoing programme. The O.B. apparatus is connected to the nearest control room by land line, which is leased from and maintained by the General Post Office (P.O.). BBC Lines Department staff are responsible for general liaison, testing and acceptance of all lines from the Post Office.

Sometimes a programme contribution occurs at an inconvenient time for broadcasting. Then it is usually recorded, and played back at an appropriate time in the programme. Both disk and tape recording systems are available though the majority of recordings are done on tape machines, which have the advantage that they require little attention. Disk recording is unlikely to be completely superseded because it has some advantages over the tape system when very rapid editing is necessary and also when long-term storage has to be considered. Recording and reproducing machines may be grouped in a central recording and reproducing room, so arranged that one operator can supervise a number of machines, which in the recording condition can be started or stopped by remote control from the programme source or in the playback condition by remote control from a continuity position (Section 2.6). The programme to be recorded is passed to the recording suite through the main control room, a monitoring replay head* returning the programme to the studio manager for check purposes.

When replay is required for a programme contribution, it is sent via the control room to the continuity position. The latter is a key point in the sound broadcasting chains for the three services, Home, Light and Third (and Network 3), all items making up the programme being passed through it. The continuity announcer carries executive responsibility and decides what shall be done if a given programme is under-running, over-running, or owing to

* The terms *replay*, *play-back* and *reproducing* are synonymous and no preference is assumed in this manual.

fault conditions cannot be broadcast. The continuity operator has to ensure that his apparatus is functioning correctly and that the incoming programme quality is satisfactory, and has to give the go-ahead signal. To prevent artists being caught unprepared, a lamp-signalling system is used between the continuity control and all local sources of programme. With outside broadcasts the lamp-signalling system cannot readily be extended to the O.B. point, and cueing may be achieved verbally, by initially-synchronised clocks or by listening to the preceding programme.

One of the most important duties of the continuity operator is the monitoring of the programme by listening and controlling (when necessary) within certain limits the volume registered on a meter. Normally compression of the dynamic range of the programme has been carried out before the programme is supplied to continuity, either by the outside broadcast engineer or by the studio manager. The continuity suite has an acoustically-treated listening cubicle containing a high quality loudspeaker, and the operator is expected to query any effects or noises which obtrude themselves on the programme. This means that he should be familiar with the problems of the studio manager and the outside broadcast engineer, and he must be fully conversant with and able to name the various types of distortions.

To make certain that the apparatus is functioning correctly, routine daily, monthly and quarterly checks are carried out. The monthly and quarterly tests are normally performed by maintenance engineers, but at the beginning of each day the complete broadcasting chain has to be lined up (Section 2.8.1) and the signalling circuits checked. In this work technical operations staff are mainly involved. If the tests show that the apparatus is not working correctly, it is the duty of the continuity operator to initiate correcting action and to give an accurate verbal report of the fault condition to his supervisor. When no linking announcements are wanted the programme is sometimes transferred from the continuity position. The engineering control position normally caters for isolated contributions rather than a complete programme. There may be a number of these positions in a control room and they are so arranged that programme sources can be cued, telephone tie-lines being connected between the control and the source and destination. Just like the continuity operator, the control position operator is responsible for pre-transmission tests, the go-ahead signal and for monitoring.

Since all programme contributions pass into the main control room before being distributed, the duties of a technical operator in a control room are mainly concerned with connecting programme feeds and telephone tie-lines between sources and destinations (these may easily exceed 100) according to the schedule given in the control-room booking sheet. He has available incoming source and outgoing (to destination) amplifier bays, source and route selection bays and desks, a telephone switchboard generally termed an Engineering Manual Exchange (E.M.X.) and test apparatus bays. Full details of the apparatus and procedures are given in Section 2.9.

The work of the operator in the recording and reproducing suites can cover a wide variety of duties from operational supervision of a large number of remotely-controlled machines to the operation of a single machine or a pair. When recording he is responsible for the initial line-up of his machine, for frequent checks on the quality of the incoming and recorded programme and for keeping a log of any faults noted, as well as of the exact starting and finishing times of each recording. The recorded tape or disk must be labelled so as to be easily identified, and editing may subsequently be involved. When recording on disk, attention must be paid to the swarf-removal system and also to the condition of the cutter and disk. The operator would be expected to be able to correct minor faults in apparatus and to know how to switch over quickly to spare apparatus in the event of sudden failure. Any major fault is dealt with by a maintenance engineer, who for the Home Service programme equipment in London is a member of the Central Maintenance Unit. Disk reproduction is normally the work of the studio manager who also deals with programme inserts on magnetic tape. The replay of a complete programme on magnetic tape is normally the concern of the technical operator, and this entails lining up the apparatus, confirming that the correct tape is available and arranging a satisfactory change-over when the programme is not confined to one tape.

2.3 THE SIMULTANEOUS SOUND BROADCAST SYSTEM

There are five main distribution networks in the BBC Sound broadcasting system:

Basic Home and Regional Home Programme Distribution

Light Programme Distribution

External Services Distribution

Third Programme Distribution

Television Sound

2.3.1 *Home Service Distribution*

Some idea of the complicated nature of programme distribution for the Home Service is given by the simplified diagram of Fig. 2.2.

It is not feasible to provide a comprehensive chart because changes are often being made to the distribution system. The large rectangles indicate a regional studio centre, the smaller squares are the smaller studio sub-centres, and the circles represent transmitting

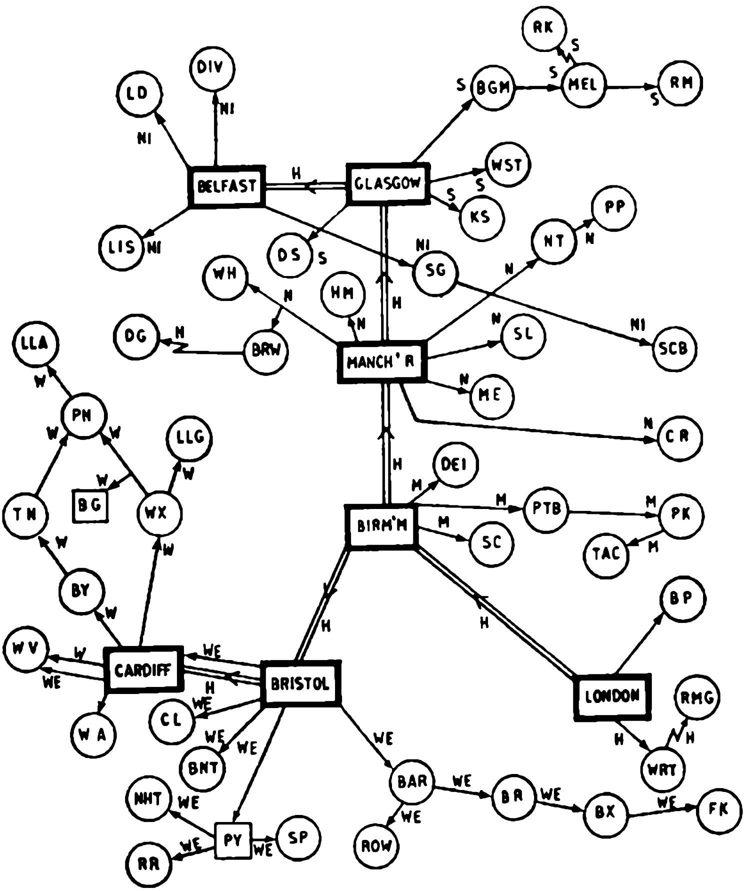


Fig. 2.2. Basic Home Service and regional Home programme circuits

stations. The letters against the distribution lines indicate the programme service supplied to the various transmitters, thus H = Home Service, M = Midland Region, N = Northern Region, N.I. = Northern Ireland, W = Welsh Region, W.E. = Western Region, S = Scottish Region. The key to the abbreviated place names is as follows:

List of Abbreviations for Figure 2.2.

DIV	Divis	PP	Pontop Pike	WA	Washford
LD	Londonderry	HM	Holme Moss	RR	Redruth
LIS	Lisnagarvey	ME	Moorside Edge	NHT	North Hessary Tor
WH	Whitehaven	CR	Cromer	PY	Plymouth
BRW	Barrow	PTB	Peterborough	CL	Clevedon
BGD	Burghead	PK	Postwick	BNT	Barnstaple
DG	Douglas	TAC	Tacolneston	SP	Start Point
MEL	Meldrum	SC	Sutton Coldfield	BAR	Bartley
RM	Redmoss	DEI	Droitwich	ROW	Rowridge
RK	Rosemarkie	LLA	Llandona	BR	Brighton
KS	Kirk O'Shotts	PN	Penmon	BX	Bexhill
WST	Westerglen	TN	Towyn	FK	Folkestone
DS	Dumfries	BY	Blaen-plwyf	BP	Brookman's Park
SG	Stagshaw	BG	Bangor	CP	Crystal Palace
SCB	Scarborough	WX	Wrexham	WRT	Wrotham
SL	Sandale	LLG	Llangollen	RMG	Ramsgate
NT	Newcastle	WV	Wenvoe		

Planners in regional centres are free to opt out of the basic Home programme if they desire. The substitution of a local programme in place of the basic Home Service requires switching and manning of a local continuity position at the regional centre, and a very rigid control of programme timing must be followed so that entering and leaving does not break the continuity of the service.

2.3.2 *Light Programme Distribution*

The Light Programme distribution system uses a single continuity suite in London, and all contributions are directed to this point before being distributed to the transmitters. This unified control allows a little more latitude in the time scheduling than is possible with the basic Home and Regional Home Service. The Third Programme (and Network 3) distribution is similar, a unified control system being followed; the time-table is planned to be sufficiently flexible to allow for occasional over-running of a programme.

2.3.3 *External Services Programme Distribution*

The External Services programme distribution differs considerably from those for the U.K. broadcasts, and a simplified diagram is given in Fig. 2.3. The code designations refer to External Services transmitting stations at Daventry (DX), Skelton (SK), Woofferton (WOF) and Crowborough (ASP) and to Droitwich (DEI). For engineering purposes a network colour coding system is employed: thus the General Overseas Service, radiated to English-speaking people all over the world is coded Green programme. Altogether there are about ten colour-coded networks operating at various times on a twenty-four hour schedule, and these are switched, usually automatically at the transmitting stations, to the appropriate transmitters and aerials. The carrier frequencies and aerials must be changed as required to direct transmissions to appropriate areas and to take account of changes in ionospheric conditions over the route. By the use of a central distribution point any programme may be routed to its desired destination, and any given

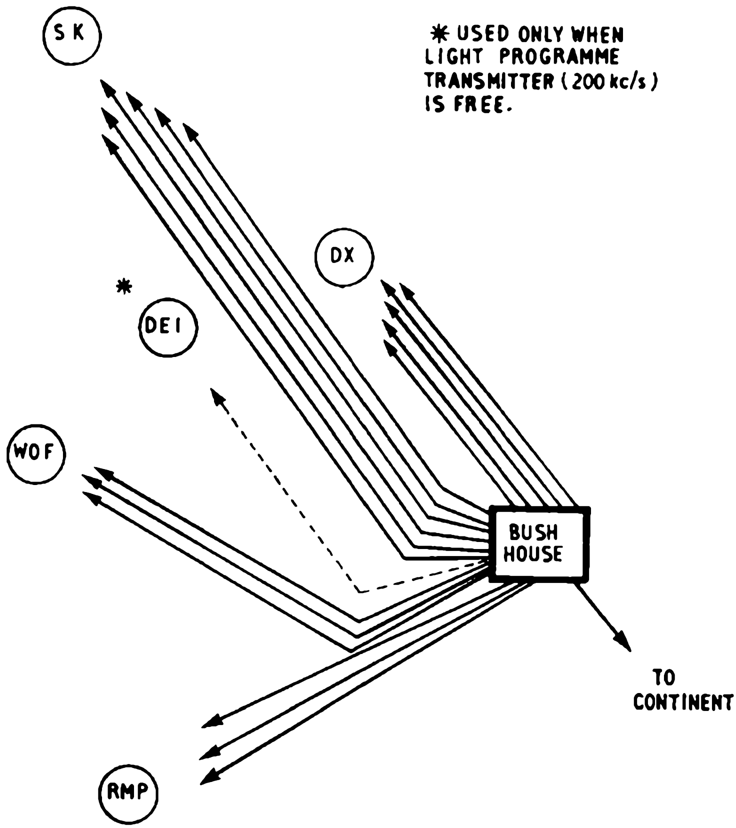


Fig. 2.3. External services programme distribution

programme line may be carrying any one of a number of colour-coded programmes. External Services programmes are timed in multiples of 15 minutes so that distribution switching may be done at 15 minute intervals throughout the twenty-four hours. In 1956 a fully automatic switching unit (ASU) was installed at Bush House to replace manual switching. The ASU employs uniselectors with a master clock to control the switching operation and it is described in Section 2.8.3.

2.4 THE APPARATUS USED IN SOUND BROADCASTING

2.4.1 *General*

At this stage it is useful to consider the minimum apparatus required for one of the links shown in Fig. 2.1. The schematic diagram, Fig. 2.4, illustrates a small studio followed by a control position. a line link and the programme input equipment at a transmitting station. There are three programme sources: two microphones in the studio and one disk replay head in the studio control cubicle. Source amplifiers A1, etc., increase the signal level so that it is large compared with any noise which may occur on the interconnecting lines or which may be produced by movement of the wiper over the contacts of individual source faders (F1, etc.). The faders allow selection and mixing of the various sources; the mixing is accomplished by connecting the fader outputs separately to a network in which they are added or combined. An amplifier (B1) is necessary to compensate for the inevitable losses in the combining network and to bring the signal up to an adequate level before the main gain control (MGC1). This control normally has a loss of 20 dB but the loss can be decreased if the incoming programme volume is too low for an acceptable signal level to be passed on to the B2 amplifier, from which the programme is distributed to continuity control.

In the studio control cubicle the faders F1, F2, etc., are used to adjust the programme volume from individual microphones, and the main gain control determines the combined output volume. Faders F4, F5, etc., at the continuity control position are known as channel faders and through them the technical operator has access to all sources of programme and can select any desired contribution. Usually the technical operator at continuity control only selects programmes sequentially and does not mix them. Consequently faders F4, F5, etc., serve only for switching purposes and any adjustments to compensate for variations in the programme volumes of sequential contributions have to be made at the main gain control (MGC2). This second main gain control attenuates the programme by 20 dB and a general purpose amplifier (GPA) is necessary to increase the programme volume to that of all other programmes connected to the control room C amplifiers, which are used to feed the P.O. lines to the transmitting station.

The purpose of the C amplifier (voltage amplification about unity) is to act as an isolator supplying a separate programme feed to each destination, so that fault conditions on one line to a destination do not affect a line to another destination. The term trap-valve amplifier is often used for this kind of isolator and its input impedance is high enough to allow a number of such amplifiers to be connected to the same programme line without appreciably affecting volume.

Monitoring equipment is absolutely essential and the monitoring amplifiers (MNA) serve two purposes; they check that the apparatus

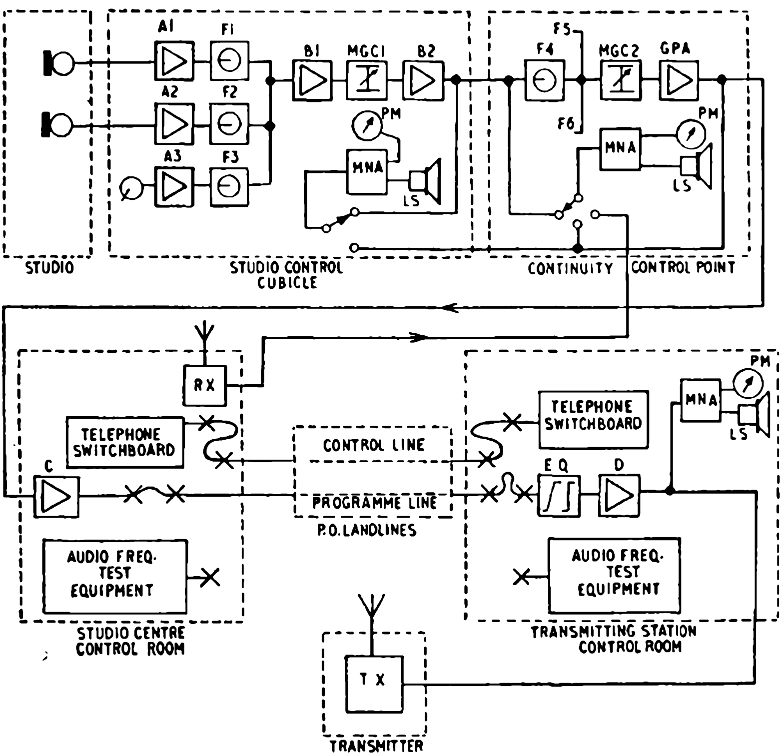


Fig. 2.4. Minimum requirements of a link in a broadcasting chain

in the main chain is working satisfactorily and also isolate the monitoring headphones or loudspeakers so that a fault on the monitoring circuit does not affect the programme feed to the main chain. Measurement of programme volume is carried out at various points by programme meters (P.M.) which, though measuring the peak volume of programme, do allow some estimate of average volume to be made. These meters provide the means of sampling programme 'quantity', as far as transmitter overload and transmission path noise is concerned. The monitoring loudspeaker samples programme 'quality', and 'quantity' in terms of relative loudness. The programme meter and monitoring loudspeaker in the continuity control cubicle can be switched to monitor the cubicle output, the continuity output or the check-receiver output. Since one of these three points is the output from the check receiver tuned to the appropriate transmitter, direct comparison can be made between incoming signal and the broadcast signal. Any fault conditions leading to poor quality are therefore quickly detected.

To ensure that faults are diagnosed and remedied as quickly as possible, engineering control lines are terminated alongside the programme lines, and they link transmitter, central control room, continuity and studio control rooms. Only one control line is shown in Fig. 2.4 together with the telephone switchboards (E.M.X.); the audio-frequency test apparatus, with which performance checks are made to ensure correct functioning of the programme apparatus and the lines is also indicated.

The line link to the transmitter does not attenuate all audio frequencies equally and there is generally a greater attenuation at extremities of the audio range. To restore the quality of the original signal an equaliser (EQ in Fig. 2.4) is required at the transmitter and this attenuates the low and middle frequencies so as to achieve an equal response at all frequencies. To make up for the attenuation in the line and equaliser a general-purpose amplifier (G.P.A.) known as a D amplifier is included before the transmitter. The monitoring loudspeaker at the transmitter can be switched to the output of the D amplifier or to a check receiver.

2.4.2 *Terminology*

Before embarking on a description of the separate items of equipment at studio centres, it is desirable to define the meanings of a number of special terms that are used to identify the signal at various points in the programme chain, and also the path of the signal. In some instances there are two meanings for the same word, depending on whether it refers to the Home or Overseas Services, and when this is so both are given.

Programme. For engineering purposes, programme means the signals conveying information to be broadcast as distinct from test signals.

For administrative purposes, the term programme is applied to a sequence of items to be broadcast as a continuous service, e.g., Home Programme. Engineers also use the term in this sense when routing programme services over the S.B. (simultaneous broadcasting) system.

Contribution. Although a programme item such as a play or an outside broadcast is normally known as a programme, engineering personnel usually speak of it as a contribution to a programme when dealing with the signal chain prior to the continuity suite.

Insert. A part of a contribution originating at a source other than the main source of the contribution.

Programme Source. The point of origin of a programme or part of a programme, normally understood to be a studio, O.B. point or reproducing suite, but the term is used in a much wider sense by engineering staff who relate it to incoming programmes in a general sense, e.g., in a headquarters control room the continuity programme output signal is available as a source.

Channel. A one-way path for the electric currents corresponding to a programme or a contribution to a programme. A channel may be prefixed with a term describing the purpose which it is fulfilling, e.g., *Microphone Channel, Studio Channel, Continuity Channel,* etc.

Chain.

(a) *Programme Chain:* the items of equipment, connected in tandem, which are used to carry programme signals from source to destination.

(b) *Chain (External Services):* any one of the routes carrying programme from the studio centre to the transmitter stations.

Network.

(a) A collection of chains carrying a programme to two or more transmitters.

(b) *External Services:* the continuity programme output signals available for switching to chains. The networks are colour-coded, e.g., Green network implies all the chains over which General Overseas Services are broadcast.

Simultaneous Broadcasting (abbrev. S.B.). A broadcast by two or more transmitters, within a single broadcasting system, of the same programme at the same time.

2.5 PROGRAMME SOURCE EQUIPMENT[1]

A survey of programme source equipment must start in the studio with the microphone, in the reproducing suite with the reproducing equipment and at the O.B. point with the O.B. apparatus.

2.5.1 *Microphones*

A detailed description of the various types of microphone used by the BBC is given in another manual[2]. This section is confined to certain general principles which affect the frequency response and directional properties. Microphones used for broadcasting can be divided into two classes, namely pressure-operated and differential pressure-operated types.

Pressure-operated Microphones. A microphone is said to be pressure-operated when only *one* face of its diaphragm is subjected to air pressure variations caused by the incident sound waves.

The pressure-operated microphone has a substantially flat frequency response to sound waves arriving from the front, as long as the wavelength of the sound is much greater than the dimensions of the front of the microphone. At high audio frequencies, having wavelengths comparable to the microphone dimensions, the force experienced by the diaphragm tends to increase due to the modification of the sound field brought about by the microphone body. Standing waves due to reflection from the front of the microphone cause the effective sound pressure at the diaphragm to be increased; it may rise to twice the normal free-field value.

Corresponding to the pressure-doubling at the front there is a sound shadow at the back of the microphone, so that its directional response at high frequencies is appreciably modified. A high-frequency sound arriving from behind the microphone shows a greatly reduced output compared with that obtained from one arriving from in front of the microphone. At low frequencies neither pressure-doubling nor sound-shadow effects occur and the response is omnidirectional as shown in Fig. 2.5.

At high frequencies the diaphragm is comparable with the wavelength of the incident sound and when the sound is off-centre from the microphone axis, the pressure varies over the diaphragm face to cause a reduction in the effective pressure experienced by the diaphragm. In an extreme case when the diameter of the diaphragm face is equal to about a wavelength of the incident sound, and the sound is at right angles to the face, half the diaphragm may be subjected at one instant to a pressure which is equal and opposite to that on the other half. This accounts for the reduction in off-axis response at the 90° and 270° positions shown in Fig. 2.5.

A microphone having the particular directional properties shown will tend to pick up equally from all directions the low- and medium-frequency reverberant sound produced by sound reflections from the walls of the studio, and there will be a tendency for the room

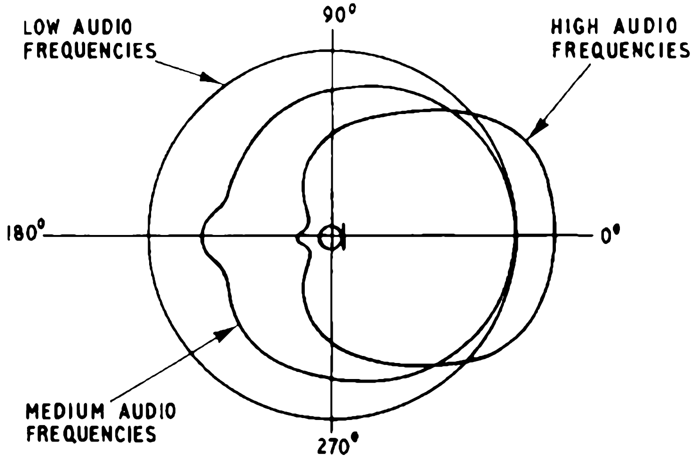


Fig. 2.5. Directional response diagrams for a pressure-operated microphone

acoustics to be more noticeable if the microphone is placed at some distance from the source of sound.

Differential Pressure-operated Microphones. If both sides of the microphone diaphragm are subject to air pressure variations from the incident sound, the force actuating the diaphragm will be deter-

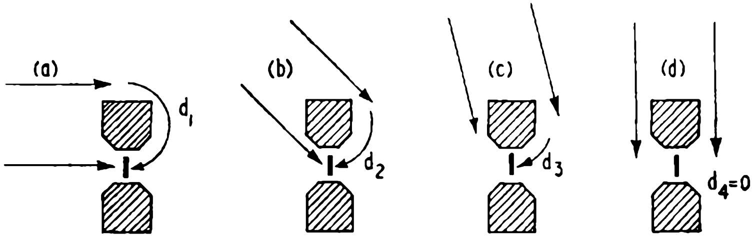


Fig. 2.6. Directional effects with the differential-pressure microphone

mined by the phase difference between the pressure wave arriving at the front and that arriving at the back of the diaphragm. Ribbon microphones operate on this principle and are sometimes termed 'pressure-gradient' microphones. The difference in path-length from the front to the back of the microphone is d_1 for an incident wave normal to the front of the microphone (Fig. 2.6 (a)). As the angle of the incident sound wave to the normal increases, the distance d decreases and so the pressure difference between front and back reduces until when the incident wave is at 90° to the normal (Fig. 2.6 (d)) there is no pressure difference to actuate the

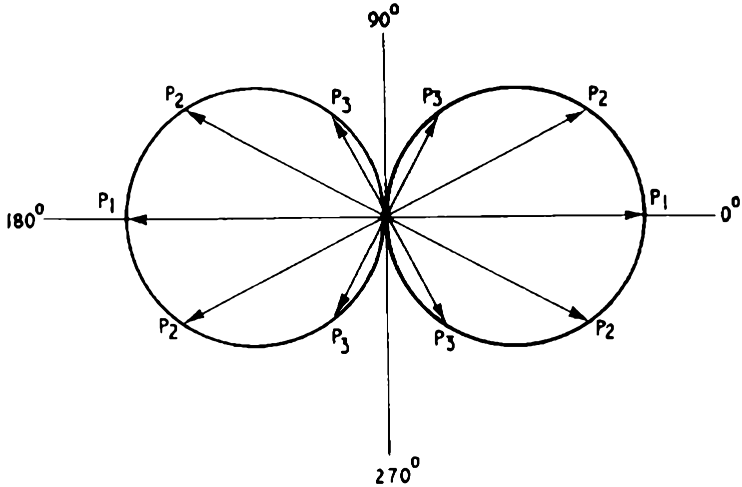


Fig. 2.7. Figure-of-eight response from a differential-pressure microphone

microphone diaphragm. A directional diagram similar to that of a figure-of-eight is therefore obtained as shown in Fig. 2.7; provided the width of the ribbon is small compared with the wavelength of the highest audio frequency, the figure-of-eight directional diagram is independent of the sound frequency. Examples of this type of microphone are the BBC-Marconi AXBT, the BBC PGS and the S.T. and C. 4038A, B and C. The amount of reverberant sound picked up by the differential pressure-operated microphone is very much less than that picked up by the omnidirectional pressure-operated microphone. Hence it may be used at a greater distance from the sound source and this has considerable advantages, particularly for orchestral programmes. A discussion of the factors which determine the positioning of microphones in relation to the type of programme is in another BBC publication[1]. It is possible to combine pressure-operation and differential pressure-operation in one microphone so as to produce a cardioid or heart-shaped directional diagram (Fig. 2.8) and such microphones are of value for theatre performances when it is desired to reduce the pick-up of sound from the audience. The live side of the microphone faces the performers and the dead side the audience.

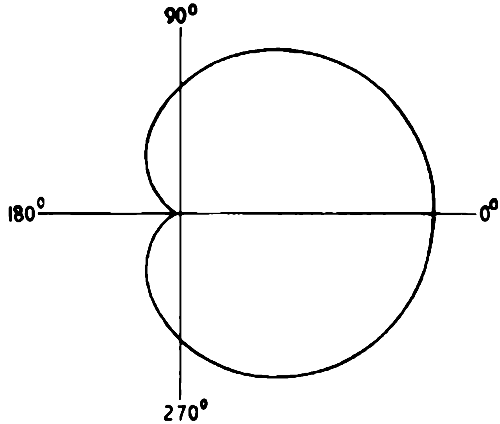


Fig. 2.8. Cardioid response of a specially designed microphone

2.5.2 *Reproducing Equipment*

Another important source of programme is provided by material which has been recorded on magnetic tape or direct on to acetate disks, and by gramophone records (pressings). The increased use of magnetic tape recording and of slow-speed long-playing commercial pressings by the BBC has led to a considerable reduction in the use of 78 r.p.m. recordings. Details of reproducing equipment are given in Section 2.10 so that it is only necessary here to state the three types of disk-reproducing desks which are to be found in the studio control cubicles. They comprise the TD/7 (78 r.p.m. only) the DRD/5 (33⅓ and 45 r.p.m.) and the RP2/1 (33⅓, 45 and 78 r.p.m.) desks. All incorporate pre-fade listening so that checking and editing is easily achieved.

2.5.3 *Outside Broadcast Equipment*

Outside broadcast equipment is designed to provide easily-assembled transportable studio and control room facilities with the minimum amount of apparatus but with sufficient spares to deal with the more usual fault conditions. Two types are employed;

the earlier OBA/8 equipment, though still in use, is being replaced by the more compact OBA/9 trolley-assembled apparatus. Electrically there is not much difference between the two types, which provide for 4 microphone inputs, and have two amplifier units, incorporating a microphone and a line-feeding amplifier, two power-supply units which can be fed from batteries or the a.c. mains, a programme meter and an isolating circuit for feeding a monitoring loudspeaker. A schematic diagram of the OBA/9 is shown in Fig. 2.9. It is usual to have one amplifier unit and one power supply unit as a stand-by, and when battery and mains supplies are both available, one power supply unit is often connected to the batteries and the other to the mains, so that a fault condition in amplifier or power supply need not cause a long interruption of programme. Where possible two identical lines are used for connecting the programme and local telephones to the studio centre, and change-over switches allow the programme to be transferred to the telephone line in the event of failure of the programme line.

The schematic diagram for the OBA/8 is similar to that for the OBA/9, but the units of the latter are lighter and smaller. The microphone mixer, distribution panel, the two amplifier units, loudspeaker and trap-valve distribution amplifiers, as well as the supply units, are all stacked on a transportable trolley, which also carries the microphone and interconnecting and mains supply leads.

2.6 STUDIO EQUIPMENT

New designs for studio equipment were produced between 1945 and 1955. These took the form of desk or console units, known as Studio Equipment Type A and Type B. A commercial product, the Marconi Console, modified to BBC requirements, is also used and since it has many features in common with the Type A Studio Equipment but is simpler, it will be described first.

2.6.1 *The Marconi Console*

The schematic diagram of the Marconi Console in Fig. 2.10 shows that high-level mixing is employed. Each programme source is immediately followed by its own amplifier, to which it is connected by a line balanced to earth. The balanced form of connection is used because it tends to cancel noise and interference voltages induced in the lines; these voltages may otherwise be comparable in value with the low-level signal voltages. Individual source faders, F1, etc., precede the mixing pad, and the faders and mixing pad are of the constant-impedance type, so that variation of one channel setting does not affect the programme levels of the other channels. The high insertion loss due to the use of constant-

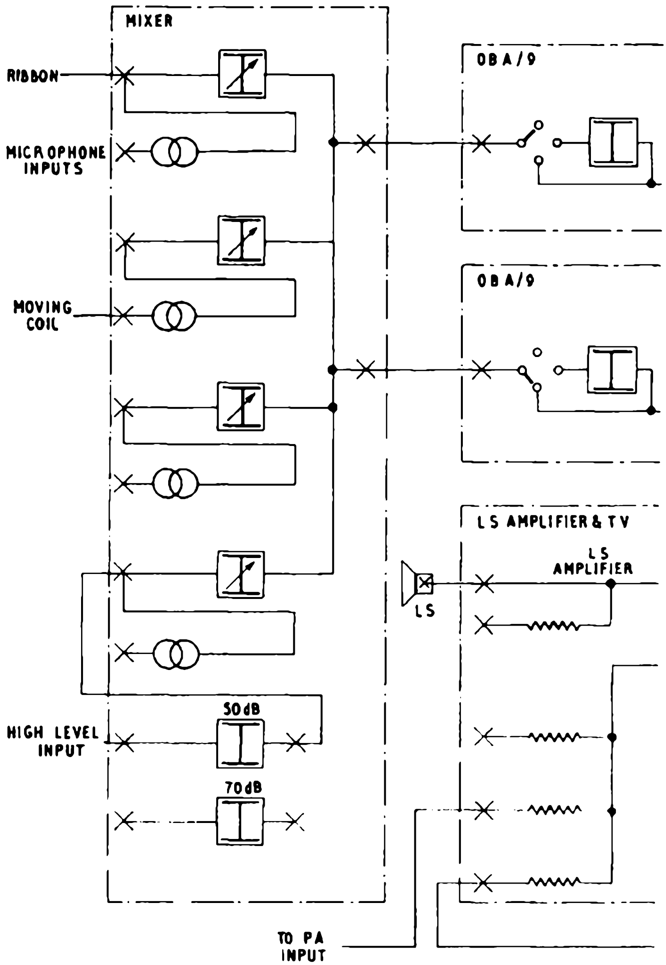
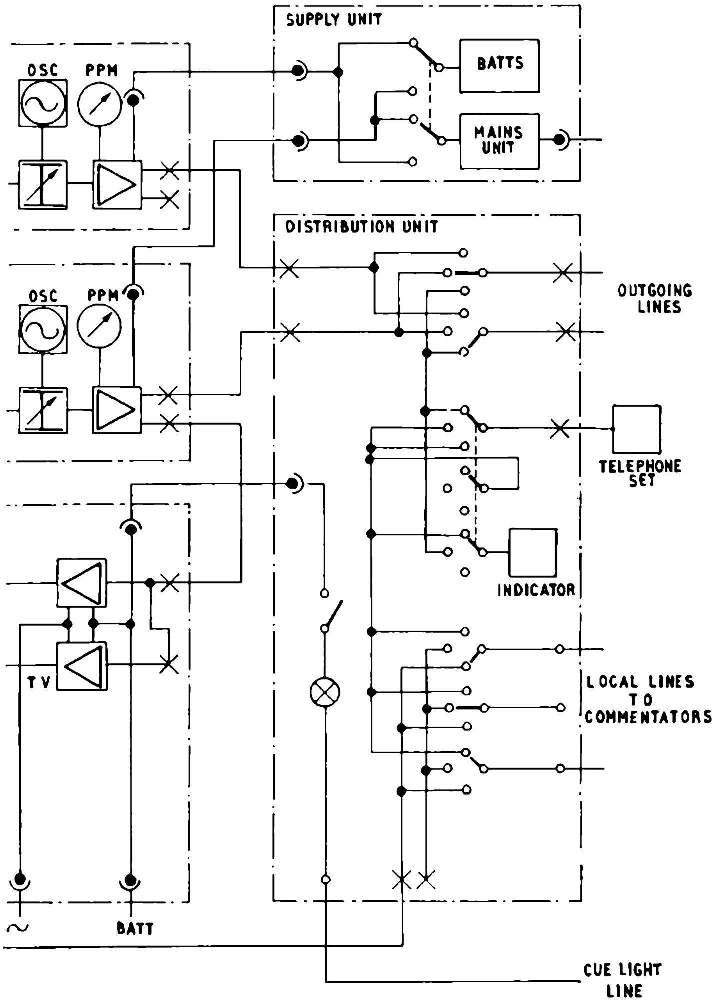


Fig. 2.9. Schematic diagram of the OBA/9 equipment


SUPPLY UNIT
BATTS
MAINS UNIT
OSC
PPM
DISTRIBUTION UNIT
OUTGOING LINES
TELEPHONE SET
INDICATOR
TV
LOCAL LINES TO COMMENTATORS
BATT
CUE LIGHT LINE

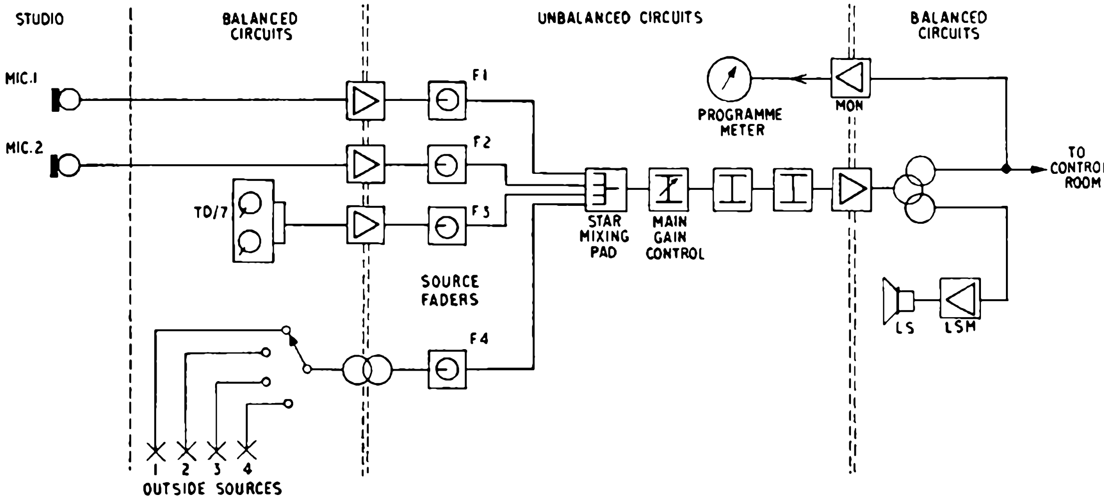


Fig. 2.10. Schematic diagram of the Marconi Talks Studio Console

impedance networks is compensated by varying the gain (in steps) of the pre-amplifier following the microphone. The output of the pre-amplifiers is unbalanced because this simplifies the mechanical design of the constant-impedance networks and reduces cost; interference induction is less serious because the signal is at high level and leads are comparatively short. A return to balanced connection is made at the output of the amplifier following the main gain control. Provision is made in the input channel 4 to inject O.B. programme sources into the chain.

2.6.2 *Studio Equipment Type A*[3]

The Studio Equipment Type A consists of a control desk, placed in the control cubicle adjacent to the studio, a control cabinet which houses amplifiers, mains units and relays, and a supply cabinet which contains mains isolators, contact breakers and mains relays.

The control and supply cabinets are installed either in the control cubicle or in an adjacent room.

The control desk is so constructed that various combinations of the three control panels can be fitted according to local needs, the panels are made to a standard size and are hinged to simplify maintenance (Fig. 2.11). The apparatus shelves in the apparatus cabinet are mounted on runners and can also be easily withdrawn.

There are two basic Type A equipments, coded Mark II and Mark V, in general use, the Mark II being designed for small general-purpose studios, and the Mark V for large general-purpose studios. The simplified diagram of the Mark II given in Fig. 2.12 shows that there are four main types of channel:—narrator, microphone, gramophone and echo. Spare amplifiers are available by operation of switches, and balanced constant-impedance bridged-T faders (I, S, E and G) are used throughout. The mixers (M) are so arranged that the faders are correctly matched under all conditions. In addition to individual control over signals from studio microphones and gramophone output, group control is available by means of the group fader (G). The contribution from the narrator by-passes the group fader, so forming an independent channel. The group fader (G) and the independent fader (I) enable an insert announcement to be made with the other programme contributions partially faded out by the group fader. This retains the original balance between the programme sources before the group fader.

Programme from each microphone channel and the gramophone channel is split by a hybrid coil (H); one part (D) goes direct to the mixer and the other (E) is used to provide artificial reverberation

Fig. 2.11. Studio control desk Type A, Mark V. The top photograph shows a general view of the control desk and the lower photograph shows the panels swung forward for inspection and maintenance with the side panel of the pedestal removed

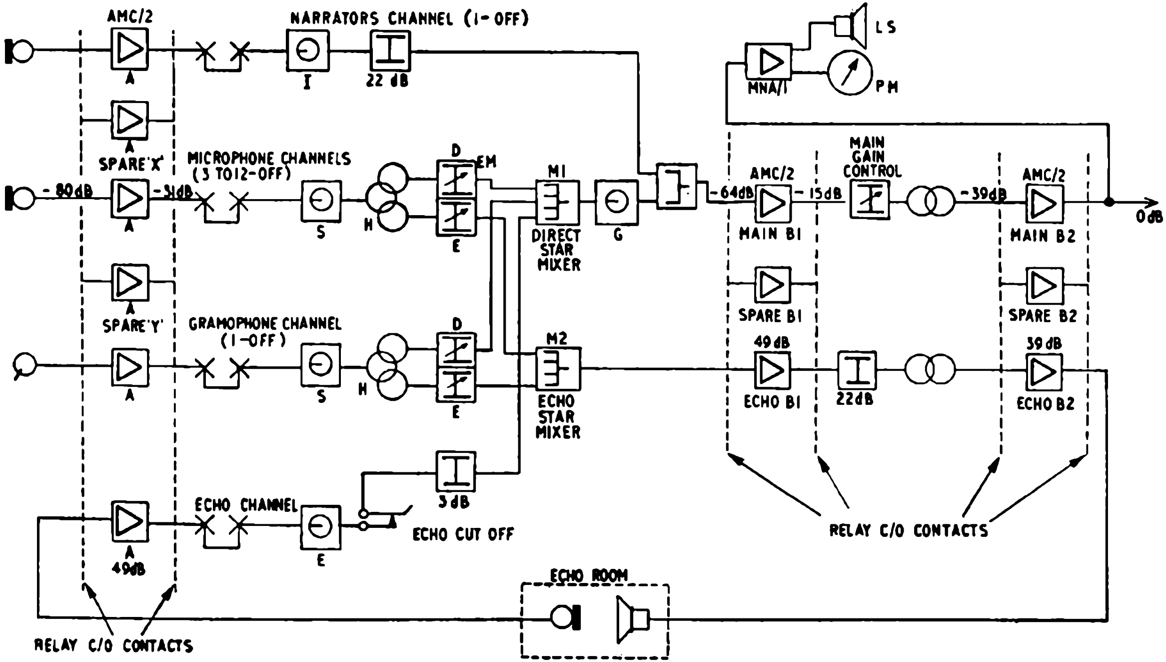


Fig. 2.12. Schematic diagram of Type A studio equipment

(usually called echo) when required. The operation of the hybrid coil is described in Chapter 6.

The 'echo' feed is via the echo mixer (M2) and amplifiers B1 and B2 to the echo room or special reverberation plate, and it is returned to the main chain mixer via the echo channel fader (E). Preliminary adjustment of the relative levels of direct and echo signals is made on ganged stepped attenuators in the direct and echo lines following the hybrid. Operation of the stepped mixture switch in a clockwise direction decreases the attenuation in the echo line and increases it in the signal line. Owing to the greater complexity of this apparatus extra loss occurs in the balancing and mixing circuits and two B amplifiers (B1 and B2) are required to bring the output up to zero level.

Modifications have been made to incorporate such facilities as remote starting and stopping of magnetic tape recorders and reproducers, clean feed output, etc. A clean feed output is a feature of the type B studio equipment and is discussed in the next section.

2.6.3 *Studio Equipment Type B*[4]

The Studio Equipment Type B is a development of Type A and provides more facilities, in particular more microphone channels. The Mark I form of this equipment is designed for talks studios and the Mark II for general purposes. Both comprise a Studio Control Desk, Apparatus Bays and a Power Supply Cabinet.

The Control Desk (Fig. 2.13) has three main panels, hinged for maintenance purposes; each of these panels consists of a basic framework into which individual sub-panels can be inserted, the number and type of sub-panels being determined by the service to be performed. The space below the operating table is occupied by cable termination blocks and switching relays.

The Apparatus Bay usually consists of a 19-inch bay framework equipped with 20 microphone amplifiers and four mains power supply units, two of which act as spares. There is a Supply Distribution Panel carrying the outputs of the four mains units to the various groups of amplifiers; there is also a Mains Distribution Panel connecting power supply to the inputs of the mains units.

The Power Supply Cabinet is wall-mounted and contains equipment for supplying 50-volt d.c. to relays, relays for connecting mains supplies to signal lamps, and mains supply control equipment such as miniature circuit breakers.

A simplified schematic diagram of the Mark II equipment given in Fig. 2.14 shows that the Type B retains many of the features of the Type A, but there are some major changes which reduce costs.

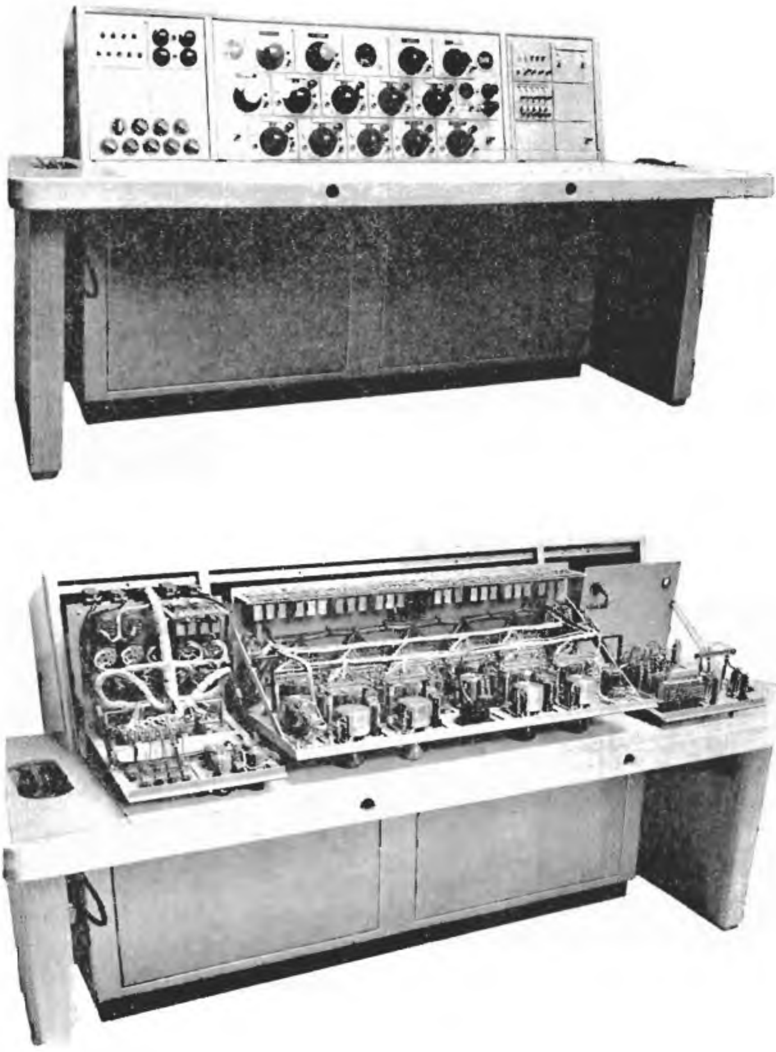


Fig. 2.13. Type B studio control desk. The top photograph shows a general view, while the lower photograph shows all three panels hinged forward. This gives very easy access for maintenance. The left-hand panel has effects units and echo hybrid transformers mounted at rear. The centre panel has the main and echo star mixers together with group and echo switching relays mounted at rear

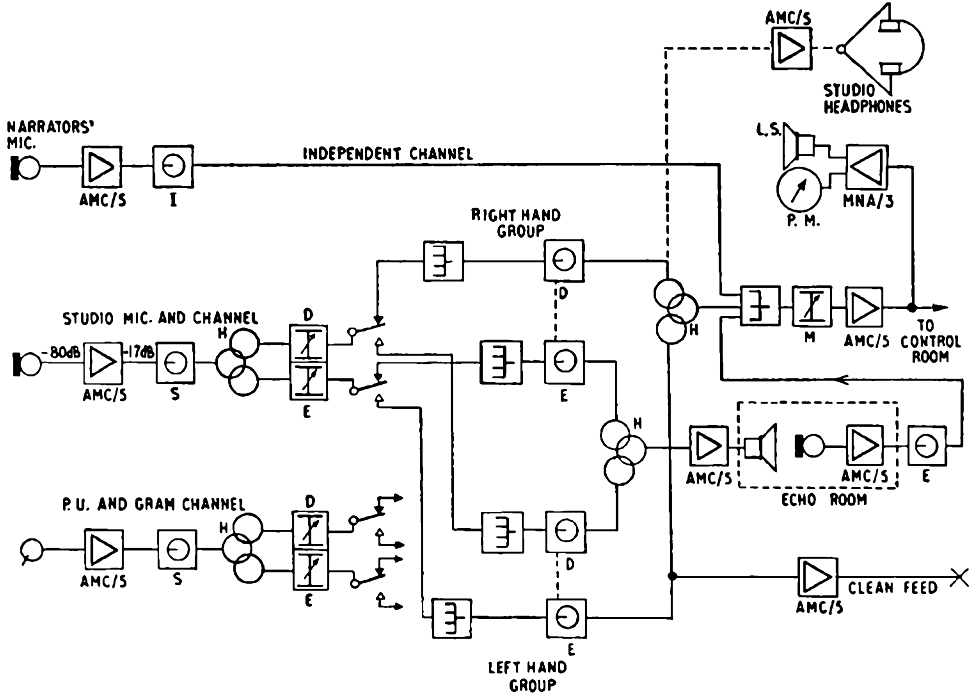


Fig. 2.14. Schematic diagram of a Type B studio installation

After the source amplifiers (AMC/5) unbalanced circuits replace the balanced circuits so that unbalanced bridged-T faders can be used instead of the more expensive balanced type. The AMC/5 amplifiers used throughout have a much higher gain than the AMC/2 amplifiers of the Type A (normally 63 dB compared with 49 dB) and only one main amplifier is needed. The reverberation or 'echo' facilities are provided on each channel by a hybrid-splitting connection (H) as for the Type A. On the Mark II desk there are 7 microphone channels (only one is shown in Fig. 2.14) and two gramophone channels, one of which (Channel 8) may be used as an additional microphone channel with the two gramophone channels tied to channel 9. The output from the gramophones may be connected to the 'acoustic effects' loudspeaker in the studio. This allows selected inserts to be reproduced in the studio, and is a valuable facility for certain purposes because it allows the insertion to be made without fading out the studio, so preserving the same 'atmosphere' and providing an aural cue for the artistes.

Outside sources are fed at zero level from the central control room to the studio cubicle, where they can be heard on headphones by using pre-fade keys. They are attenuated by 73 dB (to bring them to about the same level as a microphone output) before being plugged into the source amplifier of one of the 7 channels normally intended for use with a studio microphone.

There are two group faders, and any channel except the narrator's can be switched to the left-hand or right-hand group fader so that control over either of the two sets of programme is obtained without affecting the balance of the individual sources. The two group outputs are added in a hybrid coil and the combined output arrives at the input to the main chain via the main gain control (M). The hybrid connection is used instead of a simple resistance mixing network because it reduces interaction between the two groups to a very low value and allows a 'clean feed' to be taken from the left-hand group. Clean feed is the term used to describe the outgoing programme minus the incoming contribution when it is fed back to the incoming contribution point, whereas cue programme is the total output including the incoming contribution when it is fed back to the contribution point. An indication of how clean feed operates is given in Fig. 2.15. The output from studio 1, which may be regarded as the ' slave ' studio is fed as an incoming contribution to the studio manager in the cubicle associated with studio 2 (the master studio) and he mixes it into the outgoing programme. Only the studio 2 contribution to the programme is fed back to studio 1 and it is then known as clean feed. The programme contribution from studio 1 can be fed on headphones to the artiste in studio 2 and it is then acting as a clean feed. Provided headphones are used in each studio and the gains of the interconnecting circuits are adjusted to prevent 'howl-back', the clean feed system allows a discussion to take place between artistes in both studios. The outputs from each studio can be mixed at studio 1 as well as studio 2 to give a combined output when the clean-feed system is used and the term 'two-way working' is applied to this arrangement.

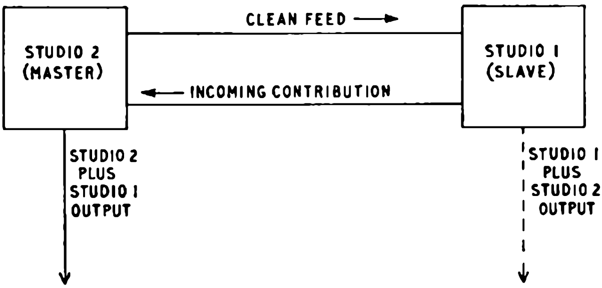


Fig. 2.15. Operation of a clean-feed system

An important feature of a studio installation is the talk-back facility giving two-way communication between the studio cubicle and the narrator's and main studios. During rehearsal, operation of the talk-back key on the cubicle control desk connects the output of the talk-back microphone to the loudspeakers in the studio, and to prevent howl-back cuts off the cubicle loudspeaker. When on transmission, the studio loudspeakers are automatically disconnected from the talk-back line unless all the studio microphones are faded out, but talk-back can if necessary, be provided to the artists via headphones.

2.7 CONTINUITY CONTROL EQUIPMENT

The Continuity Control Position was introduced just before the outbreak of the last war and a rack-mounted OBA/8 amplifier and mixer MX/18 formed the basis of the equipment. Since those early days many developments have occurred and Fig. 2.16 gives a simplified circuit diagram of the equipment used in a Broadcasting House continuity suite. It is, of necessity, more versatile than a Regional continuity suite (or those used in External Services) and it can, when desired, be used as a production mixer and for the replay of tape recordings. Provision is made for rehearsal facilities, local listening and balance tests and for clean-feed output.

The continuity announcer's studio has two RP2/1 replay desks and a microphone, and there is a pre-set gain adjustment in the

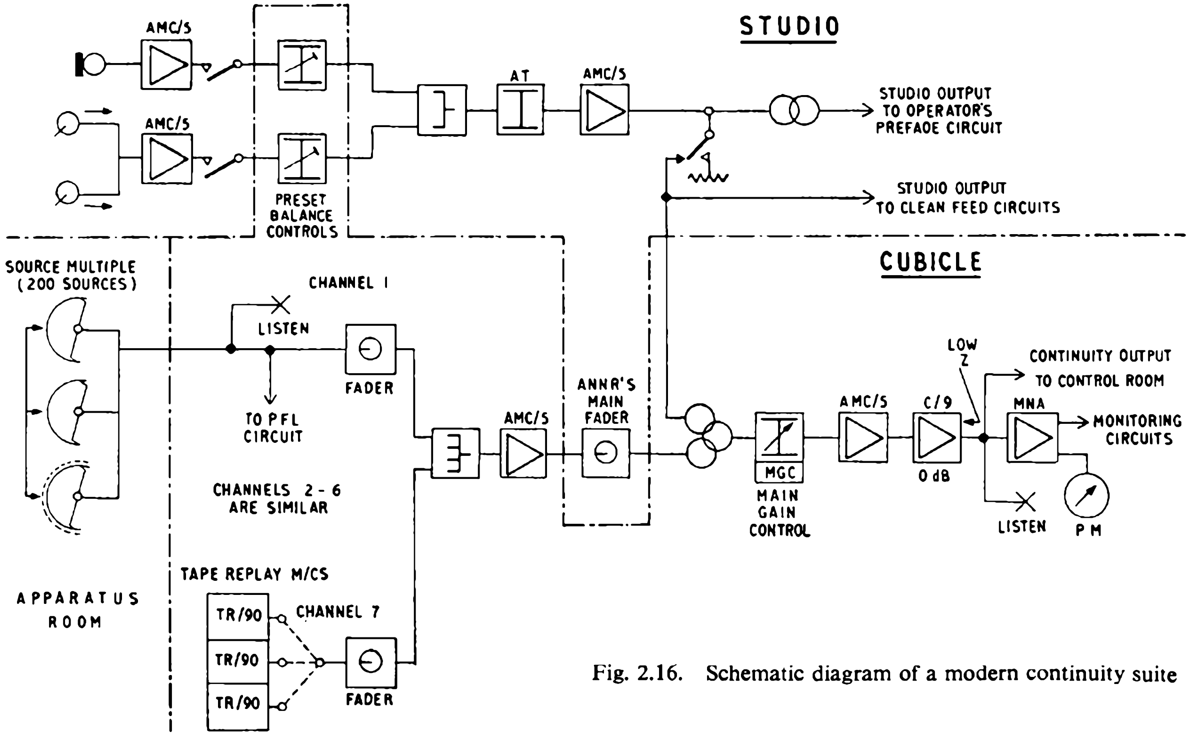


Fig. 2.16. Schematic diagram of a modern continuity suite

continuity cubicle for achieving balance between the outputs. The replay desk outputs are intended to provide a programme contribution or 'fill-up' programme material when a programme underruns. The main fader in the programme chain is brought out on the announcer's desk so that he can fade out external sources of programme in order to make his linking announcements. The fader can be by-passed when desired by operating a switch in the continuity control cubicle.

There are seven channels associated with the continuity control desk in the cubicle; one is tied to the TR90 tape replay machines and the other six are given access to 200 programme sources via uniselectors operating in groups of three as described in Section 2.7.3. The operator responsible for source selection and control has an assistant to operate the tape replay machines as well as carry out any general duties.

Each amplifier in the continuity apparatus has a spare which can be quickly switched into service, and the main gain controls can be replaced by a fixed attenuator pad. Comprehensive checking facilities are available to announcer and operator so that they can pre-fade listen and monitor. The check points include uniselector outputs, as well as studio, continuity and check receiver outputs. Since uniselectors are being used the operator automatically gains access to the signalling, to the communication and to the cue programme circuits associated with the source as the programme is being selected.

When the continuity suite is used as a production mixer suite the cue programme circuits are usually turned into clean-feed circuits, i.e., all programmes are fed back to the source except that originating from the source. These circuits may also be used for talk-back purposes through the talk-back microphone in the announcer's studio. The talk-back is heard in the studio cubicle on the talk-back loudspeaker in the ordinary way.

2.8 MAIN CONTROL ROOM APPARATUS

In Section 2.1 it is shown that the chief purpose of the main control room is to accept programmes from many sources and route them to their correct destinations. A simple link in the S.B. distribution system, that between two control rooms, is shown in Fig. 2.17. The frequency response and level at different points in the link are indicated in Fig. 2.18.

2.8.1 *The P.O. Line Link and the Associated BBC Apparatus*

The output from the C amplifier (Fig. 2.17) goes to the P.O. line via a repeating coil and U-links: it is received at the other end via

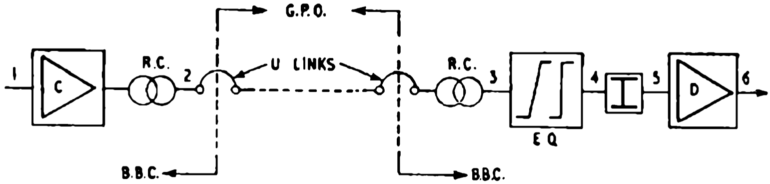


Fig. 2.17. Simple link between control rooms

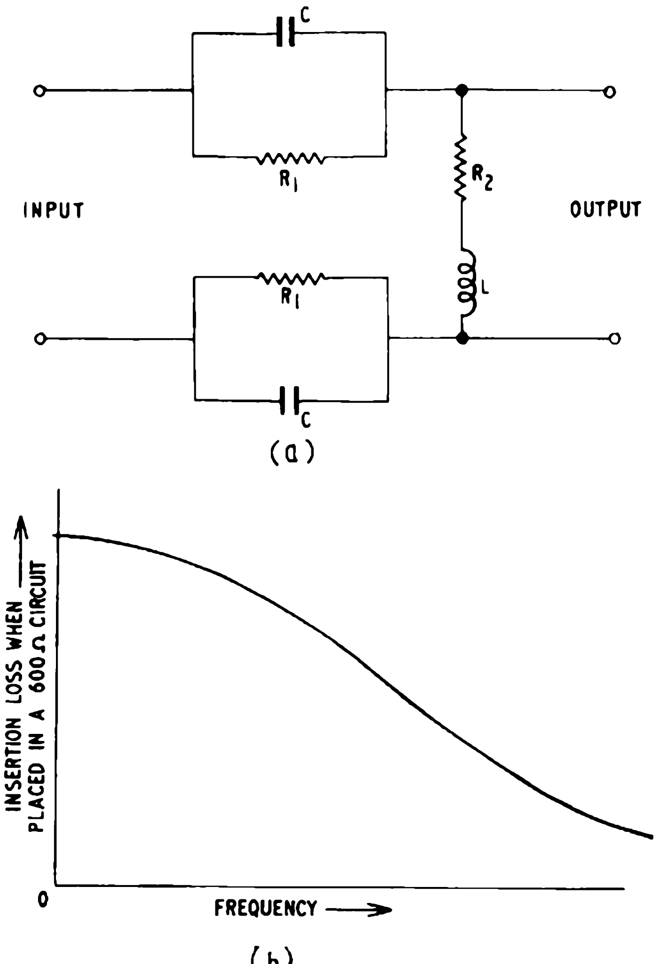


Fig. 2.18. (a) Typical equaliser for correcting attenuation distortion in a line; (b) Frequency response of the equaliser

another pair of U-links, the U-links marking the boundaries between P.O and BBC responsibility. Since neither the input impedance of the line nor its transmission characteristics are constant over the audio-frequency band, attenuation distortion (Section 1.6.5) will be present in the programme received at the far control room, the effect being mainly loss of the high audio frequencies. This must be corrected by inserting an equaliser to attenuate the low audio frequencies in such a manner as to restore an over-all flat

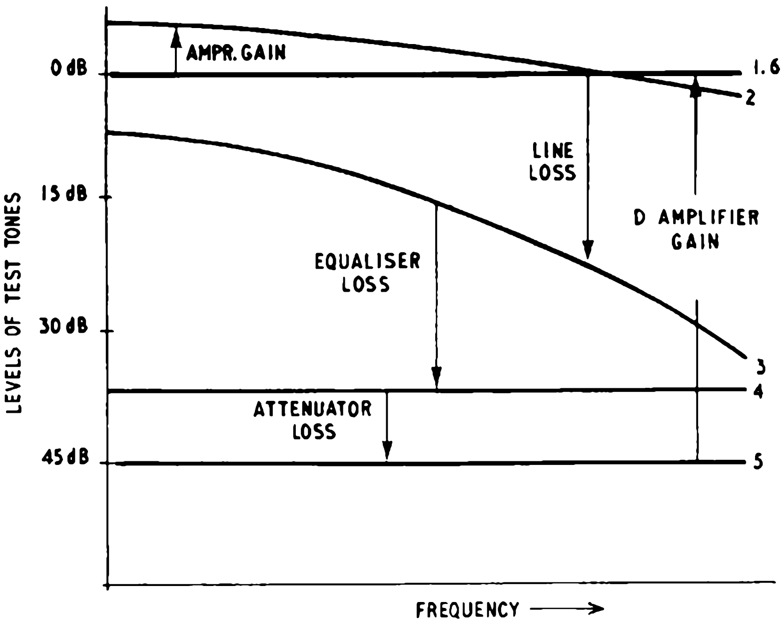


Fig. 2.19. Frequency response and levels at different points in the control room link of Fig. 2.17

frequency response. An example of an equaliser correcting for h.f. loss in the line is given in Fig. 2.18 (a) and its frequency response is shown in Fig. 2.18 (b). The *LC* and *R* component values are chosen to give a response over the a.f. band which is the reverse of the line response, so that the variation in levels and frequency response at the points 1, 2, etc., marked in Fig. 2.17 are as indicated in Fig. 2.19. Horizontal line 1 represents the input level (usually 0 dB) to the C amplifier at the initiating control room. The C amplifier increases the general level by about 4 dB and its output will have a frequency response similar to that shown by curve 2. The shape of this curve is dependent on the input impedance variation of the line and on the output impedance of the C amplifier. The level at 3 falls due to the over-all loss of the line and to its high frequency discrimination so that frequency response is as shown by curve 3. The frequency-selective attenuation of the equaliser restores the frequency response to a straight line 4 but increases further the over-all loss. An attenuator is included after the equaliser to reduce the level to a standard value of —45 dB and the D amplifier brings this level back to 0 dB (line 5).

When connected to a P.O. line the C amplifier output impedance is maintained at 600 Ω, and examples of this type are the TV/18, TV/20 and C/8 amplifiers. Sometimes, however, the C amplifier is required to feed a ring main supplying programme listening circuits whose load is very variable. A very low output impedance (5 Ω) is then required of the amplifier and examples of this are found in the TV/19 and TV/21 amplifiers. The C/9 amplifier can be used for either purpose, its output impedance of 126 Ω being increased to 600 Ω by series resistors or reduced to 4·5 Ω by a 5·5 to 1 matching transformer.

2.8.2 *Amplifiers and Monitoring Apparatus*

General purpose amplifiers (GPA) are used in the A, B and D positions in the programme chain; thus a modified form of the GPA/4 (the AMC/5) is used in the A and B positions of the Type B studio equipment (Fig. 2.14) whereas the GPA/4A is normally used in the D position. The D amplifier, type GPA/4A, has a constant resistive input impedance of 600 Ω with an input attenuator variable in 0·5 dB steps. This enables the equaliser to be correctly terminated and the amplifier output level to be set very closely to the standard zero level (0 dB) of 0·775 volts on line-up tone at 1 kc/s.

The monitoring amplifier is an essential part of the control-room equipment and there are two important types, the MNA/1 and MNA/3, the latter being a miniaturised version of the former. The circuit is similar for both types and provides an output for a monitor loudspeaker and also an output to the meter measuring programme volume. The loudspeaker provides means for checking aurally programme continuity, loudness, quality and distortion, as well as for observing noise and other faults. It is also necessary to have visual indication of programme volume so as to ensure satisfactory transmitter operation without overload. For this purpose the BBC uses a peak-voltage measuring device, known as a Peak Programme Meter[5], which has the merit of giving sufficient indication of relative loudness to allow an operator to control the programme in a manner to prevent it being masked by noise in the transmission path. A schematic diagram of the BBC Peak Programme Meter circuit is shown in Fig. 2.20. The peak value of the programme voltage level is rectified by two diodes, one of which deals with positive peaks and the other with negative. The charge rate of the capacitor C is very rapid (about 2 milliseconds) but the discharge rate is slow (about 3 seconds). This has two advantages,

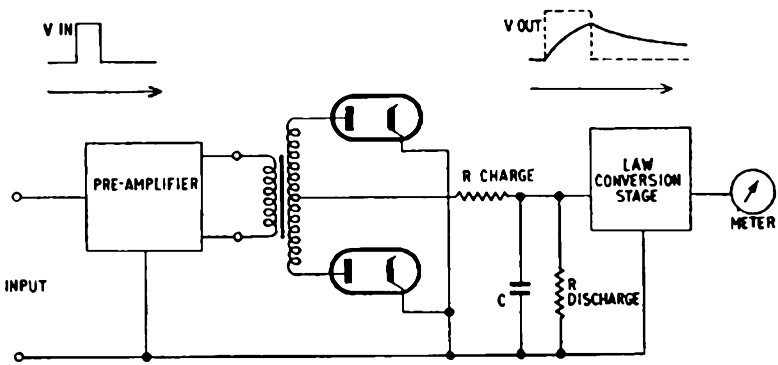


Fig. 2.20. Simplified diagram of the BBC peak programme meter circuit

namely, the meter at the output is subjected to less violent movement, which reduces the strain of reading it, and it gives some idea of average programme volume. The output from the capacitor is fed to a valve stage in whose anode circuit the meter is placed. This valve circuit is specially designed to give an anode current proportional to the logarithm of the peak input signal over a limited range of signal, so that the meter gives a linear indication of the volume in decibels.

The meter itself is a moving-coil d.c. type with a right-hand zero. This is necessary because to achieve an approximate logarithmic law, the valve must be biased negatively by the peak output from the capacitor and the larger the peak signal is, the smaller is the anode current.

The divisions on the meter scale are numbered 1 to 7. From 2 to 7, the divisions represent changes in programme volume of 4 dB; the change between divisions 1 and 2 is slightly greater. Programme volume is normally so controlled that the meter operates between divisions 1 and 6 giving a programme range of approximately 22 dB. Division 6 represents the volume that corresponds to 100 per cent modulation of a transmitter. Transient peaks to 7 may occur but provision is made at transmitting stations to prevent such peaks from causing damage to the transmitter. If however the normal programme volume is allowed to peak consistently to 7, the transmitter may very well be overloaded and put out of action.

2.8.3 *Programme Switching Systems*

In the control room itself one of the most important operations is that of correctly linking sources and destinations and this involves either switching or plugging. An early method used change-over relays, which are in effect remotely-operated switches, and the system was known as 'B' and 'C' input switching. Banks of remotely-operated relays allowed any source to be connected to any one B input fader, each fader having as many relays as there were sources. A similar scheme connected each B amplifier output to a C amplifier input.

This scheme was discontinued with the outbreak of war and was replaced by a plug and jack system in conjunction with OBA/8 equipment. This method has the merit of versatility but suffers from the disadvantage that it requires considerable physical activity from the operator, and the location of faulty apparatus usually takes longer. Some OBA/8 control rooms are still in use so that a brief description of the general principles involved is required. Each jack has inner and outer contacts which are broken on the insertion of the plug, Fig. 2.21 (a). The sleeve of the plug connected to the red lead of the cord makes contact with the jack body, 1. The tip (white lead in the cord) makes contact with 4 and the blue lead in the cord with 2, at the same time breaking the switching to the inners 3 and 5. On apparatus bays the jacks are normally arranged in banks of three as shown in Fig. 2.21 (b). The banks are sometimes arranged vertically as shown and sometimes horizontally. In a vertical bank, the lower jack has the programme source connected to its *outers* and is designated Line Jack. The *inners* of the lower jack are permanently connected to the inners of the middle jack called the Apparatus Jack; the outers of the Apparatus Jack are connected to the input or output of the apparatus, e.g., amplifier, equaliser, etc. A parallel connection is taken from the outers of the apparatus jack to the outers of the top jack which is called the Listen Jack. Jacks on an apparatus bay are usually mounted in rows or strips, a number of strips being called a jackfield and coded, e.g., JF/3 indicating 3 rows in the field.

The advantages of this three-jack method of distribution are that faulty lines or apparatus can easily be taken out of circuit and replaced by spares; when, for example, an amplifier is faulty, this operation, sometimes called cross-plugging, involves plugging from the line jack of the faulty 'amplifier in' bank to the apparatus jack of the 'amplifier in' bank for the spare amplifier, and from the apparatus jack of the spare 'amplifier out' bank to the line jack of the faulty 'amplifier out' bank.

The need for quick selection and routing of programmes together with their communication and cue circuits has led to the use of

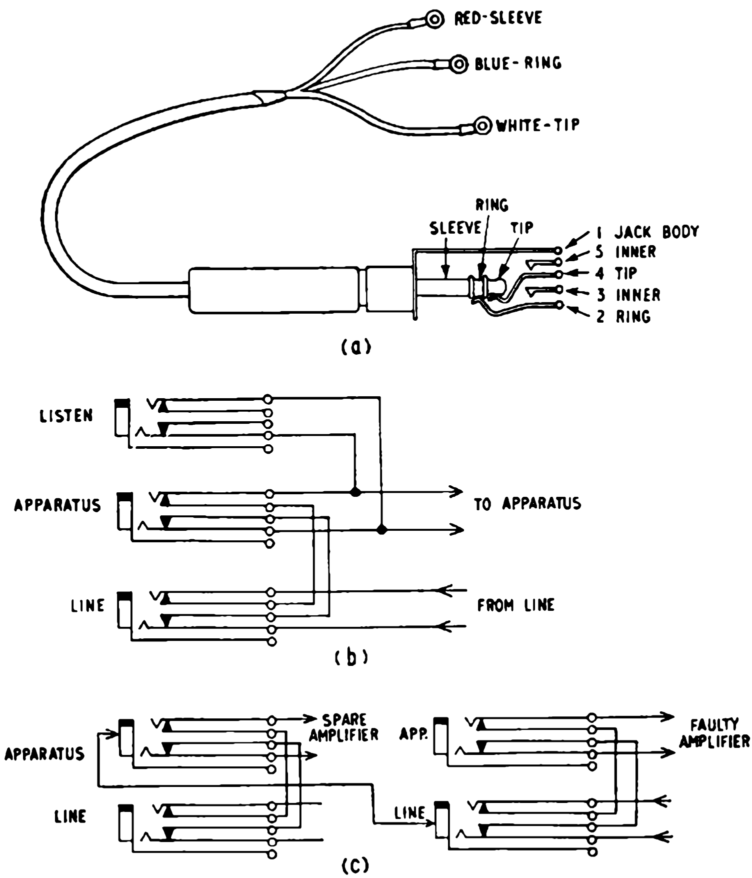


Fig. 2.21. (a) Plug and jack connections; (b) jack connections providing listen, apparatus and line facilities

uniselectors similar to those employed in automatic telephone exchanges. A photograph of the uniselector is shown in Fig. 2.22 and it is seen to be a motorised rotary switch to which tie lines from sources are connected. The rotor makes two revolutions per second when driven, and its contacts are connected to a destination. The wiring is arranged so that a line from a particular programme

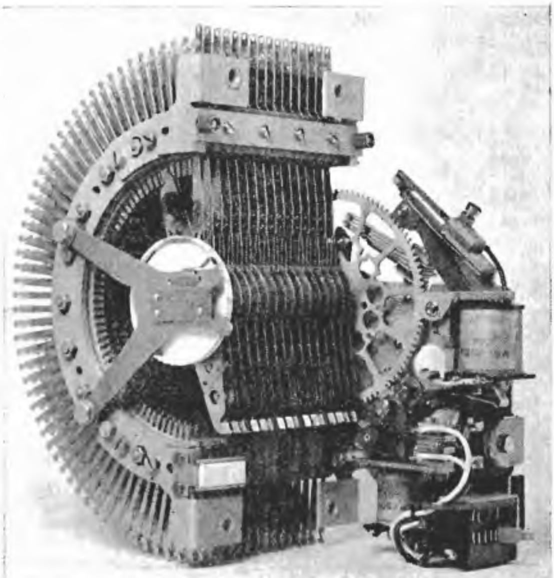


Fig. 2.22. Motorised uniselector switch (by courtesy of Associated Electrical Industries)

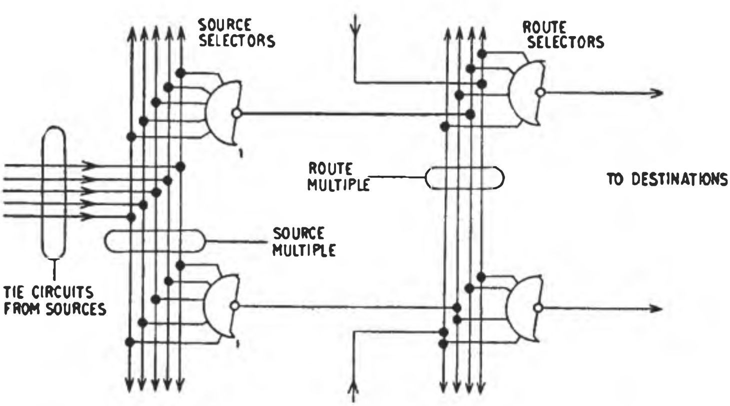


Fig. 2.23. Source and route selection by uniselector

source is connected to a given contact on all the uniselectors in a given group as shown in Fig. 2.23 and these interconnections are known as a 'source multiple'. Each uniselector has sixteen rotating wipers mounted radially one behind the other along the driving axis. Each wiper tracks over fifty-two stationary contacts, which are arranged in sixteen semi-circular arcs in a contact bank. Fifty of the stationary contacts can be used for programme or other switching; they are called 'outlets' and the fifty outlets plus their associated wiper are collectively known as a 'level'.

In a typical control room the sixteen levels of the source selector may be allocated to the following uses:—

Levels 1 and 2	Programme circuits
3 and 4	Cue programme circuits
5 and 6	Telephone circuits
7 and 8	Telephone control lines
9	Programme routing indicator lamp
10	Remote recording machine starting relay
11	Remote recording machine set-up lamp
12	Studio signalling and remote reproduction start
13	Operates the units lamps on the indicator panel to show which programme source is switched in
14	Operates the tens lamps on the indicator panel
15	Marking levels for units
16	Marking levels for tens

The important levels are 1 and 2 concerned with programme switching and 15 and 16 with marking.

Pre-selection of a source is carried out on code switches arranged in two ranks, one representing units and one tens. Thus if a studio coded 26 is required, the push button marked '2' on the ten level is pressed and '6' on the unit level. This marking operation determines where the uniselector motor will come to rest when the starting switch called 'Select Switch', 'Operate Key' or 'Master Operate Button' is pressed, and in the particular case quoted, the uniselector rotates until the wipers in the levels 1 and 2 reach the stationary outlets carrying the programme from the studio coded 26. Operation of the press-button pre-selection marker switches prepares a circuit involving levels 15 and 16. This circuit has associated with it a high-speed relay which interrupts the selector motor supply and applies a brake which arrests the wipers in a position of correct contact with the stationary outlets. The correct rest position is found by searching for a completed circuit which includes battery, earth, the high-speed relay and the pre-selection switches. If the relay should fail to operate, the selector continues to rotate and an alarm circuit warns the operator of this fact. There is danger of overheating the motor windings if the drive is continued for any

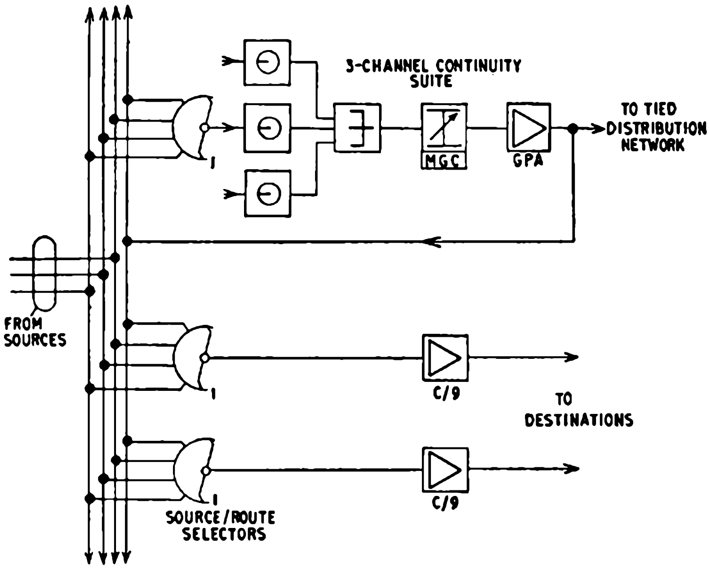
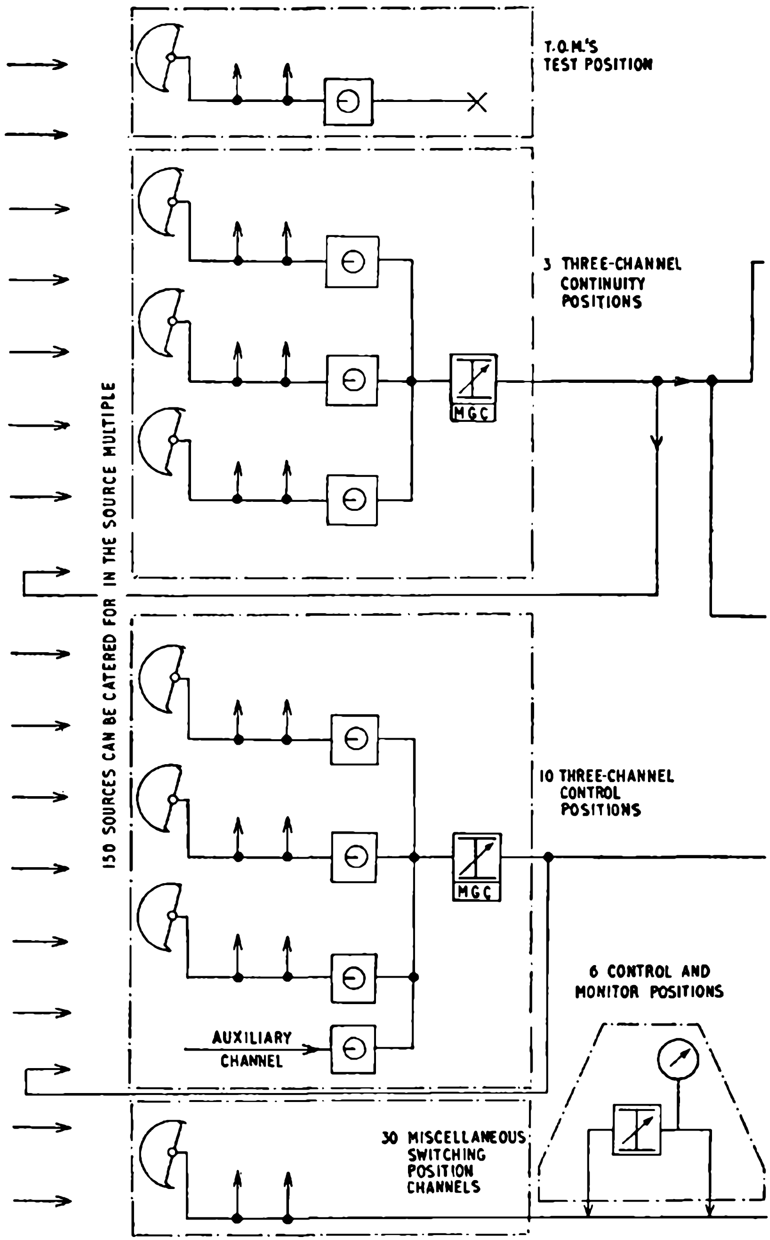


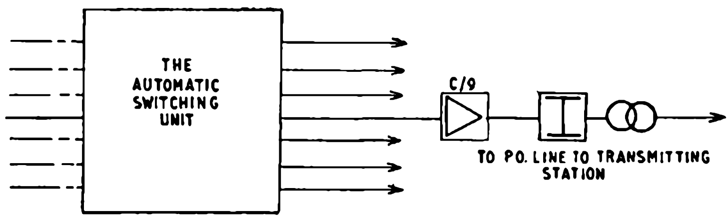
Fig. 2.24. Schematic diagram of the Glasgow uniselector control room

length of time, and the selector must not be allowed to make repeated efforts to find its rest position.

The planning of a particular uniselector control room depends on what facilities are required and it will be clear that a Regional Control Room will require much less than a Central Control Room such as the one at Broadcasting House or at Bush House. The arrangement used at Glasgow and other regional stations is shown in the schematic diagram of Fig. 2.24, which has been simplified to show only the switching circuits for the programme lines. The cue programme, telephone and signalling circuits associated with each programme circuit are not shown, neither are the equalisers and amplifiers required for the S.B. and O.B. sources indicated before the source multiple. A monitoring system is incorporated so that an operator can quickly and easily check that the instructions fed to the uniselectors and their subsequent actions are correct.



T.O.M.'S
TEST POSITION
3 THREE-CHANNEL
CONTINUITY
POSITIONS
MGC
150 SOURCES CAN BE CATERED FOR IN THE SOURCE MULTIPLE
10 THREE-CHANNEL
CONTROL
POSITIONS
MGC
6 CONTROL AND
MONITOR POSITIONS
AUXILIARY
CHANNEL
30 MISCELLANEOUS
SWITCHING
POSITION
CHANNELS



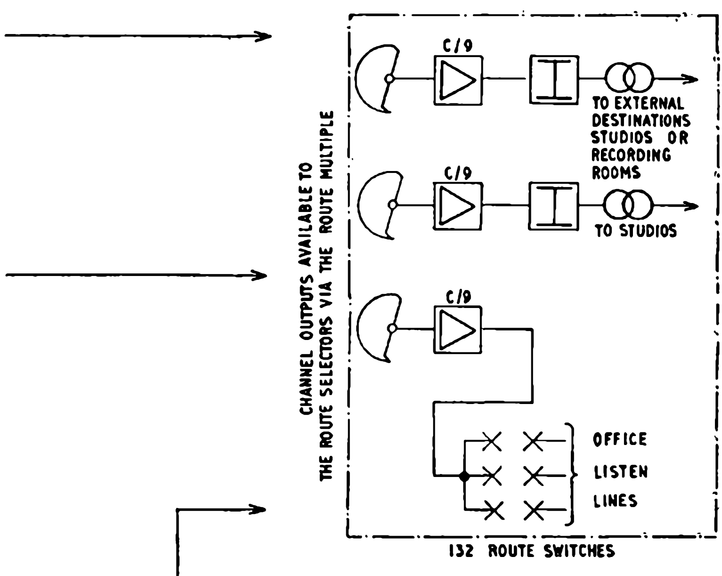


Fig. 2.25. Schematic diagram of the Bush House control room switching

Broadcasting House Control Room. The programme chain schematic diagram for Broadcasting House (London) is very similar to that for Glasgow. Single-banked direct Source/Route switching is employed but in order to reduce the number of programme switches the 200 programme sources have been divided into four groups of fifty, designated A, B, C and D.

The A and B groups contain those sources which require all facilities such as cue programme, telephone, studio signalling and remote start circuits, and therefore use all the available levels on a standard uniselector. The C and D groups contain the programme sources which need fewer associated subsidiary circuits, e.g., O.B. and S.B. circuits. The C and D groups of sources are connected to a single set of uniselectors, each group being allocated only a few of the sixteen available levels on a standard uniselector; thus the output from a Group C source appears on some of the wipers and that from Group D on others of the same uniselectors. In this way groups of three selectors are made to serve 200 sources whereas normally they could only deal with 150. Smaller uniselectors, with fewer levels are used for those destinations which have few facilities to be extended to the sources.

Since there are 200 sources the marker push-button system must allow the particular group as well as the source number in the group to be selected. This is achieved by adding another row of push buttons designated A, B, C and D. Thus the sources are coded A00–A49, B00–B49, C00–C49 and D00–D49 and only the particular uniselector A, B or C/D is driven when the select switch of a particular channel is operated. The operating controls for the respective uniselectors are situated at the despatch position, continuity positions, control positions and the miscellaneous switching position.

External Services Control Room. The arrangements at Bush House Control Room are different from those at Broadcasting House, route as well as source selectors being used. The 150 programme sources are given full facilities (similar to groups A and B at Broadcasting House) and three standard 16-level selectors are provided for each channel, each selector accommodating 50 programme sources. The 150 programme sources are coded A00–A49, B00–B49 and C00–C49, and are marked up on three rows of push buttons designated ABC, 0 to 4 and 0 to 9. The source selectors switch mixer and MSP channels to sources; the outputs of continuity and control positions and the 30 MSP channels are connected to the route multiple, which contains 132 route switches.

A simplified schematic diagram of the Bush House control room switching arrangements is shown in Fig. 2.25: the 43 switching tie lines connect to three continuity-suite three-channel positions, ten three-channel control and continuity positions and a miscellaneous switching position of 30 single channels. In addition there is a technical operation manager's supervisory position which gives access for testing purposes to all programme sources. The three continuity suites and the control positions allocated to other networks are tied to the automatic switching unit (ASU) which switches them as required to the lines going to the transmitters. Any one of the 30 Miscellaneous Switching Position (MSP) channels may be used to switch any one of the 150 sources to one or more routes. Associated with six of the MSP channels are six control and monitor positions on which aural and visual monitoring or control may be conducted. All route selectors have access to all 150 sources via MSP channels; each selector is followed by a C/9 amplifier, an attenuator pad and a transformer, which is then connected to a destination line. The destination may be a studio outside source line, recording room, line to Broadcasting House, etc., listening room or ring-main listening line.

Automatic Switching Unit. The automatic switching unit is a device which automatically connects the continuity outputs to the P.O. lines to the External Services transmitting stations. It stores all the information necessary for repeating a twenty-four hour programme schedule and does this by means of a coding selector associated with a programme selector as shown in Fig. 2.26. Transmission schedules are changed six times a year and the marking code selector is set to conform by insertion of appropriately coloured combs against time scales. Daily amendments may be dealt with by insertion of combs or by over-riding. Each coding selector motor receives an impulse every quarter of an hour to step it on to the next set of contacts and it returns to its starting position every twenty-four hours to begin a repeat of the schedule if no change has been made in the combs. The coding selector sets up a series of relays which mark the associated programme selector, and when the programme switching pulse is given to the programme selector motor, it homes on to the contact which has been specially marked by the code selector, thereby connecting the appropriate programme to its own line to a transmitting station.

The automatic switching unit is controlled from a master clock which has duplicate timing units C1A and C1B. Only one is in use for controlling the coding and programme selector motors and both are similar to all the other motor units. A comparator is maintained in balance as long as both units are functioning correctly; the units are stepped on every half minute during the

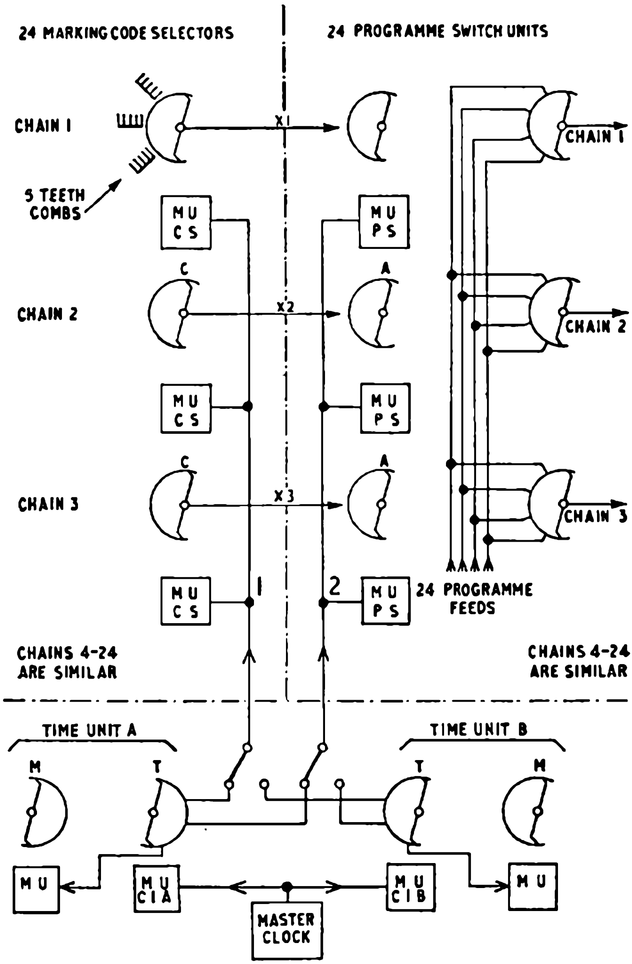


Fig. 2.26. Schematic diagram of the automatic switching unit

first 14½ minutes of every quarter of an hour and on every two seconds for the last half minute, making a total of 44 steps. The rotor of the timing motor provides a pulse on line one at quarter-hour intervals to operate the coding selector motors CS which set the coding switches to their correct positions just after the beginning of the quarter-of-an-hour period at the end of which the change has to be made. The marking code and programme selectors are triggered by one of the duplicate timing units; these each consist of two motor uniselector switches and associated relays. If the duty and stand-by timing units get out of synchronism a 'time synchronising alarm' is sounded. Both are controlled by a master clock, itself controlled by Greenwich time signals. The duty timing unit integrates timing pulses from the clock and triggers the marking code and programme selectors at 15-minute intervals so that programme chains are switched as marked by the Marking Code Selector. The programme selector motors (PS) are given the release signal so that they can home to the marked contacts at 18 seconds before the quarter-of-an-hour period is due to begin, the signal being sent from the timing unit by line two. This allows time for switching operations at the transmitters. At the end of the 24-hour period the coding and quarter-hour units are back to their starting point ready to establish the programme routing for the following day.

2.9 CONTROL ROOM TEST PROCEDURES

In order to maintain satisfactory technical quality of outgoing programmes from a control room it is not only necessary to listen to the programme from time to time but it is also essential to make measurements on the apparatus and the lines carrying the programme. This section deals with the test apparatus and procedures involving daily, monthly and quarterly routine tests.

2.9.1 *Daily Tests*

Routine tests are carried out daily on studio and studio cubicle equipment and on the S.B. system.

Studio Testing. Checks are made daily by control room staff on equipment in studios and studio cubicles. The first task is to ensure that all circuits to the control room are in working order. Tone (1 000 c/s available at zero level on the studio desk) is generally used and the cubicle programme meter zero level setting (4 divisions on the meter) is checked at the same time against a standard meter in the control room. Microphone leads, sockets and faders are tested for mechanical faults and microphones are checked by speech. The gramophone desks are tested for sensitivity by means of tone specially recorded on disks, and the standard test recording, Teddy Bears' Picnic, is also used. As a rule all tie-lines for carrying outside sources from the control room are also tested.

Testing the S.B. Chain. A line-up test on the S.B. chain is usually carried out before a programme is scheduled to start or when there is a convenient break. Amplifier gains are adjusted at specified points in the chain so that the level remains constant from day to day. Test tone is provided by a 1 000 c/s oscillator and the measuring instrument is generally a test programme meter (similar to a peak programme meter). At the programme source the tone is injected into the amplifier to give an output reading of 4 divisions on the peak programme meter and this reading must be repeated at selected points in the chain right up to the transmitter. The amplifiers whose gains are to be adjusted during line-up are clearly indicated and it is essential that at each point the tone level is correctly adjusted, otherwise distortion can result. It is also essential that any correcting action for low gain shall take place at a stage prior to the fault condition. If this is not done and the gain is increased at some subsequent point, signal-to-noise ratio will suffer, and what may be more serious, the following programme, which might be from another source without the fault condition, could be switched in before the additional gain had been removed. It would then be reproduced at far too high a level causing distortion, overload and possible damage to apparatus. When the line-up tone at 4 divisions on the peak programme meter reaches the transmitter the modulator circuits are adjusted to give 40% modulation, which means that when a reading of 6 divisions (8 dB greater) is obtained, the transmitter is 100% modulated.

2.9.2 *Monthly and Longer Period Tests*

The less frequent and more comprehensive tests occur about once every month or every quarter, and the following measurements are generally made:

(1) the gains of amplifiers and losses of attenuators,

(2) the over-all frequency response of amplifiers and chains,

(3) the total harmonic content,

(4) the noise content of the programme chain.

These results are recorded and indicate any long-term deterioration. The measuring equipment is known as the AC Test Bay[6];

there are two types in current use and they contain the following apparatus:

	AC/49 (*22″ bay*)	*AC/55* (*19″ bay*)
Fixed frequency oscillator	OS/9	OS/10A
Variable frequency oscillator	TS/9	TS/10
Amplifier Detector	AD/4	ATM/1
Test Programme Meter	TPM/3	
Filter High Pass	FHP/3	FHP/3A
Aural Sensitivity Network	ASN/1	ASN/4
Jackfield		
Mains Units, etc.		

On the AC/49, there are two tone sources (oscillators) for supplying the input test frequencies. The OS/9 provides the 900 c/s fixed-frequency output, whereas the TS/9, a Wien bridge RC oscillator, provides frequencies covering the range from 40 c/s to 20 000 c/s. The TS/9 has attenuators providing outputs from —50 to +20 dB with reference to zero level (1 mW in 600 Ω or a voltage of 0·775) when the output voltmeter is set to a special mark on its scale. Other variable tone sources may be used such as the TS/7 beat-frequency oscillator.

A valve voltmeter called the Amplifier-Detector (Amp. Det.) type AD/4 is used to measure voltage. The AD/4 has a comparatively high input impedance (about 30 kΩ) and this allows it to be connected across any 600 Ω circuit without noticeably affecting the voltage at that point. When using the amplifier-detector care must be taken to ensure that apparatus requiring a 600 Ω termination has already been terminated in this value, otherwise the reading obtained will have little significance. The amplifier-detector has a pre-amplifier with a gain of 55 dB so that the normal deflection mark 0 dB on the meter corresponds to a signal —55 dB with reference to zero level of 0·775 volts. The meter is calibrated in 0·2 dB steps up to 1 dB and in 0·5 dB steps from 1 dB to 2 dB on either side of the zero dB mark. In some equipments the 0·2 dB divisions are continued to 2 dB. Two variable attenuators are connected in the pre-amplifier circuit. These are the main controls of the unit; one attenuator is calibrated in steps of 5 dB from —50 to +10 dB; the other is calibrated in steps of 0·5 dB, from —5 to zero, to allow for intermediate values.

A high-pass filter FHP/3 is available for harmonic distortion measurements; the fundamental and harmonic outputs are measured on the amplifier-detector with the filter out of circuit and then with the filter inserted to remove the fundamental. The ratio of harmonic to fundamental plus harmonics is expressed in dB as the distortion figure for the apparatus under test. There are two sections to the filter and either can be selected by a switch. In one position the high-pass filter attenuates 100 c/s and in the other 1 000 c/s by approximately 60 dB. Measurements can therefore be made of harmonic distortion for a 100 c/s and a 1 000 c/s input frequency.

A special network having a frequency response somewhat like that of the ear and known as the aural sensitivity network (ASN) is employed for noise measurement in order to obtain a reading more nearly corresponding to the nuisance value of the noise. A test programme meter similar to the peak programme meter is used for the noise measurement instead of the amplifier-detector.

Turning now to the routine measurements themselves, let it be assumed that the gain of a C amplifier, which is lined up to give an increase of 4 dB, is to be checked. The TS/9 tone source, terminated in 600 Ω and set to give 0 dB output at 1 000 c/s, is connected to the amplifier-detector whose attenuator controls are set to 0 dB. The amplifier-detector 'adjust gain' control is operated to give a reading of 0 dB on the amplifier-detector meter. The output from the TS/9 is now transferred to the input of the C amplifier, which itself has a high input impedance and therefore requires the 600 Ω terminating resistor for the TS/9 to remain in circuit. The amplifier-detector attenuators are set at 4 dB loss; the output of the C amplifier terminated in 600 Ω is connected to the amplifier-detector and the gain of the C amplifier adjusted until a meter reading of 0 dB is obtained. The C amplifier can now be inserted in the programme chain between 600 Ω terminations and will give a gain of 4 dB. If it is not correctly terminated in 600 Ω at the output terminal the gain will be other than 4 dB; thus with no resistance across its output terminals the voltage will be twice its value when terminated by 600 Ω and the amplifier will give a voltage gain of 10 dB (6 + 4). The C amplifier may in fact be connected to a line only nominally of 600 Ω impedance and its gain will not then be exactly 4 dB.

Whilst lining-up the amplifier by using the above procedure a 600 Ω shunt resistor is connected across the TS/9 output terminals, but for the routine month-to-month measurements it is omitted because there is no guarantee that exactly the same resistor will be available, and the small variations of gain due to using another resistor of the same nominal value would mask a gradual deterioration in amplifier performance. In this test, which is known as the '600 Ω Gain Test' because the amplifier is connected to a 600 Ω source and is terminated in a 600 Ω measuring instrument, the

TS/9 tone source without the 600 Ω across the C amplifier input delivers an output voltage 6 dB higher than that shown on the calibrated output attenuator dials. Consequently, there will be a discrepancy of approximately 6 dB between the 'working (600 Ω input termination)' condition and the measured 600 Ω gain test result.

The procedure used for the '600 Ω Gain Test' is repeated for the overall frequency response test, except that the frequency of the

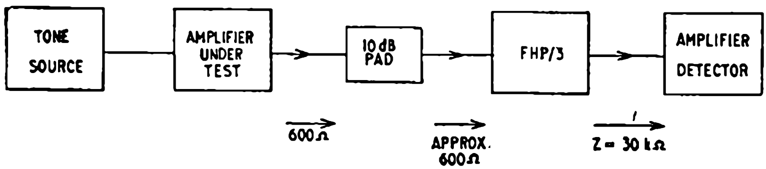


Fig. 2.27. Measurement of total harmonic content

input is varied over the a.f. range and the output level is noted on the amplifier-detector.

A schematic diagram of the harmonic content test is shown in Fig. 2.27. The output of the amplifier under test is connected through a 10 dB attenuator pad to the high-pass filter FHP/3 which is correctly terminated internally. Measurements of fundamental-plus-harmonic and of harmonic output from the filter are made

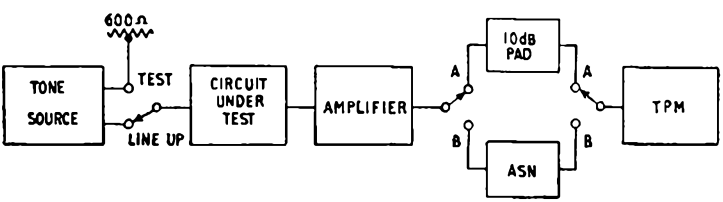


Fig. 2.28. Measurement of noise content

by the amplifier-detector using the high input impedance terminals with the input tone and the frequency selector switch on the filter set at 100 c/s or 1 000 c/s.

If, for example, the fundamental-plus-harmonic output registers −10 dB, and the harmonic output alone gives −55 dB, then the harmonic distortion content is −45 dB corresponding to a total harmonic percentage of 0·562.

Noise measurement is carried out with the test programme meter as the measuring device and a schematic diagram of the apparatus is shown in Fig. 2.28. The circuit includes a 10 dB pad or an aural sensitivity network before the test programme meter (TPM). The aural sensitivity network which takes into account the response of the ear at different frequencies introduces a loss into the circuit even at its mid-frequency (approximately 6 000 c/s) and the 10 dB pad is included in the alternative path to compensate for this. A C amplifier having a gain of 10 dB neutralises the loss in the pad and brings the input to the test programme meter up to the output from the circuit under test. With the 10 dB pad switched into circuit, 1 000 c/s tone is applied at the input to the test circuit which is lined-up to give a reading of 4 divisions on the TPM. The tone source is now switched out of circuit and is replaced by a 600 Ω resistor (the output impedance of the tone source) and the attenuator associated with the test programme meter adjusted until a reading of 6 divisions is obtained. The reading of 6 divisions is the value which would be obtained under maximum signal conditions, so that the amount of attenuation removed represents the maximum signal-to-noise ratio separation but it is an ' unweighted ' value, which does not represent the nuisance value. To obtain the latter the aural sensitivity network must replace the 10 dB pad, and the TPM attenuator must be readjusted to give a reading of 6 divisions. The total attenuation removed represents the 'weighted' noise separation.

2.9.3 *Interpretation of Test Results*

The tests described above can be used by the maintenance engineer to indicate possible faults on apparatus which is out of tolerance; thus if the gain of an amplifier is low, valves are likely to be the cause, but if there is no improvement by changing them then it is probable that the fault is due to a shunt component like a decoupling capacitor which has short-circuited or to a low h.t. supply voltage produced by a high resistance in the smoothing choke or smoothing resistance. Under some circumstances gain may be greater than normal and this would point to an open-circuited decoupling capacitor, a disconnected voltage negative-feedback control or an increase in resistance in this control. Departure from the flat frequency response is normally the result of change of component value, thus attenuation of low frequencies could be due to a partial open-circuited coupling or cathode by-pass capacitance, whereas high-frequency loss could be due to a reduction in grid-leak resistance. A fault on a transformer will also produce an effect on the frequency response, but it is generally associated with low gain. When an appreciable noise interference appears to be present, the ASN circuit can be used to determine whether the noise is due to hum produced by a fault on the heater or h.t. supply or to supersonic noise produced by spurious oscillation from a negative feedback circuit or other cause.

A listening test with the aural sensitivity network switched in and out will confirm whether the noise is low-pitched hum or inaudible noise.

2.10 RECORDING AND REPRODUCTION OF SOUND PROGRAMMES

2.10.1 *Introduction*

The chief advantage gained by recording broadcasting programmes is that a complete programme in, say, the Home Service, can be repeated in the same or some other service at a later time or date. Other advantages are: (1) the recording can be made at a time convenient to the artiste, (2) the programme if unrehearsed can be edited to pick out the 'highlights' and improve its programme interest, and (3) the programme even though broadcast at the time of its origination may have historical significance, and be required for archive purposes.

Another important use of recordings is for providing special sound effects, such as the starting of a car, needed from time to time for programme inserts.

Two systems of sound recording are at present operated by the BBC: one uses magnetic tape, the recording occurring on the tape as variations of magnetic flux throughout its length, and the other uses lacquer-coated disks, on the surface of which is inscribed a spiral groove containing lateral variations corresponding to a specially modified form of the sound signal. Magnetic tape accounts for about 75% of the BBC recordings but it is interesting to note that about 1 500 disks are still cut each week. Tape recording has the economic advantage that the material on which the recording is made can be used again and again, since the original signal can easily be erased and another substituted. On the other hand, if permanent copies of a recording are wanted for archive or other purpose, pressings can be obtained from disks whereas there is no economic method of processing magnetic tapes.

It is however common practice for the original recording to be made on tape and re-recorded, or 'dubbed' on to disks for processing.

Another advantage of tape recording is that reproduction can be carried out with little wear and negligible loss of quality whereas the quality of the signal from a lacquer-coated disk deteriorates due to groove wear and deformation with repeated replay. Tape will as a rule enable a much longer recording to be made before a change-over from one spool to another is required, and there is no loss of quality corresponding to that which occurs as the spiral groove approaches the inside of the disk. On the other hand, quick editing is easier with a disk since the signal is spread out over the surface and any part can readily be selected.

The principal recording centres in London are at Broadcasting House (Home Service), Bush House (Overseas Services) and Maida Vale where the Transcription Service records disks and tapes for use by overseas broadcasting services. On special occasions the functions of all these services may combine or overlap. The normal twin-machine tape channels permit a continuous recording or reproduction to be made, with a smooth transition from one tape to another without the listener being aware of it. Direct disk recording machines are installed in pairs for the same reason. Similar facilities are provided at the regional studio centres.

In London, there are central recording and reproducing rooms containing up to 16 tape recorders, all of which can be remotely operated from studios and continuity suites. Generally 3 staff members are required for the 16 tape recorders and they deal with pre-transmission and line-up tests and with loading and rewinding of tape spools. There are also special rooms for tape-editing.

Battery-operated midget tape recorders are available for the use of news, talks and features producers who may wish to make on-the-spot recordings in street, factory, etc. The Outside Broadcast Department has tape recorders installed in cars and these are used for recording programmes far from any suitable P.O. line. Each installation has microphones, amplifiers and the necessary connecting cables. Disk recorders installed in cars are also available for special purposes.

The Transcription Recording Unit at Maida Vale normally records the programme on tape before copying it on to a disk for processing; the disks are sent to commercial gramophone companies for processing, and the pressings are returned to Transcription Unit for despatch to overseas broadcasting organisations.

2.10.2 *Principles of Magnetic Recording*

One of the important problems in any form of recording is to prevent 'wow' and 'flutter'. Wow is characterised by a slow variation in the pitch of what should be a sustained note whereas flutter is a variation in pitch at a frequency rate greater than about 20 c/s. Both types of interference are due to speed fluctuations in the driving system and it is therefore essential that the magnetic tape should be driven at a constant speed past the recording and reproducing heads.

The tape must also be prepared for recording by bringing it to a state of non-magnetisation. This is achieved by subjecting it to a high-intensity varying magnetic field at a frequency within the range

25 to 100 kc/s, a typical value being 75 kc/s. Fig. 2.29 is a diagrammatic representation of the process. As the tape enters the magnetic field of the erase head it is subjected to rapid variations which reach a maximum when the tape is at the centre of the gap.

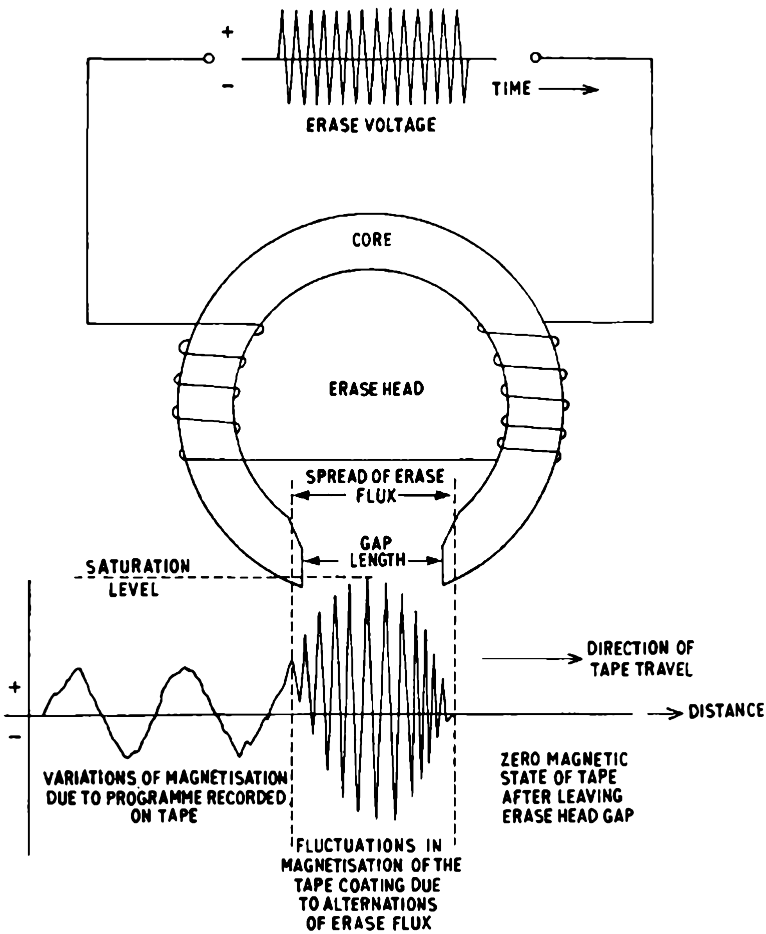
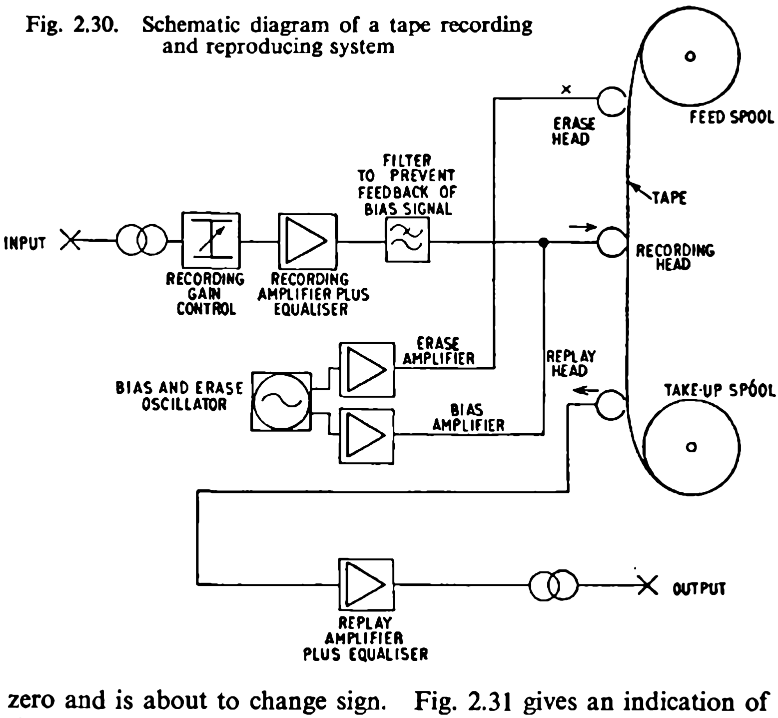


Fig. 2.29. Action of the erase head

Thereafter the amplitude decreases and eventually becomes zero so that when the tape leaves the erase head field it is completely demagnetised and free from any previously-recorded programme as well as almost entirely free from any random variations of magnetic flux, which might produce noise when the tape is being replayed. The same principle is used to demagnetise the hair spring of a watch but in this instance a much lower frequency (the 50 c/s mains frequency) is employed.

A schematic diagram of the complete recording and reproducing process is shown in Fig. 2.30, and it is seen that from the erase head the tape passes to the recording head to which the signal to be recorded is applied. If this signal is the only one applied to the head, the remanent magnetism left on the tape after passing the head is non-linearly related to the recording magnetic field, particularly at the point where the remanent magnetism approaches

Fig. 2.30. Schematic diagram of a tape recording and reproducing system



zero and is about to change sign. Fig. 2.31 gives an indication of the recorded signal distortion for a sinusoidal recording signal. Distortion can also occur on the peaks of the signal if the recording intensity is so large that the tape approaches the saturation condition. The distortion at the centre of the waveform can be almost entirely eliminated by applying a supersonic signal as well as the desired signal to the recording head. For convenience the frequency of the bias signal is the same as that supplied to the erase head.

The function of the supersonic bias signal can be stated quite simply: it is to make linear the remanent flux-magnetising force

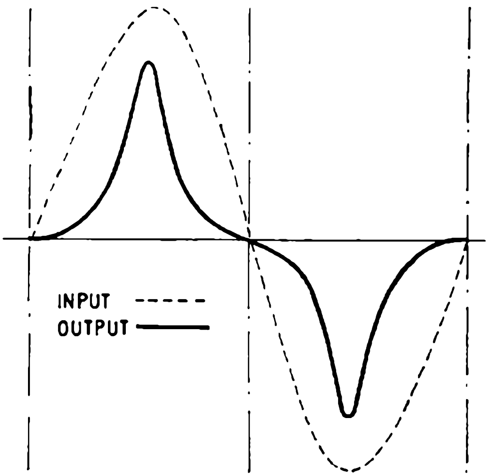


Fig. 2.31. Reproduced waveshape when a sinusoidal tone input is applied alone to the recording head

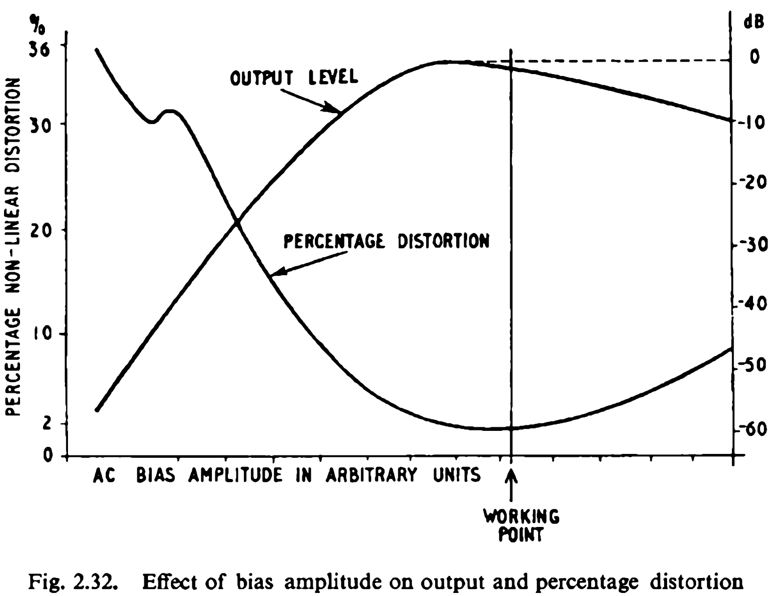


Fig. 2.32. Effect of bias amplitude on output and percentage distortion

characteristic of the tape: a simple explanation of how it achieves this has not been found and the magnetic conditions existing in the tape material itself are as yet only partially understood. It may be said with certainty that the combination of the bias signal with the recording signal produces a displaced or asymmetric bias wave of magnetic force, the degree of displacement being directly proportional to the voltage of the recording signal over the period of the bias wave.

This displacement determines the remanent flux left on the tape after leaving the head and by suitable adjustment of the amplitude of the bias wave the remanent flux can be made directly proportional to the displacement or asymmetry of the bias wave. An indication of the effects of variation of the bias amplitude on relative output level and percentage harmonic distortion is shown in Fig. 2.32 for a 1 kc/s input signal. Maximum signal-to-noise ratio is obtained at a bias amplitude greater than that required to give maximum output and minimum distortion.

The effective magnetisation on the tape is unfortunately dependent on frequency, and the higher frequency components of the recording signal have to be given increased amplitude to compensate for the increased iron loss in the recording head and the self-demagnetisation that occurs on the tape due to a reduction in wavelength as the frequency increases. By self-demagnetisation is meant the cancelling effect due to close proximity of points of opposite magnetic polarity on the tape. Equalisation must therefore be provided in the amplifier supplying the recording head. Self-demagnetisation is of considerable advantage in preventing the remanent recording of the bias signal on the tape. This could cause overload of the reproducing amplifier if it were reproduced.

The replay head is similar to the recording head and each has a non-iron gap. In the replay head the varying flux on the magnetic tape passing over the gap produces in the iron circuit of the head a flux variation similar to that on the tape. A coil wound over the iron translates these flux variations into voltage changes which are passed to the replay amplifier. The voltage developed across the replay coil is proportional to the rate of change of the flux and this causes a frequency response characteristic rising with frequency at the rate of 6 dB per octave at the lower frequencies. Increased low-frequency response must be included in the replay amplifier in order to offset this rising frequency response. The length of the gap is very important because if the wavelength recorded on the tape is equal to the gap length, flux variations in the iron core of the reproducing coil are very much reduced and produce opposing voltages in the two halves of the coil (See Fig. 2.33).

The frequency at which this marked reduction in output occurs is known as the extinction frequency and it should be placed well outside the audio-frequency range; at half the extinction frequency there is a loss of about 3 dB. The extinction frequency is directly proportional to the tape speed, and a typical gap width of 0·65 mil*

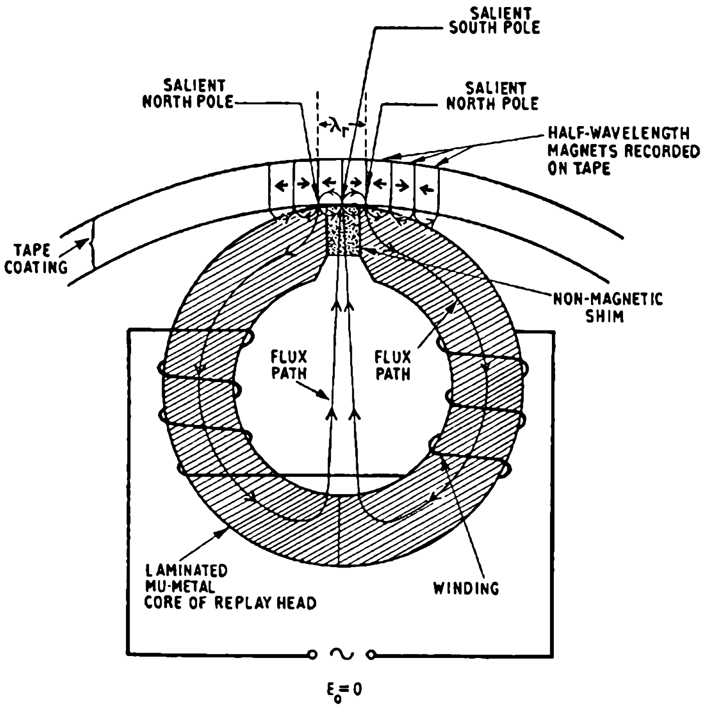


Fig. 2.33. Effect of gap length of replay head when the effective gap length is equal to the recorded wavelength of the extinction frequency

giving an extinction frequency of 11 500 c/s at 7·5 in./sec. produces an extinction frequency of 23 000 c/s at 15 in./sec. Gap misalignment effectively increases the gap length and reduces the extinction frequency. The response at the high audio frequencies is also reduced by losses in the iron core of the replay head, and equalisation is necessary in the replay amplifier to increase the response at these high frequencies.

* (1 mil = 1/1 000 in.)

2.10.3 *The Main Elements in Magnetic Recording Apparatus*

The main elements in apparatus for recording sound on magnetic tape are:

(1) the magnetic tape,

(2) the drive system consisting of a constant speed motor for pulling the tape, and two variable speed motors for spooling,

(3) the three heads, erase, recording, and replay,

(4) the erase and bias oscillator,

(5) the amplifier and equaliser for the recording signal,

(6) the amplifier and equaliser for the reproduced signal,

(7) miscellaneous items such as tape counter, stroboscope and control panel.

The Tape. The recording material is a plastic tape about 1·6 mil thick coated with iron oxide to a thickness of about 0·5 mil. The tape is 0·25 in. wide and about 2 400 ft is contained on a spool to give 32 minutes recording time at a speed of 15 in./sec. The iron oxide retains its magnetisation until a demagnetising signal is applied.

The Motor System. This is required to pull the tape past the heads at a constant speed and to spool and re-spool the tape. A spring-mounted constant-speed drive motor is flexibly coupled to a smooth capstan against which the tape is pressed by a spring-loaded rubber-covered pressure roller. An example of this type of motor and its mountings is shown in Fig. 2.34. The capstan itself is too smooth to allow it to drive the tape satisfactorily, and it and the pressure roller are made wider than the tape so that the capstan drives the roller and the roller drives the tape. An oil-damped flywheel is attached to the capstan rod to reduce still further any flutter components which may exist in the motor drive. Separate induction-type motors are generally used for the take-up and feed-spool drives. The take-up spool motor speed adjusts itself to the load so that the tape is kept taut and is wound up smoothly despite the fact that the effective diameter of the take-up spool is changing. A similar motor is used for the feed spool but it is energised at reduced power and in such a way that it would rotate in the opposite direction were it free to do so. It is therefore being pulled round by the tape and this helps to keep the tape taut as it passes over the heads. Normal tape speeds are 7½ in./sec. and 15 in./sec, and the motor system can be switched to either speed as required. A few of the BBC recording machines are able to run at 15 or 30 in./sec because some of the recorded programmes obtained from overseas are recorded at the higher speed.

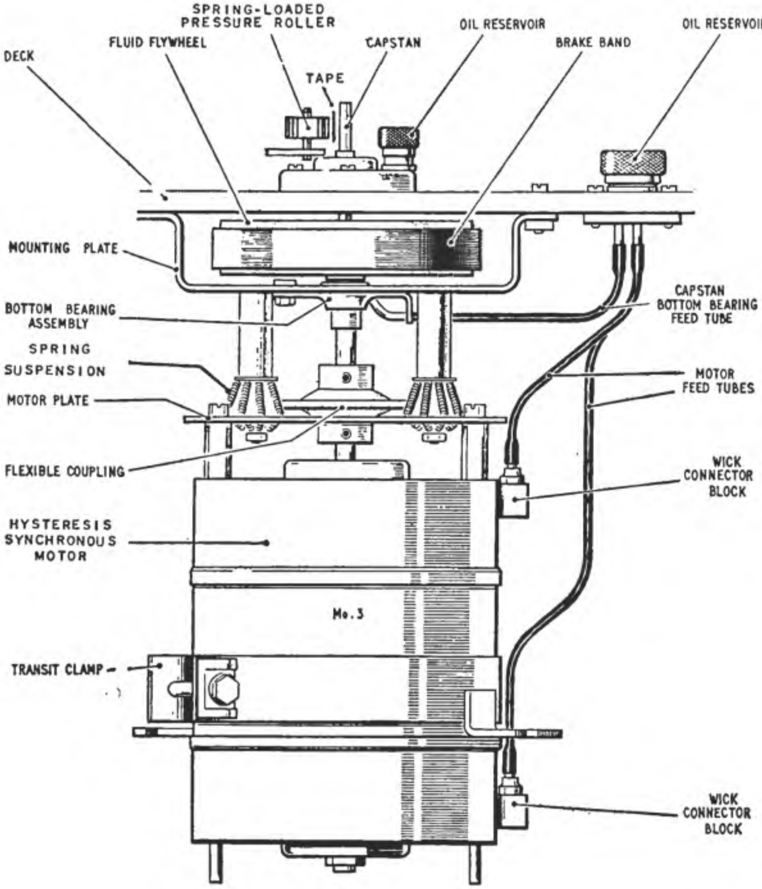


Fig. 2.34. Constant-speed drive system (by courtesy of Electrical Musical Industries Ltd.)

The Head Assembly. The three heads required for erase, recording and replay are usually mounted on a single assembly. Each head is of the same type and consists of a ring of laminated soft-iron divided into two half-sections separated by non-magnetic spacers (Fig. 2.33). The thickness of the spacers depends on the function of the head assembly; thus the erase head spacer is about 20 mil thick whilst the recording head spacer is about 1 mil and that of the replay head 0·25 mil thick. The coils are wound on each half of the ring and connected in series. As stated in Section 2.9.2, it is essential that the gap alignment should be at right angles to the direction of the tape travel and a diagrammatic sketch showing the arrangements for obtaining correct alignment of the recording and replay heads is given in Fig. 2.35.

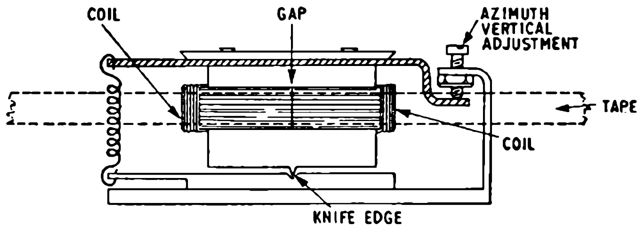


Fig. 2.35. Arrangement for adjusting gap alignment

The Bias and Erase Oscillator. An oscillator operating at about 75 kc/s is required to provide the wiping current for the erase head and the bias current for the recording head. The oscillator is of the conventional type but care must be taken to reduce the even harmonic distortion to a minimum because it has been found that such distortion tends to impair the signal-to-noise ratio of the reproduced signal.

The Recording Amplifier and Equaliser. The recording head does not require a large signal power input for operation and it is only necessary to make certain that the recording amplifier can produce

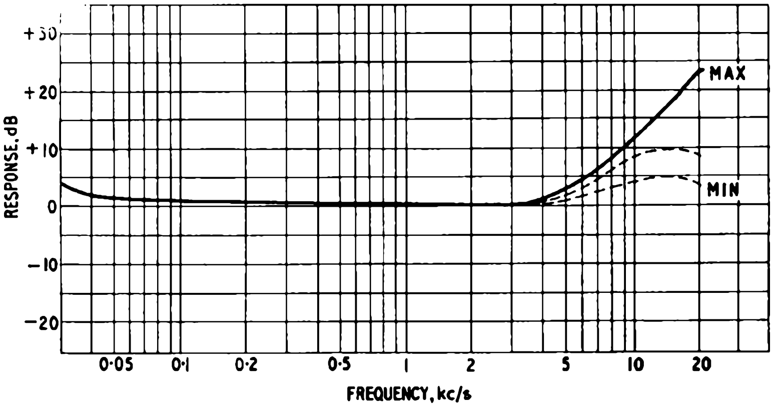


Fig. 2.36. Overall frequency response of the equaliser and amplifier supplying the recording head

sufficient output after the necessary equalisation has been included. The overall response of the equaliser is indicated in Fig. 2.36. The increased response required at the high audio frequencies is necessary to offset the decrease in permeability of the recording head iron core and the self-demagnetisation that occurs on the tape at high recorded frequencies.

The Replay Amplifier and Equaliser. The output from the replay head is quite low and an appreciable degree of amplification is required to bring the signal up to the normal zero level (0 dB). Again an equaliser is included for the reasons stated in Section 2.9.2 and a typical response curve is shown in Fig. 2.37. At low frequencies there is a 'bass boost' of 6 dB per octave to compensate for the attenuation due to the fact that the output voltage is proportional to the rate of change of the flux in the iron core of the replay head. At high frequencies 'treble boost' is employed to offset the attenuation due to the width of gap in the replay head.

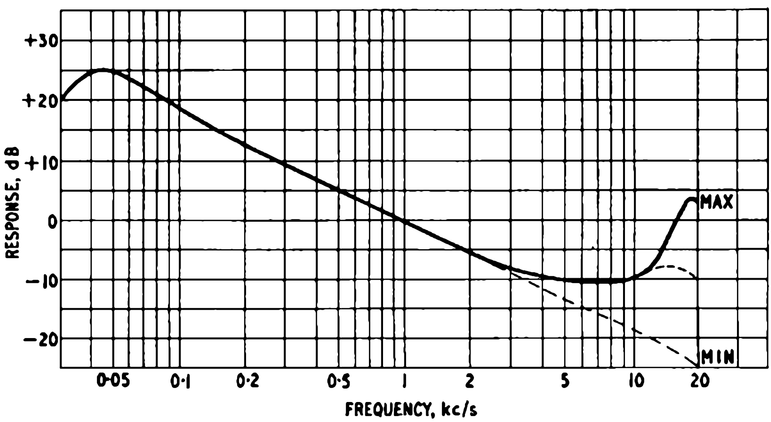


Fig. 2.37. Equaliser characteristic for replay

Miscellaneous Items—The Tape Counter. Most of the BBC magnetic tape recorders have a counter mechanism operated by the travel of the tape itself to indicate the length of tape actually recorded. The pointer associated with the counter is marked in minutes and has two scales giving a maximum recording time of 60 or 30 minutes for speeds of 7½ or 15 in./sec respectively. The tape guide roller which drives this pointer is generally fitted with a stroboscopic disk containing holes beneath which is placed a neon lamp operating from the mains supply. When the pattern produced by the passage of the holes over the neon lamp is stationary the tape is travelling at the required $7\frac{1}{2}$ or 15 in./sec. If the pattern rotates in the same direction as the tape, the tape is travelling too fast and vice versa. The speed of the tape travel can be controlled by varying the tension of the spring maintaining the pressure roller in contact with the tape and the constant-speed drive capstan.

The Control Panel. The E.M.I. B.T.R. machines have a control panel on which are the stopping, recording, playback and spooling controls operated from four push-buttons marked 'off', 'record', 'playback' and 'spool'. The spooling control varies the voltage to the spooling and feed motors and it is arranged to give forward or reverse rotation; the spooling motor pulls the feed motor in the reverse direction to its free running rotation to preserve the tension on the tape. A programme volume indicating meter permits the recording head input level to be monitored and it can be used to measure input line and output line levels; an anode-current meter associated with selector switches on the individual amplifiers allows valve currents to be checked. There are two gain controls, one for the recording chain and one for the replay chain, and also a three position switch marked 'manual', 'autofollow' and 'remote control'. In the manual position the control is at the machine itself. In the 'remote control' position the apparatus can be controlled from the remote source such as a continuity suite and in 'autofollow' position the second machine of a pair can be started from the first machine to facilitate quick change-over.

Tape Editing. One of the great advantages of magnetic recording is the ease with which editing can be carried out once the required point on the tape has been found. The part which has to be selected or deleted can be cut out and the tape spliced by joining the two ends with an adhesive patch. When it is necessary to insert additional matter care must be taken to ensure that the programme-to-noise ratio on the edited parts of the tape does not change markedly.

Portable and Midget Tape Recorders. There is a considerable range of portable and midget tape recorders; some are in the transportable category, such as the trolley-mounted E.M.I. type TR/90, and the Leevers-Rich equipment[7] which uses standard spool sizes and operates from a 12-volt battery, the h.t. being provided by a motor generator beneath the tape deck. Both can provide good quality recordings with a frequency response within ± 2 dB from 50 c/s to 15 kc/s.

A midget tape recorder, deriving its power from dry cells or a miniature rechargeable accumulator and measuring $15\frac{1}{4}$ in. $\times 8\frac{1}{2}$ in. $\times 7\frac{1}{2}$ in., is also used; its 5 in. diameter spools holding enough tape for 15 minutes recording at a speed of $7\frac{1}{2}$ in./sec.

There is also a mains-operated portable rehearsal recorder with a combined recording-reproducing head and choice of two recording speeds $3\frac{3}{4}$ and $7\frac{1}{2}$ or $7\frac{1}{2}$ and 15 in./sec; this apparatus is not intended to provide recordings for transmission.

2.10.4 *The Principles of Disk Recording*

In disk recording the equivalent of the sound waveshape is cut on a surface by a cutter which moves from side to side and produces a V-shaped groove of constant depth with lateral variations. The variations follow the waveshape of the electrical waveform actuating the cutter, which is electro-magnetically driven by a voltage proportional to the sound pressure. The cutter head carrier must be linked with a lead-screw which enables it to cut a spiral groove on the disk, and the spacing of the adjacent grooves must be such that the maximum excursions of the programme will still leave adequate space between grooves. If is of course essential to have some means of removing the swarf cut from the disk surface so that there is no interference with the action of the cutter.

2.10.5 *The Main Elements in Disk Recording Apparatus*

Two types of disk recording equipment, the Presto[8] and the BBC type D recorder[9], are in use by the BBC. In this section a detailed survey of both types will not be undertaken but discussion will be concentrated on the essentials of a disk recording equipment. When an illustration is required reference will generally be made to a feature of the type D recorder.

The important parts of the disk recording apparatus are the disk itself, the turntable drive mechanism, the cutter head and cutter, the swarf removal system, the variable equaliser for automatic radius compensation, the recording amplifiers and the linking bay. A schematic circuit diagram of a twin-machine recording channel is shown in Fig. 2.38.

The Disk. In direct disk recording the medium is an aluminium disk coated with a cellulose nitrate lacquer 6 mil thick. It is essential that the surface should be flat, evenly coated and free from any blemish. The standard sizes of disk diameters used in the BBC are 12 in. and 13 in.

The Turntable Drive Mechanism. The speed of the turntable must be constant and free from wow or flutter. The drive should include insulation to prevent vibration and flutter from being

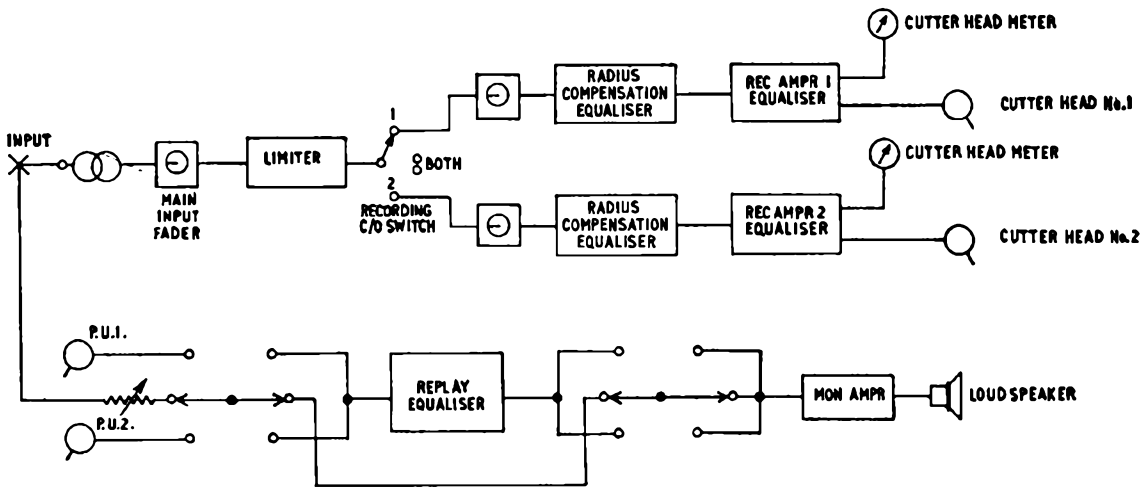


Fig. 2.38. Schematic diagram of a twin-machine recording channel

transmitted from the motor to the turntable, and Fig. 2.39 shows the drive arrangement in the BBC type D equipment. The motor, mounted vertically with an elastic mounting giving insulation against vibration, is connected through a flexible coupling to a layshaft driving through an idler wheel on to a heavy flywheel on the turntable shaft.

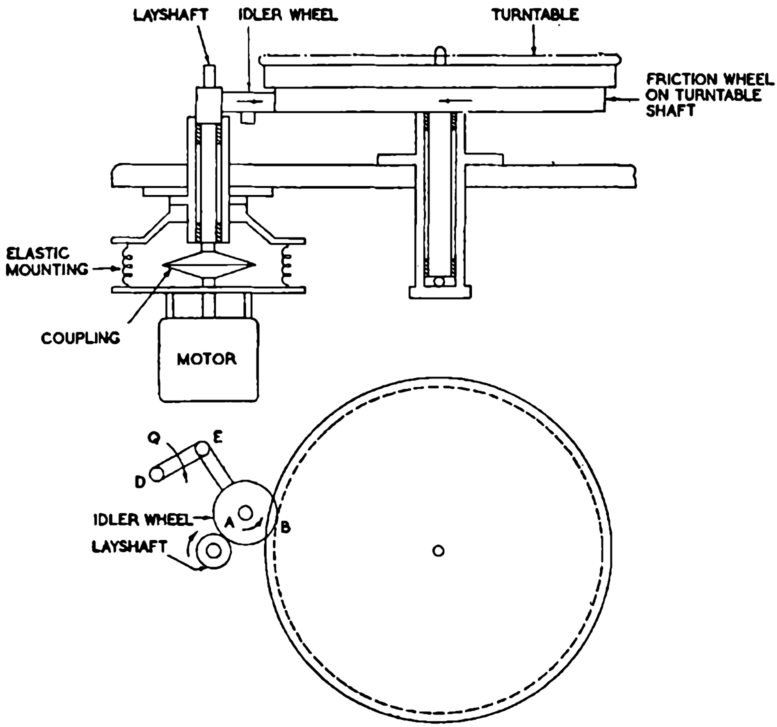


Fig. 2.39. Motor drive to the BBC Type D recording equipment

The Cutter Head and Cutter. The cutter head is in effect an electromagnetic vibrator energised by the programme output. The BBC type B head[10], most widely used, contains a moving-iron armature held by a torsion bar between a pair of energised pole-pieces. The stiffness of the torsion bar provides the necessary restoring force to return the armature to its central position. Slots in the pole-pieces accommodate the driving coil, and signal currents in this coil cause the armature to vibrate from side to side. The system is oil-damped and there is a second coil wound inside the signal-current coil to provide a feedback voltage which is injected in a negative direction into the penultimate stage of the recording amplifier to minimise attenuation and non-linear distortion. The cutting stylus is a specially-shaped synthetic sapphire mounted on a duralumin shank. The cutter head is mounted on a privoted arm which allows some vertical movement and includes a spring, whose tension is adjustable to control the depth of cut in the groove. The cutter-head mounting runs on a rail and has a half-nut engaging with a lead-screw which tracks the carriage and head from the outside to the inside of the disk during recording. The half-nut can be quickly disengaged to return the carriage to the outside of the disk where it is re-engaged with the lead-screw before commencing to cut another disk. The speed of the lead-screw rotation determines the number of grooves per inch on the spiral track. Normal groove spacing is 104 grooves per inch for 78 r.p.m., 120 for 33⅓ r.p.m. and 250 for fine-groove 33⅓ r.p.m. recording. For cutting fine-groove recordings the stylus is heated; this softens the lacquer, giving a smoother wall surface to the groove and reducing the resistance experienced by the cutter at high audio frequencies. Improved programme-to-noise ratio and less high-frequency loss on recording is achieved.

The Swarf Removal System. The swarf cut away by the sapphire has to be swept or sucked away to prevent it piling up beneath the cutter. In the BBC type D recording apparatus the swarf is first blown away from the cutter and then sucked into a container.

The Linking Bay or Console. Each disk recording channel is fitted with two separate machines so that continuous recording of a programme of long duration can be made, and a linking bay or console is required. This linking bay generally contains a limiter to prevent overloading of the cutter head, the automatic radius-compensation equalisers, a meter switch, switches to allow the programme to be reproduced and monitored, a master fader and individual fader for each machine. The meters measure the volume (dB) supplied to each individual cutter head and are used for line-up purposes. The recording amplifiers for each machine and the monitoring amplifier are also included. The limiter is required in order to maintain as high a programme-to-noise ratio as possible and the recording chain is lined up to ensure that the maximum permissible amplitude is recorded when normal peak level programme is supplied to the input. The limiter takes care of the occasional excessive programme peak and prevents it affecting the cutter head.

Automatic Radius Compensation Equaliser. In normal disk recording high frequencies recorded at and reproduced from the centre of the disk are appreciably attenuated compared with those recorded at the edge of the disk. With a 12 in. disk at 78 r.p.m. the loss is of the order of 6 dB from outside to inside. The reason for this is that the resistive load presented to the cutting tip increases as the speed of the disk past the tip decreases, and the effect increases as frequency increases. In order to correct for this loss a variable

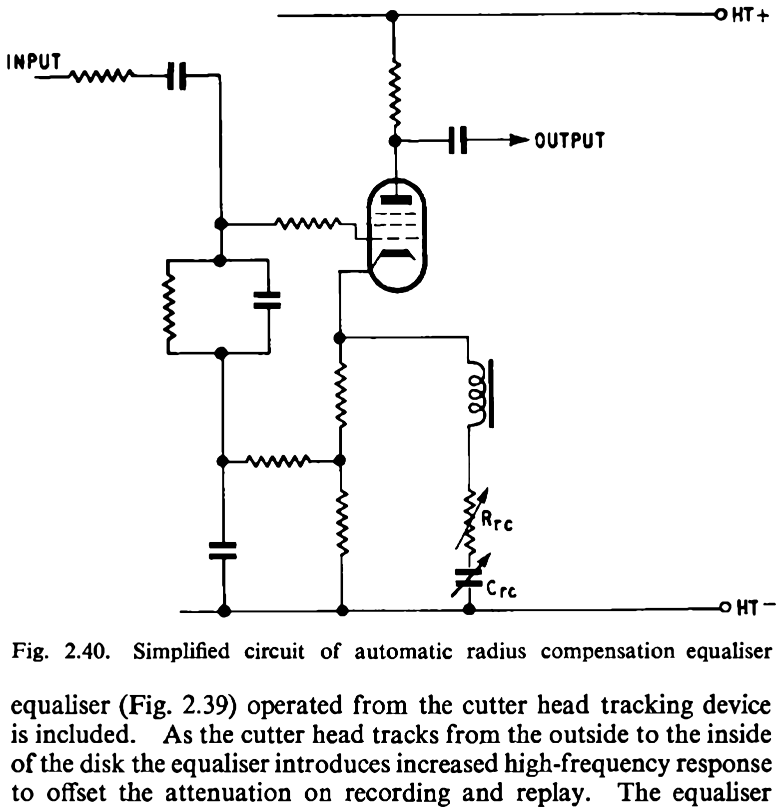


Fig. 2.40. Simplified circuit of automatic radius compensation equaliser

equaliser (Fig. 2.39) operated from the cutter head tracking device is included. As the cutter head tracks from the outside to the inside of the disk the equaliser introduces increased high-frequency response to offset the attenuation on recording and replay. The equaliser is introduced during the recording because increase of high-frequency response in the replay chain would increase the background noise and reduce the programme-to-noise ratio. The attenuation on replay is due to a number of factors including the play-weight of the head and the size of the replay stylus tip which may not permit it to follow accurately the groove wall variation. In the BBC type D disk recorder the automatic radius-compensation equaliser consists of a series-tuned circuit shunted across a cathode resistor in one of the valves in the recording amplifier, and a simplified circuit is shown in Fig. 2.40. C_{rc} and R_{rc} are varied as the cutter head tracks towards the centre, giving a progressively lower value of cathode impedance at high frequencies, so reducing the negative feedback.

The Recording Amplifiers and Cutter Head Meters. The recording amplifier of the type D equipment has to provide an output of about 75 volt-amps to drive the cutter head, and the output stage consists of six pentodes in parallel push-pull. An equaliser is included in the preceding stages to give the correct recording characteristic. Each amplifier output is connected to a meter so that a constant check may be kept on the volume at the recording head. A microscope is generally available to enable the depth of cut and the condition of the disk and cut to be checked. The ratio of the width of the groove to that of the intervening wall between grooves, normally known as the ' groove-to-land ratio ', it should be about 2: 1 when viewed through the microscope. The actual ratio is less than this (1·5: 1) because the groove is partially embossed, the raised edges to the grove giving it an apparently greater width. Great care must be taken to prevent the cut penetrating too deeply and actually reaching the aluminium base, for then the sapphire may collect aluminium at the end of its tip to produce a damaged groove with a very poor programme-to-noise ratio.

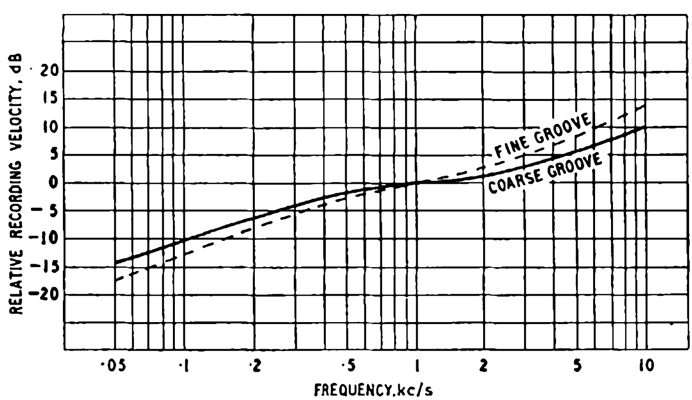


Fig. 2.41. C.C.I.R. recording characteristic

The Disk Recording Characteristic. The moving-iron cutter heads used by the BBC are devices depending on current for their operation and the tendency is for a fixed input voltage to produce on the driving coil a current which decreases as the frequency is increased. Excessive current must be prevented at low frequencies, otherwise saturation of the iron core of the head may occur and this will produce flattening of the recorded low-frequency waveform. In order to prevent this occurring it is normally necessary to attenuate all frequencies below 350 c/s. It is also necessary to increase the high-frequency response in order to maintain a good programme-to-noise ratio because the noise components mostly occur at the high-frequency end of the spectrum. The shape of the C.C.I.R.* disk recording characteristic for 78 r.p.m. disks is shown in Fig. 2.41, where stylus r.m.s. velocity is plotted against input signal frequency. The characteristic for fine-groove recording is similar in shape. The stylus velocity is scaled in dB with reference to a r.m.s. velocity of 2 cm/sec. An equaliser producing the inverse effect in the replay equipment is included to restore the frequency balance.

Line-up Procedure. The test frequency is 900 c/s and its level is adjusted to give the zero reference value of stylus velocity of 2 cm/sec. In order to verify that this is being obtained, a recorded output from a test-cut with line-up tone is compared with the output from a standard pressing upon which a similar frequency has been recorded at this velocity. A comparison of the stylus velocity at various frequencies can be made by using the principle of the Buchmann-Meyer image. When parallel beams of light are made to impinge on the grooves of a disk upon which a sinusoidal tone is recorded the reflection seen by the eye is that of a narrow band of light, and the width of this band of reflected light is directly proportional to the r.m.s. velocity of the cutting stylus irrespective of the recorded frequency or the diameter of the spiral groove. A variable-frequency tone at constant velocity should therefore show a band of reflected light of constant width.

Fine-groove Disk Recording. An objection to the normal groove spacing used in disk recording is that only a comparatively short duration of programme can be recorded on one disk. This can be greatly increased if fine-groove disk recording is employed, the number of grooves being increased from approximately 100 to 250 per inch. A much shallower cut has to be made in order to accommodate the increased number of grooves. The decreased groove spacing can increase programme time on a 12 in. disk recorded at 33⅓ r.p.m. from about 8 minutes to 30 minutes. The amount of disk material required is greatly reduced and the problems of storage are simplified. Lightweight reproducing heads with fine-pointed styli are essential; the overall quality of reproduction is generally much better than with the wider groove spacing. As stated earlier,

* C.C.I.R.=Comité Consultatif International des Radiocommunications.

satisfactory fine-groove recording requires the point of the cutting sapphire to be heated and this is achieved by winding a small heating coil round the sapphire. Direct fine-groove recordings cannot be played more than a few times without serious damage and fine-groove recording is normally used by the BBC only for producing

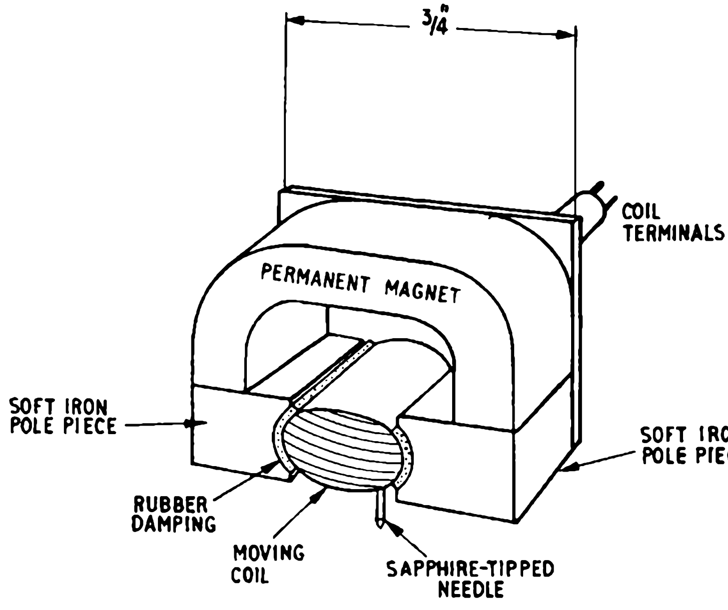


Fig. 2.42. Moving-coil replay head

processed records for archive purposes or for overseas distribution by Transcription Service.

2.10.6 *Disk Replay Systems*

For the replay of programmes recorded on disks the same standard of speed constancy and quality of replay heads is required as for recording. The most important component in the reproducer is the replay head which may be either a moving-coil, moving-iron, or crystal type.

Moving-coil Replay Head. The replay stylus in a moving-coil head is attached to a small coil pivoted between soft-iron pole-pieces energised by a permanent magnet. As the needle tip follows the groove variations, the coil moves in the field of the permanent magnet and this generates a voltage which is proportional to the velocity of coil movement. Such a replay head is the equivalent of the moving-coil microphone and Fig. 2.42 shows a sketch of its construction. The coil is wound on a plastic former which carries the stylus. Surrounding the coil and plastic former is a rubber sheath which retains the coil between the specially-shaped pole-pieces and also provides damping. Such heads are fragile and expensive and are only used by the BBC for special purposes.

Moving-iron Type. In one form of moving-iron replay head the stylus is attached to a soft-iron armature pivoted between energised pole-pieces and surrounded by a coil in which the reproduced voltage is induced. When the armature is central there is no resultant flux threading the armature and coil, and movement of the stylus brings the armature nearer to one or other of the pole-pieces causing flux to flow in one direction or the other depending on which pole is approached. This change of flux induces a voltage in the coil surrounding the armature, the voltage being directly proportional to the velocity of the stylus tip. In an alternative form, often called the variable-reluctance type (Fig. 2.43), the armature itself is magnetised and moves in the air gap of a soft-iron yoke around which are wound the replay coils. The flux threading the left-hand

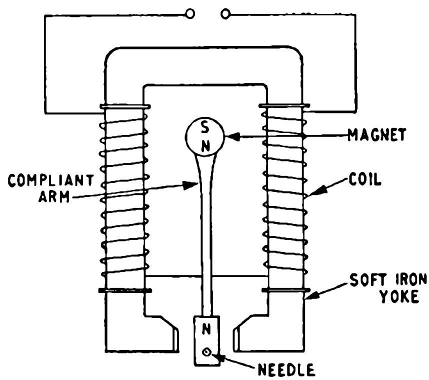


Fig. 2.43. Variable-reluctance moving-iron replay head

coil increases when the armature moves towards it and the flux in the right-hand coil decreases and vice versa.

The earliest types of moving-iron heads were heavy and had low-compliance movements; this resulted in excessive downward pressure which, coupled with the stiff movement, caused considerable wear on both disk and needle. Whilst this could be tolerated with old-type shellac records, the introduction of direct-recorded disks and vinyl pressings made lightweight pick-ups a necessity. The E.M.I. type 12 was one of the first lighter weight moving-iron pick-ups to be produced and is still used on some BBC reproducing desks, but for general use, crystal pick-ups gained popularity, largely because of their lighter play weight and higher compliance.

Crystal Replay Head. The crystal replay head operates on the same principle as the crystal microphone described in Section 1.5.1. The construction of the crystal head is shown in Fig. 2.44. The

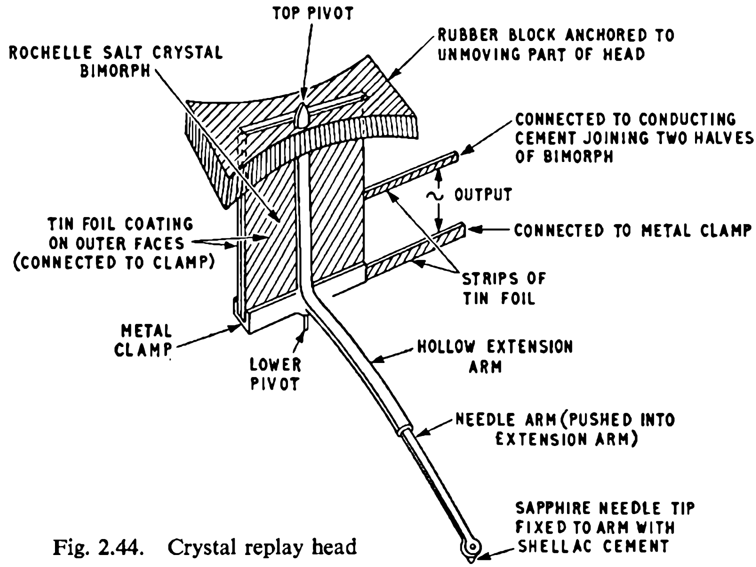


Fig. 2.44. Crystal replay head

sapphire stylus is attached to the plastic crystal holder, and the stylus movement causes twisting of the plastic holder, which in turn twists the Rochelle-salt crystal; this produces an output voltage across opposite faces of the crystal, proportional to the stylus displacement. Since the output is proportional to displacement and not to velocity very little equalisation is required in the replay amplifier.

Disk Reproducing Channels[11]. There are three types of disk reproducing channel in use by the BBC: the TD/7 general purpose coarse-groove reproducer, the DRD/5 desk for reproducing fine-groove recordings and the general purpose RP2/1 desk for reproducing fine- or coarse-groove recordings.

The TD/7 Desk. The TD/7 desk uses twin 78 r.p.m. turntables, lightweight moving-iron reproducing heads and parallel-tracking with groove-locating units. The replay head is attached to an arm which is tangential to the grooves. The arm projects from a carriage which runs on ball bearings over a bar at right angles to the arm. The arm is associated with a scale and vernier control which enables a particular groove to be located with reasonable accuracy. A drop-start arrangement may be incorporated and then the disk is held off the continuously-rotating turntable. The replay stylus rests in the correct groove and upon receiving a cue the operator moves a lever which lowers the disk on to the revolving turntable. With machines not fitted with a drop-start the replay stylus is lifted off the disk after the correct groove position has been found and the disk is left rotating. The head is lowered on to the rotating disk upon receipt of the cue signal and at the same time the gain control is 'faded-up'. The programme circuit of the TD/7 reproducer is shown in Fig. 2.45. The replay head is transformer-coupled to an attenuator followed by a bass response equaliser to correct for the low-frequency current limitation imposed by the recording characteristic. Pre-fade listening facilities are taken from the attenuator output. The main purpose of the attenuator is to balance output volumes from the replay heads of the twin machines. When direct recordings are being reproduced, the noise reducing filter is not required and it is only inserted when pressings are being used.

The DRD/5 Desk. The DRD/5 reproducing desk is specially designed for the reproduction of fine-groove recordings, and it incorporates arrangements for quick starting. A schematic diagram is given in Fig. 2.46. The record rests on a stationary aluminium disk which is of larger diameter than the turntable. The turntable rotates underneath the disk and can be raised to contact the aluminium disk and start the disk and record turning. The reproducing stylus is set at the required point on the record and as the rotating turntable has a high inertia and the record has a low inertia the disk is brought up to speed very quickly. To increase the starting torque when the turntable is brought against the disk the voltage supply to the motor is stepped up as the turntable is raised. To prevent wow as the disk starts to rotate, the output from the reproducing head is silenced (muting circuit Fig. 2.46) for a period just long enough to allow the normal running speed to be reached.

A crystal replay head on a pivoted arm is used and there is a special optical system to indicate accurately the position of the arm. An enlarged image of a scale connected to the replay-head arm is projected on a ground-glass panel at the back of the turntable. The

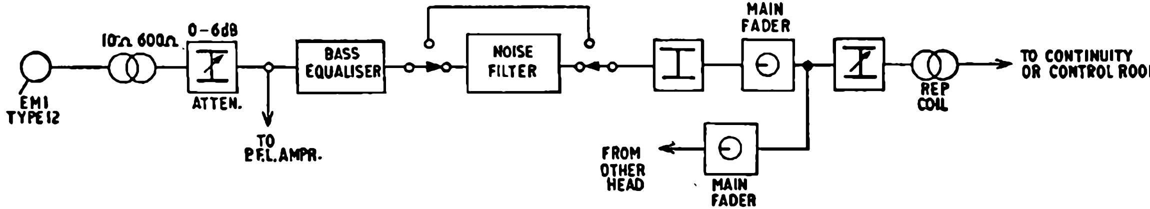


Fig. 2.45. Programme circuits of the TD/7 reproducing desk

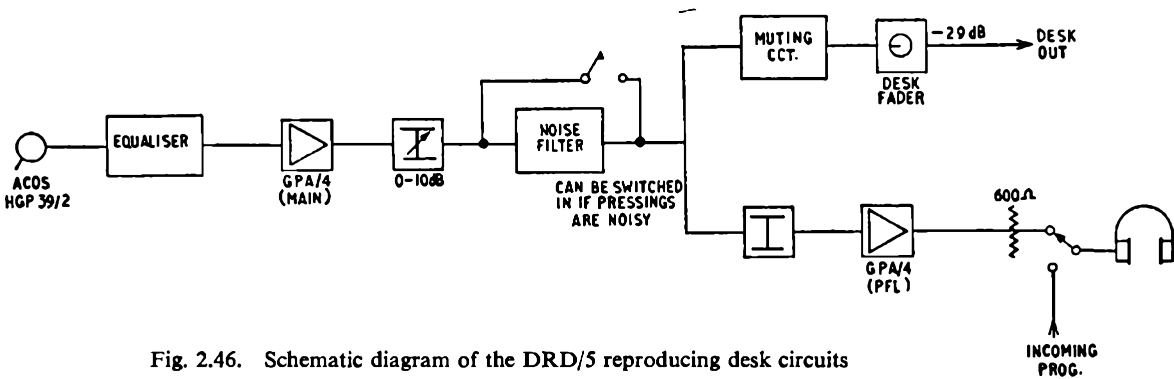


Fig. 2.46. Schematic diagram of the DRD/5 reproducing desk circuits

scale has an arbitrary marking because there would be no advantage in trying to mark groove numbers, since the groove pitch may be varied to suit the amplitude of programme applied to the disk. In addition the centre hole in the disk may have an eccentricity of up to 5 mil which could cause a swing equivalent to about 2½ grooves on a 250 groove-per-inch record. The chief merit of the scale is that it enables the approximate position of the replay head to be noted, the required position being found by moving the disk backwards and forwards by hand. Reverse rotation of the disk is possible with this type of reproducing head because the stylus is mounted on the end of a cantilever spring and the frictional forces between it and the disk do not materially change the downward pressure of the needle.

The DRD/5 equipment is intended for operating at 33⅓ or 45 r.p.m. and there is provision for fine adjustment of speed by means of an adjustable eddy-current break. Pre-fade listening facilities are available from a point just before the muting circuit and in an emergency the pre-fade listening amplifier can be used in place of the main amplifier. A noise filter reducing the higher frequency components can be inserted in the main chain if it is required. The equaliser immediately after the replay head corrects for the initial recording characteristics.

*The RP*2/1 *Desk.* The RP2/1 desk has two 3-speed turntable units for playing 33⅓, 45 or 78 r.p.m. disks. Each speed is capable of about 4% overall variation and is checked stroboscopically. The variable-reluctance replay head is mounted on a pivoted off-set overhung tracking arm and its low play-weight of 5 to 7 grams allows it to be used with all types of disks including direct recordings. The output of the head is connected to an amplifier which has two outputs, one to the programme line and the other to headphone pre-fade-listen jacks.

The replay-head amplifier chain incorporates a muting relay operated from the start switch and it introduces a delay of about 0·8 seconds to allow the turntable motor to reach its correct speed before the replay-head output is connected to line. When setting up a disk allowance has to be made for this delay, which is about ½, ⅓ and ⅔ of a revolution for 33⅓, 45 and 78 r.p.m. disks respectively.

Like the DRD/5, the RP2/1 desk has an optical scale to assist in groove location but accurate setting-up is carried out with the aid of pre-fade listening.

The Variable Correction Unit. Sometimes it is necessary to reproduce a recording made with a response characteristic other than that employed by the BBC and in order to restore the frequency balance an additional equaliser must be inserted in the replay chain. This equaliser is known as a variable correction unit and it is a combined equaliser-amplifier with zero gain at 1 kc/s. At other frequencies the response can be adjusted by a number of controls to provide the following: (1) control of the response curve above or below 1 000 c/s; (2) the reduction of the upper frequencies in order to suppress background noise or intermodulation products, cut-off being variable from 4 000 c/s to 8 000 c/s in 1 000 c/s steps; and (3) the suppression of hum by means of sharply-tuned resonant circuits.

REFERENCES

1. 'Studio Engineering for Sound Broadcasting', Chapter 3, BBC Engineering Training Manual, Iliffe & Sons Ltd., 1955.
2. 'Microphones', BBC Engineering Training Manual, Iliffe & Sons Ltd., 1952.
3. 'Studio Equipment Type A', *BBC Technical Instruction S5.*
4. 'Studio Equipment Type B', *BBC Technical Instruction S7.*
5. 'Programme Meters', *BBC Training Supplement No. 6.*
6. 'Audio-frequency Test Apparatus', *BBC Technical Instruction S4.*
7. 'Leevers-Rich Battery-operated Transportable Magnetic Tape Recorder', *BBC Technical Instruction R9.*
8. 'Presto Disk Recording Equipment', *BBC Technical Instruction R4.*
9. 'BBC Disk Recording Equipment Type D', *BBC Technical Instruction R1.*
10. 'Type B Disk Recording Head', *BBC Technical Instruction R2.*
11. 'BBC Disk Reproducing Equipment', *BBC Technical Instruction R5.*

CHAPTER 3

TELEVISION STUDIOS, TELECINE AND TELERECORDING

MANY of the problems of providing a co-ordinated television service are similar to those already described in the previous chapter on Sound Studio technique but there are many additional ones such as the conversion of the image of the scene into the electrical impulses forming the vision waveform, the distribution of this waveform, the provision of suitable lighting, the co-ordination of the sound with the vision and the fading or cutting from one scene to another or the superimposition of two scenes.

The same procedure will be followed as in Chapter 2, namely, the duties of the technical staff will be dealt with first, then the apparatus will be considered and finally the operational and test procedures essential for the efficient functioning of the Television Service will be considered.

3.1 WORK OF TECHNICAL STAFF IN TELEVISION STUDIOS AND ASSOCIATED TECHNICAL AREAS

3.1.1 *General Outline*

Since the overriding control and co-ordination of television programmes is mainly exercised in London, it is appropriate that the illustrations and procedures described should be based on London practice. Some modifications to the London pattern occur in the Regional television studios but they are of a minor character. A simplified schematic diagram of the operating positions in a television broadcasting chain from studio to transmitter is given in Fig. 3.1. Two separate programme chains are needed, one for vision and one for sound signals. When pictures are wanted from a number of different angles, three or four cameras may be necessary in the studio itself; some of the cameras may have to be almost continuously changing position, others may be stationary. Pulses are supplied from the Central Apparatus Room to the camera channels via the Vision Apparatus Room to operate the camera scanning circuits and to provide the synchronising

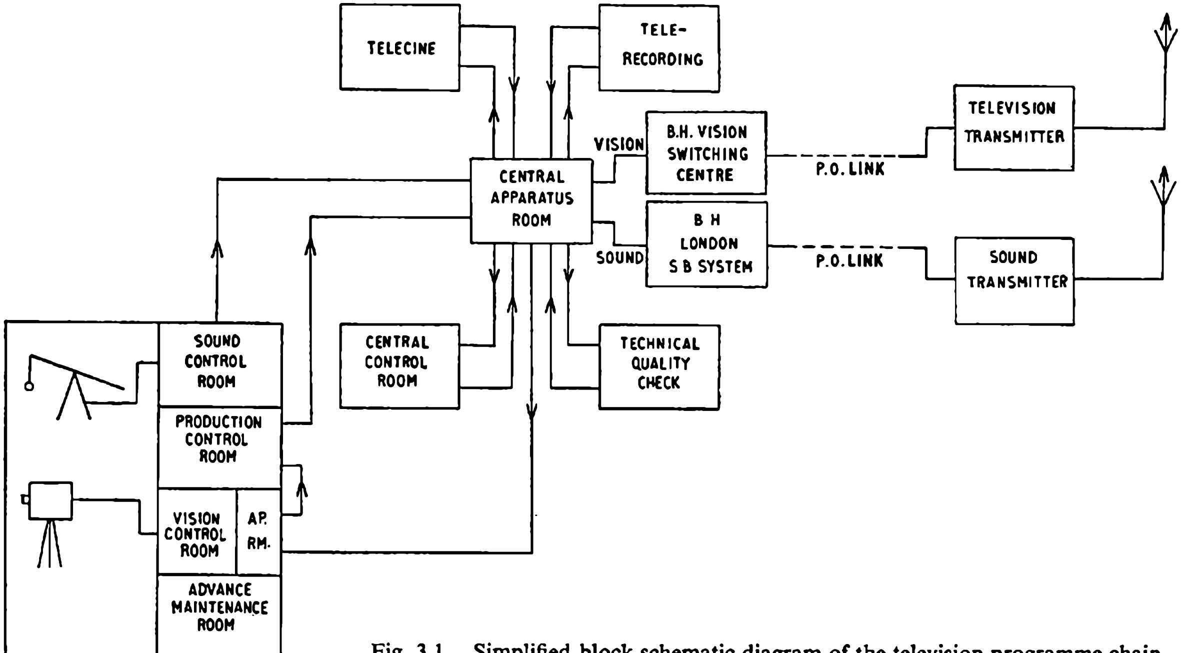


Fig. 3.1. Simplified block schematic diagram of the television programme chain

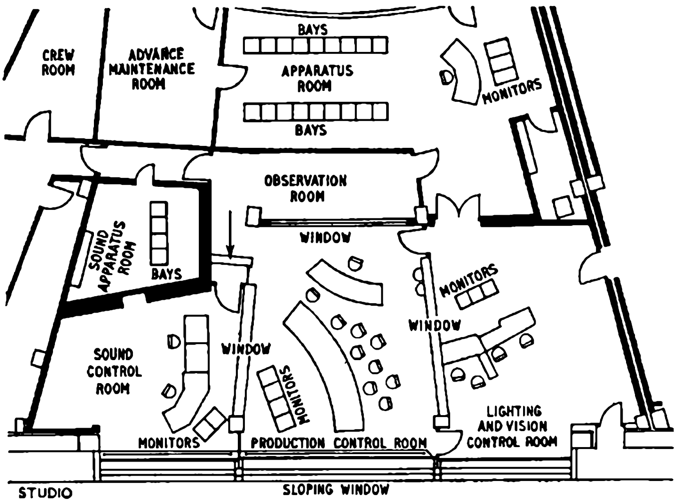
pulses for the vision waveform. The microphone must generally follow the movement of the artistes in the studio and it is carried on a boom that can be extended or retracted by the boom operator. Film inserts may be required and these are provided from a telecine room (see Fig. 3.1), the outputs from which feed into the Central Apparatus Room. An outgoing line from the latter to the telerecording section enables a programme to be recorded on film or magnetic tape.

Alongside the Production Control Room is a Sound Control Room which contains all the sound control equipment. A window between this and the Production Control Room can be lowered if direct speech is required between the two. The sound insulation provided by the double window enables the operator to appraise sound quality without disturbing the Production Control Room staff; picture monitors are provided and disk and tape reproducing equipment is included for music inserts and sound effects.

The output from each camera is taken to the Vision Control Room where the electronic operational controls for the camera tube are located. Here the operator has picture and waveform monitors to allow him to adjust lift, gain and gamma so that the best picture possible is obtained. The outputs from the cameras are fed from the Vision Control Room to a vision mixing desk in the Production Control Room which gives a view through double windows down into the studio. Picture monitors allow the output of each camera channel to be seen, as well as the output of any contributing source such as telecine. One of the picture monitors immediately in front of the producer shows the picture actually on transmission. The sound and vision outputs from the studio are sent to the Central Apparatus Room from which they are passed to the television network feeding the transmitters. All signals from the Central Apparatus Room pass to the Central Control Room where continuity control is exercised in the same manner as for sound programmes: adjoining the Central Apparatus Room is a Technical Quality Room for checking picture and sound quality. The vision signal is then passed on to Broadcasting House switching centre from which it is sent by P.O. link to the vision transmitters. The accompanying sound signal is also passed to Broadcasting House, London, and distributed via the Simultaneous Broadcast (sound) chain like any sound programme. Associated with the studio is an Advanced Maintenance Room which allows quick repairs and minor routine maintenance to be made to apparatus. Fig. 3.2 (a) gives a plan view of the technical areas associated with a studio and it is typical of the layout at Television Centre, London.

Technical staff in the Television Service can be divided into

(a)



(b)

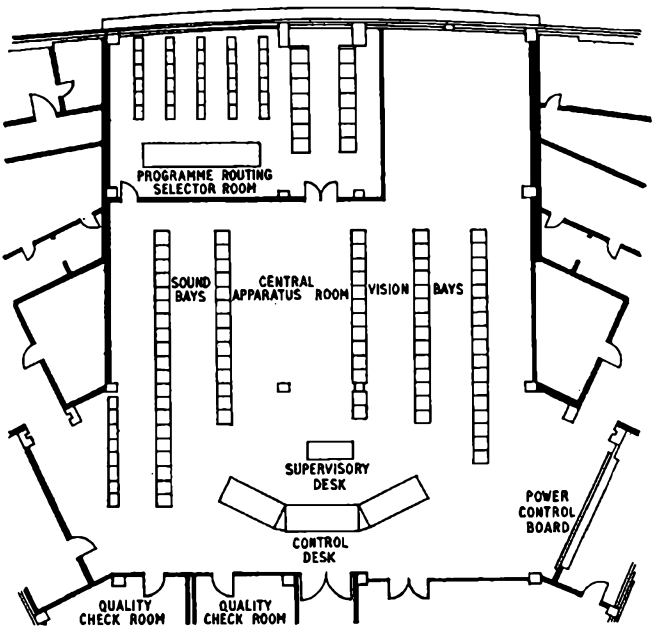


Fig. 3.2. (a) Plan view of a typical studio at television centre; (b) Plan view of the central apparatus room at television centre

two categories: those concerned with operating the equipment and those concerned with maintaining it. Major overhauls to the equipment can only be undertaken by base maintenance workshops which serve all the studios.

3.1.2 *The Studio Operating Staff*

In the studio and its associated technical areas, the technical operating staff are organised into a crew consisting of about 20 members supervised by a Technical Operations Manager. The composition of a typical crew is as follows:

The Television Studio

3 Cameramen, 1 Assistant Cameraman/Dolly Operator

3 Dolly Operators

1 Microphone Boom Operator

1 Microphone Boom Operator/Sound Supervisor Relief

1 Sound Floor Assistant

Vision Control Room

1 Lighting Supervisor and Assistant (if required)

1 Vision Control Room Supervisor

1 Assistant

Production Control Room

1 Technical Operations Manager

1 Vision Mixer

1 Inlay/Transparency Operator

Sound Control Room

1 Sound Supervisor

1 Gramophone Operator

All studio floor staff are fully briefed on their part in a particular production; for example cameramen and microphone boom operators must know the action sequence and the kind of camera-shot wanted. During rehearsal, difficulties may arise and adjustments have to be made by the technical operations manager and in this he may be helped by suggestions from senior members of the crew.

The responsibility for composing the picture satisfactorily at any given moment rests on the cameraman with only occasional instructions from the producer. When the cameraman is carried on the camera dolly there must be somebody to position the equipment and this is performed by a dolly operator to instructions from the producer and the cameraman himself.

The microphone boom operator must ensure that the microphone is in such a position that it can satisfactorily pick up the required sound, and, what is almost equally important, that it and its shadow are out of the picture. The sound floor assistant moves the boom into position and looks after stand microphones and the microphone cables on the floor or those suspended. His work is similar to that of the dolly operator on the camera.

The vision control supervisor and assistant in the Vision Control Room are responsible for adjusting all the camera controls such as lift, gain, etc., so as to give the best overall picture.

The cameraman will generally adjust the brightness and electrical focus of this viewfinder, but preset controls on his camera are initially set up by the maintenance man. Optical controls, such as focus and correct choice of lens are his chief concern, and he is often provided with 'camera-shot cards' by the producer's secretary to remind him of the various changes which he might have to make during the programme. The sound supervisor in the sound control room selects, balances and controls the various microphones and recorded outputs.

At least four people are present in the Production Control Room; they are the producer, his secretary, the vision mixer and the Technical Operations Manager. The vision mixer selects the required camera channel for transmission and operates the faders and 'cut' buttons to the producer's instructions. The lighting supervisor and his assistant are responsible for planning the positioning and the power of the lights and they give instructions to the studio electricians as to the actual rigging. If changes have to be made in the lighting arrangements during a performance they operate the lighting console, which may be in the Vision Control Room or adjacent to it.

Attached to each studio are two maintenance engineers, who perform the initial line-up and carry out the routine maintenance tests as well as first-aid maintenance.

3.1.3 *The Central Apparatus Room and Central Control Room Staff*

The work in the Central Apparatus Room and Central Control Room includes maintenance as well as operations and these areas are manned by engineering staff. The Central Apparatus Room at Television Centre, a plan view of which is given in Fig. 3.2 (b), is in the charge of a Senior Television Engineer, and the duties of the staff are to arrange for the distribution of the pulse signals for the camera channels, telecine and telerecording, and for the acceptance of the vision signal back from the Studio Production Control Room. They are also responsible for dealing with the vision signals from telecine and outside broadcasts and with those going out to the transmitter, to the producer and telerecording section. They ensure that all apparatus under their control is working correctly and carry out first-aid repairs.

Continuity control is exercised through a senior programme official located in the Central Control Room, where the various programme sources are remotely faded and switched. This official sees that the programme continues smoothly and initiates the steps to cope with over- or under-running or breakdown of programme.

3.1.4. *Telecine and Telerecording Staff*

Telecine Operation. The telecine engineer deals with the conversion of all programmes originating on film (telerecordings or other films) into television signals. If the inserts are of short duration only one machine may be used, but a completely-filmed programme may require two machines with a change-over from one to the other at a given point in the programme. Under these circumstances the engineer must ensure by adequate pre-transmission tests that there is no marked difference in the quality of reproduction from the two machines. His duties include the lace-up of film for transmission, the lining up of the machine(s), the sending of test vision and sound signals before the start of each showing, and the monitoring of picture and sound output. He may make adjustments to control the gain and 'lift' of the picture, and when certain machines are used he may also vary the gamma of the reproduced picture. The sound signal may be recorded optically or magnetically on the film or it may be on a separate magnetic film. The apparatus must be lined up for either system and the sound must be synchronised with the picture when the sound is recorded on a separate magnetic film.

Telerecording Operations. Telerecording staff may have duties connected with the vision and/or sound electronic equipment, with darkroom operations, sensitometric work or with the telerecorder cameras.

The vision electronic apparatus has to be prepared before a recording, the signal processing units being lined up to correct for the various aberrations of the overall filming process including the contribution which the telerecording system makes to the overall gamma of the television chain (see Section 1.9.2).

The degrees of illumination of the display screen for given input signal levels must be determined with the aid of a photometer. These photometric checks must be made before the recording and in between rolls of film when the alternative display screen and its associated film camera are in use.

The sound channels must also be lined up to give the conditions required by the sound track of the particular film in use, each batch of film received from the manufacturers being tested to find the correct conditions. Sound may be recorded as a combined optical track on the same film as the recorded picture or when higher quality is required, it may be simultaneously recorded on a separate magnetic track.

Telerecorder camera staff must be capable of accurately loading the camera, and of thoroughly cleaning it before each reload; with some systems these tasks must be performed well within a 10-minute period while the alternative camera is taking the programme.

Darkroom staff work by sense of touch unloading magazines removed from cameras and transferring the exposed film to cans for dispatch to the processing laboratories. They also uncan new film, load it into magazines for the camera, and label each magazine with the amount of film it contains. Correct labelling is most important because a recording may be lost if a film runs out prematurely.

Test signals and reference densities are recorded at the beginning of each film in order to provide a control for the processing laboratories. Telerecording sensitometric staff check these results.

Staff in charge of machines (Ampex) for recording and reproducing vision signals on magnetic tape have to maintain as well as line up their apparatus. The object of lining up is to ensure that the vision circuits do not introduce distortion, and that the servo-mechanisms are all operating satisfactorily. A saw-tooth or equivalent test signal is passed through the chain in order to check that the vision performance is satisfactory. The magnetic tape is laced, the tip projection of the rotating heads set, the switch changed to the 'operate' position and vision and sound test signals are recorded to act as a reference enabling correct settings to be made when playing back a recording. The quality of reproduced picture and the programme-to-noise ratio are noted and any necessary readjustments made to the recording and reproducing controls including the servo-mechanism. The Ampex video tape recorder has a large number of test points to enable the waveform of the voltages for given recording signals to be checked on a cathode-ray oscilloscope. The sound channel functions in a similar manner to that which has been described in Section 2.10.2.

3.1.5 *Maintenance Staff*

Maintenance staff have to be on duty in the studios in order to line up the camera channels and check all the equipment prior to rehearsal and transmission, as well as to undertake any first-aid repairs and fault clearance. There is also a base maintenance area where major overhauls and repairs of all equipment concerned with television studio operation and distribution are undertaken.

3.2 TELEVISION DISTRIBUTION NETWORK

The television coverage of the United Kingdom by the BBC follows a very similar pattern to the sound coverage by medium-frequency transmissions. There are high-power transmitters to cover large and densely populated areas, with medium- and low-power transmitters to serve the remoter areas. These provide some 98 per cent population coverage. To complete the coverage as far as is practicable, and to improve reception in areas where signals are weak or interference is severe, low-power satellite stations are being installed. These satellites are placed on top of a suitable hill where a satisfactory signal can be picked up from the nearest high-power or medium-power station. The incoming signal is amplified and its frequency changed before retransmitting at another frequency from an aerial with a different polarisation, whose propagation is directed towards the local area to be served. There are five high-power stations, at four of which the vision transmitter supplies 50 kW to the aerial; the aerial concentrates the radiation into a comparatively narrow horizontal beam which effectively raises the radiated power to 100 kW. (See page 319 for a definition of effective radiated power—E.R.P.) The Crystal Palace transmitter has an even more efficient aerial and from an input power to the aerial of 30 kW an effective radiated power of 200 kW is obtained. Fig. 3.3 shows the main outlines of the television distribution network and the position of the major television transmitting stations (circles) serving the U.K. All television programmes, except 'opt-out' items such as regional news bulletins, are supplied from Television Centre, London, via the distribution network. From the Central Apparatus Room in London the outgoing vision signal is sent via the Switching Centre at Broadcasting House to the P.O. Museum Exchange and from this point responsibility for distribution to each transmitter is undertaken by the Post Office.

The regional studio centres have means by which they can take over the local transmitter from the national network. The distribution links may be by coaxial cable (full line in Fig. 3.3, for example

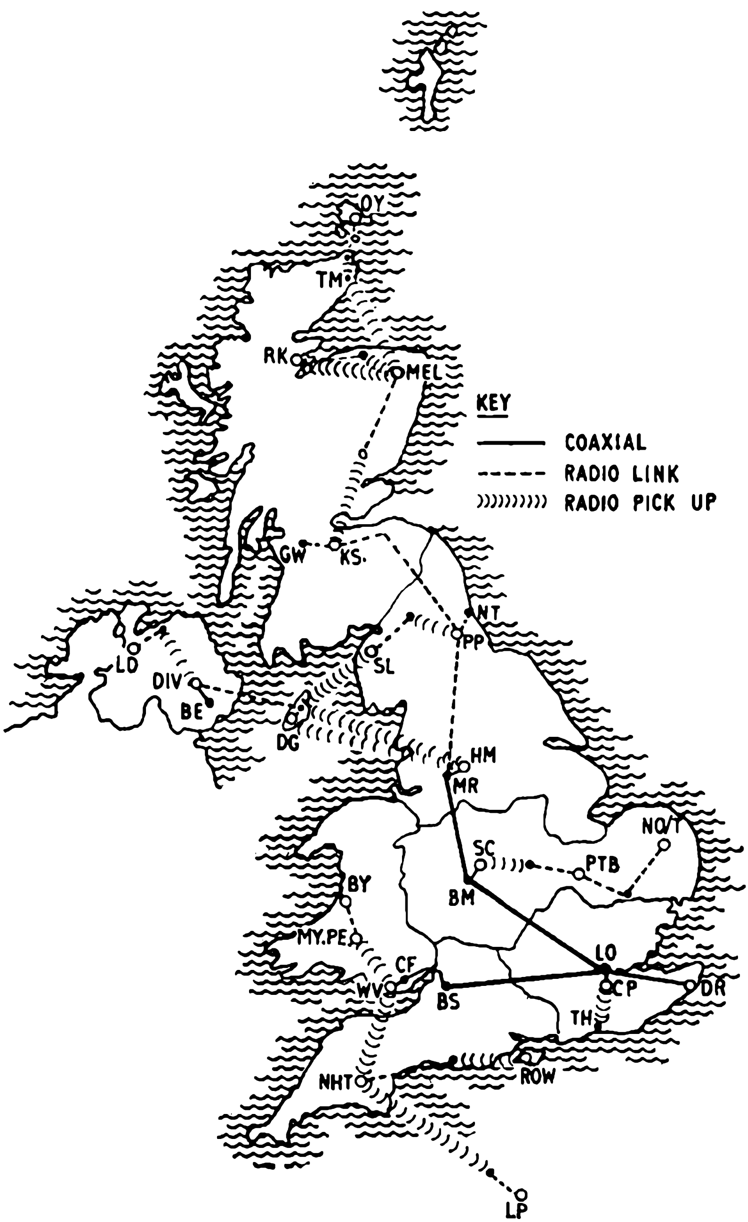


Fig. 3.3. The television distribution network (simplified)

London to Birmingham) or by radio link (chain line such as Manchester to Kirk O'Shotts). Both systems require the signal to be amplified at certain points but many more repeater stations are required on the coaxial cable than on the radio link. Thus repeaters (amplifiers) are spaced approximately six miles apart on the London to Birmingham coaxial route (90 miles) whereas there are only seven repeating stations on the 250 mile route using s.h.f. carriers (4 000 Mc/s) from Manchester to Kirk O'Shotts. On certain routes where there is no Post Office link, a programme feed is obtained by direct pick-up from the nearest high- or medium-power transmitter; thus Thrumster (TM) is served by direct pick-up from Meldrum (MEL). Sometimes a combination of direct pick-up and radio link is employed, as for example from Wenvoe (WV) to Blaen Plwyf (BY) via Mynydd Pencarreg (My Pe). The direct signal from Wenvoe is picked up at the intermediate point Mynydd Pencarreg, and the vision signal is extracted and used to modulate the radio link from this point to Blaen Plwyf.

Coaxial cable tends to be more expensive than the radio link unless the cable can be combined with telephone circuits, so that as a rule coaxial cable is used over routes which have considerable telephone traffic and radio link over routes where it is difficult or uneconomic to lay cables. The main distribution system is duplicated, so that regional contributions can be fed back to the London Central Control Room. Entry to the return network is possible at various points such as at the repeater stations or at the regional studio centres.

3.3 CAMERA AND LIGHTING TECHNIQUES AND FACILITIES

Camera operation and lighting require the exercise of artistic judgement; for this to be effective a knowledge of certain basic principles and techniques is needed and it is the purpose of this section to discuss some aspects of these techniques.

3.3.1 *Camera Operation*

The producer of a television programme may use the camera either as a reporting device or as a means of heightening dramatic content. For talks, demonstrations, sports, features, etc., the camera mainly fulfils a reporting role to present to the viewer those parts of the scene that are needed for understanding and enjoying the programme. For drama, light entertainment, etc., the camera is often required to make its own visual interpretation of the programme material. The use of the sudden close-up of a face can increase tension at a dramatic moment, or the movement of a camera in a dance sequence can give an impression of increased space and depth. The producer's approach to his problems depends on whether the camera plays a passive or an active role, but the skills needed from the cameraman are much the same whatever demands are made on the camera. In fact two skills are called for, the mechanical and the artistic. Mechanical dexterity is essential for handling the bulky television camera and its mounting so that smooth movement is achieved and accurate focusing is unobtrusively preserved. Artistic sense is required to co-operate with the producer and interpret his requirements for achieving a satisfactorily-balanced and interestingly-framed picture. Fig. 3.4 shows a photograph of a typical television camera body and the facilities that are available to the operator. The weight of the camera is of the order of 100 lb but the panning head is so constructed that the centre of gravity is maintained over the centre of the base and there is no tendency for the camera body to run away when the camera is tilted. The camera can be rotated horizontally through 360° and tilted vertically through approximately $\pm 50°$; the panning head can be locked in position or the friction of its movement adjusted to suit the cameraman's requirements.

Talk-back is provided to the cameraman from the producer, and from the vision control supervisor in the vision control room: a viewfinder, detachable for ease of maintenance and replacement, is available on top of the camera body. A cue light is mounted within the viewing hood but aural warning is also given by the producer. A red cue light mounted at the front of the camera warns the artistes and studio floor staff when the camera is on transmission.

Focus is maintained by moving the camera tube in relation to the lens; this is achieved by a direct mechanical link. The mechanical link rather than a servo-mechanism is preferred by the cameraman since the focusing action can be 'felt' more easily. The focus handle or capstan requires a relatively large movement for a small change of focus.

The movement of the four-lens turret is generally by direct mechanical link (rarely by servo-mechanism) through the centre of the main camera body, the handle appearing under the viewfinder at the back of the camera. The essential features of a satisfactory turret change-over mechanism are speed of change, positive positioning and silent operation.

The four standard lenses in the turret give angles of view of 9°, 14°, 24° and 36°, and the coverage they provide in a typical studio production is illustrated in Fig. 3.5. The picture tube will show narrower angles of view magnified to fill the same area as the 36° angle of view. A wider range of lenses is sometimes required but the possibilities are discussed in Section 4.5.1. The zoom lens,

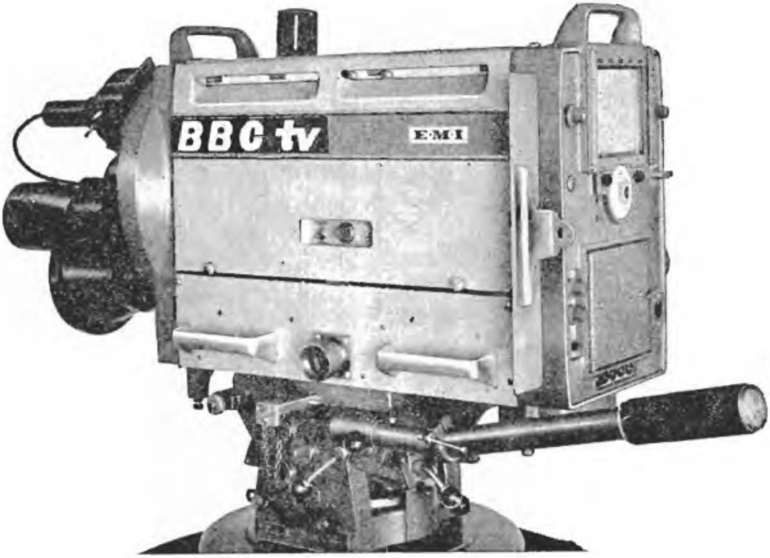


Fig. 3.4. A typical television camera body

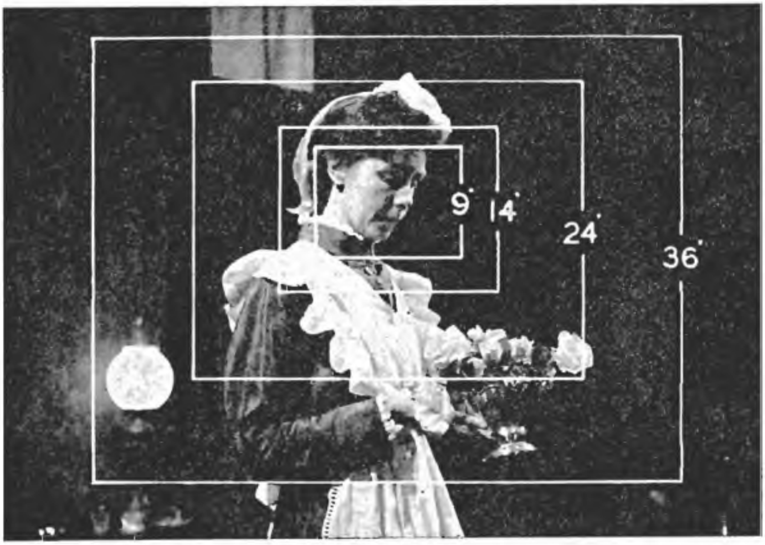


Fig. 3.5. The coverage of the various lenses

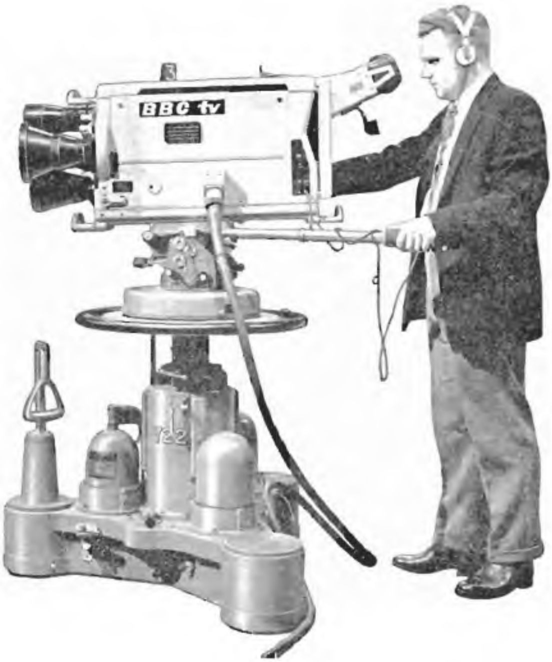


Fig. 3.6. The pedestal dolly

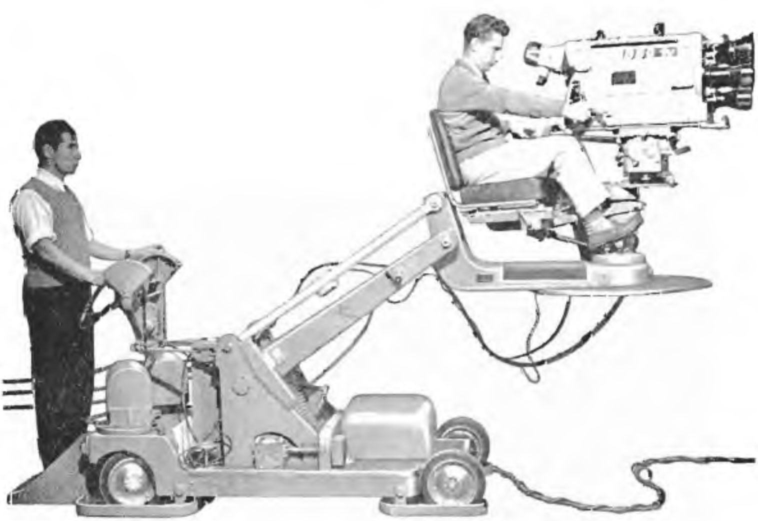


Fig. 3.7. The motorised dolly

another method of varying the angle of view easily and quickly is also used in studios but as it was originally developed for outside broadcast work, it is described in Section 4.5.1. It covers the range 9° to 32°, very nearly the same as the standard turret and has a minimum focus distance of 5 ft.

The light falling on the photo-cathode must be controlled if the camera tube is to operate under optimum electronic conditions, and this is performed by remote control of the lens iris (varying the lens aperture), by the vision control operator at the camera control unit or occasionally by means of a neutral density filter. The latter is one which absorbs equally all light wavelengths and has no effect on the tonal rendering of the colours in the scene.

The camera mountings are of two types, those designed for operation by the cameraman himself and those operated by one or more additional members of the camera crew known as trackers or dolly operators. The one-man operated mounting is usually a camera pedestal (Fig. 3.6) with manual raise and lower from the centre column. The camera and its panning head are counterbalanced to make height adjustment easy, and its three wheels may be locked to either single-wheel steering for tracking or three-wheel steering for crabbing (a sideways track). Any large movement or tracking while on transmission must be carried out very smoothly and for such work a motorised dolly such as the two-man dolly shown in Fig. 3.7 is generally used. The cameraman operates the normal pan, tilt and focus of the camera and has foot control of the powered raise-lower mechanism. When tracking, the dolly is power-driven and controlled by the dolly operator. The latter receives visual signals from the cameraman, and headphones enable him to hear instructions from the producer. With the powered camera dolly a third man is often needed to clear the cable as the camera tracks in and out, a very necessary operation when a complex programme involving a large amount of camera movement is being televised. A similar type of dolly is the motorised crane. With this type of dolly the camera and cameraman are at one end of a counterbalance boom which is swung into position manually. This enables the camera to be moved continually both in the vertical and horizontal planes as well as being tracked. This requires a total crew of three.

3.3.2 *Picture Composition*

The cameraman can make the producer's work much easier if he himself has a measure of artistic sense and is able to present almost automatically the kind of pictures at which the producer is aiming. Although television is generally regarded as a means of producing moving pictures, 95 per cent of the programmes tend to consist of what are in effect still pictures; only parts of the subject are in motion, the main mass being stationary with respect to its surroundings. For example a speaker's body may be stationary though he himself is talking and gesticulating; if there were constant movement of the camera or subject the viewer would most certainly find the general effect distracting and annoying. Exceptions to this rule are sport and some variety programmes where the material is almost entirely visual. Nevertheless a television programme can be thought of as a series of still pictures linked together by movement. A picture whether still or moving must have some order in its layout if it is to please the viewer and leave him unaware of the limitations of the television medium. For example in Fig. 3.8 (a) the face or body is filling the frame to an uncomfortable degree and any movement will probably cause the top of the head to disappear out of the frame. Fig. 3.8 (b) provides a margin of background, and movement is possible without the viewer being made aware of the confinement of the screen.

The influence of camera height on visual appearance is illustrated in Figs. 3.9 (a) and (b). In the low-angle shot in Fig. 3.9 (a) the nostrils are emphasised, the nose is short and the jaw and chin heavy. The high-angle shot in Fig. 3.9 (b) tends to elongate the face and accentuate the eyes and bridge of the nose. Figs. 3.10 (a) and (b) show how a change in camera angle can give shape and depth to a picture. The apparent depth is affected considerably by the choice of lens and perspective. Thus a wide-angle lens (greater than 24°) used from a short distance will accentuate the difference in size between the objects in each plane and will therefore increase the feeling of depth. A small studio or set can be made to appear large by this means but care must be exercised to prevent grotesque distortion of, for example, the human profile, a close-up of a full face with a wide angle lens giving an apparently enlarged nose. A narrow-angle lens used from a considerable distance gives the opposite effect, a reduction in apparent depth occurring because similar objects in differing planes seem to be of the same size.

To achieve a variation in perspective it is necessary to move the camera towards or away from the subject, and it is in this respect that the zoom lens fails. Although there is a change of image size no variation occurs in perspective and excessive zoom action tends to produce a feeling of unreality. The same effect is obtained by moving closer to a painting or photograph in order to see detail better: the objects on the painting maintain the same size relationship to each other irrespective of the position of viewing.

(a)

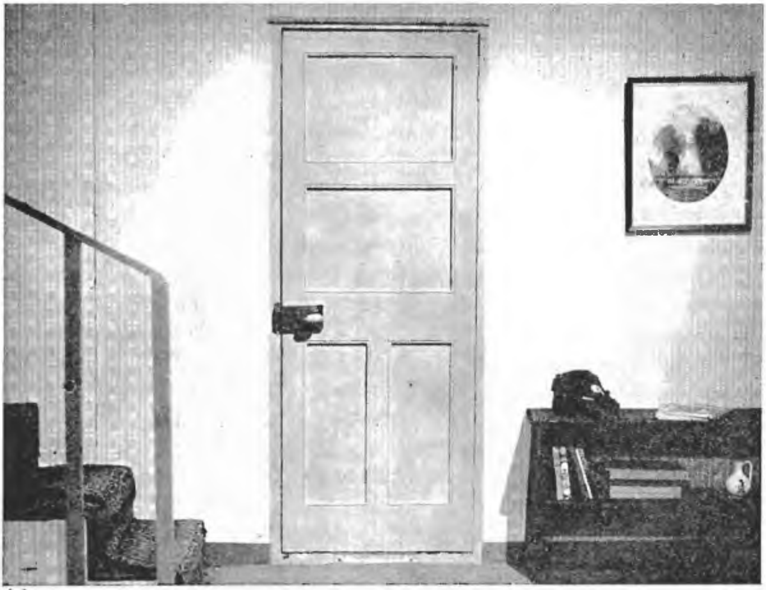
Fig. 3.8. Incorrect (a) and correct (b) framing

(b)

(a)

Fig. 3.9. Effect of low (a) and high (b) camera angle

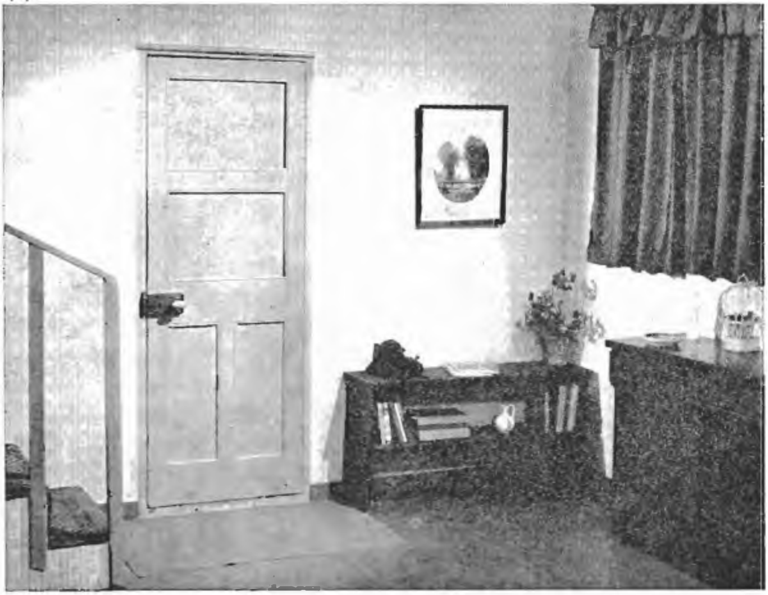
(b)



(a)

Fig. 3.10. Effect of camera angle on picture depth

(b)



A feeling of movement can be introduced into a programme by movement of the subject and/or the camera, or by cutting between vision outputs from a number of cameras. Each camera can be made to pan, track, crab (sideways track) or crane (up and down movement) resulting in a change of background and a variation in the content of the scene and of the size of the objects within the scene. The producer may also control the grouping and movement of the subject in relation to the camera position, to increase visual interest and impact.

It is not always fully appreciated that vision mixing is an essential part of production technique, and the method, timing and rate of cutting play a very significant role. There are three main methods of changing from one picture to another, namely cutting, mixing and fading. Cutting, a rapid switch over from one camera to another, is the most commonly used method and it is direct and positive in action in contrast to the gradual transition and blending of two pictures produced by mixing, one picture being taken out as the other is brought in. When fading from one camera to another, the picture is slowly reduced to a blank screen before the succeeding picture is brought in. This gives an impression of time lapse and is the conventional way of ending a programme and beginning another. The rate of changing affects the tempo of the programme. Swift cutting will increase the tempo and heighten the sense of excitement whereas slow mixing will give an impression of restfulness and relaxation. Change in picture content as well as method of camera selection can be used to influence viewer reaction. If there is a considerable difference between the viewpoint of one camera and another the effect of cutting will have more impact than if each camera has a similar viewpoint. Continual cutting between cameras presenting similar pictures appears as a 'fidget' and can cause irritation to the viewer.

3.3.3 *Lighting Technique*

A lighting supervisor must possess artistic appreciation as well as a technical understanding, because lighting effects must be visually interesting as well as technically acceptable. A sound technical knowledge of the properties of light sources and of the limitations imposed by the television camera are also essential since the lighting supervisor shares responsibility with the vision control supervisor for the tonal quality of the reproduced picture. Lighting technique is governed by both camera-tube and production requirements.

The two characteristics of the camera tube that have greatest influence are sensitivity and acceptable contrast ratio. The sensitivity or response to light intensity determines the average incident lighting level required, and 75 foot-candles may be regarded as typical for a 4½ in. image-orthicon camera operating at f5·6. The level varies according to the type of camera, an image-orthicon generally being able to operate at a much lower light intensity than a vidicon. The acceptable contrast ratio (A.C.R.) is the ratio between the lowest and highest level of illumination that the camera tube will accept and reproduce satisfactorily. A typical value is 40 : 1 indicating that light reflected from the brightest parts of the scene should not be greater than 40 times brighter than that from the darkest areas if both light and dark areas are to be reproduced satisfactorily. Although the acceptable contrast ratio of a camera tube may be quite high, the greater part of the significant picture information should be within a contrast ratio of approximately 10 : 1 since large areas of black and white are technically less acceptable. The lighting contrast of the reproduced picture can be considerably affected by the gamma correction control in the camera control unit. The range of contrast in a scene will depend on the colour and texture of the materials included in it as well as on the lighting. A scene containing a figure in a light-coloured dress against a dark background presents a high contrast ratio, but a scene providing contrast to the eye by virtue of differing colours may have little contrast in monochrome television. Thus a light-yellow and light-blue area will tend to reproduce in similar tones of light grey if they have the same effective brightness. Two such areas can be made to produce monochrome contrast by lighting each to a different level of intensity.

Set design and decor as well as lighting contribute to contrast ratio, and the lighting supervisor and set designer co-operate to ensure that the range of tones in the subject is within the acceptable contrast ratio. In a studio production, scene and lighting contrast are under complete control but this does not necessarily apply for an outside broadcast where in sunlight a scene contrast ratio of 250 : 1 or more may have to be faced. Under these circumstances the camera stop is adjusted to ensure that the important subject matter is reproduced satisfactorily.

The lighting supervisor must also take into account the restrictions imposed on his work due to the shape and the area of the studio set, and due to the movement of people, objects, cameras and microphone booms. As lighting affects and is affected by every other aspect of a studio production, the lighting supervisor plays a crucial part in the producer's planning meeting. The major part of the lighting must be rigged in position before camera rehearsals begin and there is little chance for later experimentation. The lighting supervisor has at his disposal three main variables: the direction of his lamps, the quality of the light (whether soft or hard) and the balance of the light intensity. He controls all three through the use of four types of lighting: key, base or filler, back and background lighting.

Key lighting gives shape and visual interest to the scene by means of suitably directed hard light sources; it also determines the camera aperture. The base or filler light is used to reduce the contrast of the scene to an acceptable value by raising the brightness level of the shadows thrown by the key lights. Moreover by suitable adjustment of the blackness of the shadows the whole mood of the scene can be altered. The back light provides relief to enable the subject to stand out from the background. The background lighting is of importance in adding shape and interest to the background and contrasting it with the foreground.

In practice each lamp may be doing two or more jobs and this is particularly true of those lighting the action area because they may be acting as key lights from one view point and back lights from another. The background lighting may include effects lights to produce a change of situation or time of day in a play or variety programme. Unless special effects are desired the average level of lighting should be maintained and a change of time or situation is met by varying the direction and/or intensity of the background and effects lighting, probably in conjunction with some variation of the filler intensity to alter the contrast of the lighting.

A lighting console installed in the vision control room allows the lighting supervisor to achieve quick changes of direction and intensity with single lamps or groups of lamps through remote control of dimming and switching. An additional facility enables a switching combination to be 'memorised' and pre-set lighting combinations to be brought into operation at appropriate points in the programme. One type of lighting console is shown in Fig. 3.11.

Light sources can be classified under two headings: spot lights designed to produce hard light with sharp shadows, and floods or broads designed to produce soft light with diffuse, indeterminate shadows. Spot lights can vary considerably in output and physical size from the 150-A arc to the 200-watt cub. The most common sizes are the 2-kilowatt and 500-watt (pup) sizes. An example of the 500-watt spotlight is illustrated in Fig. 3.12 (a). Broad sources are made up of units and groups of lamps; two such units are known as a scoop (one 1-kW lamp) and a 'ten light' (ten 200-watt lamps) and the latter is shown in Fig. 3.12 (b).

The lamps are suspended on lighting barrels (lengths of scaffolding approximately 8 ft long), each of which can be lifted by its motorised

Fig. 3.11. A lighting and vision control room, with lighting console shown on left

hoist to the required height. The barrels are distributed over the whole of the studio area to ensure maximum flexibility of the lighting with the minimum of rigging. Operation of the pan, tilt, spot and flood controls on the lamps by a pole from the studio floor achieves a further saving in rigging time. Four lighting outlets appear on each barrel. To reduce the mechanical loading on the barrels the lamps are constructed of light alloy or fibreglass.

The intensity of individual light sources can be controlled by dimmers which may comprise variable resistances, variable chokes or auto-transformer tappings. The latter method has the best variable-load characteristic and dimming is achieved by a remotely-controlled mechanically-driven brush tracking the transformer windings.

Each lamp is connected to a lighting socket called a 'studio outlet'. The total number of available studio outlets is greatly in excess of the available dimmer channels, and some means of linking dimmers to outlets in use is required. One method of doing this is by means of a plug-and-socket system somewhat similar to a P.B.X. board.

The total lighting power available for a studio equipped with modern image-orthicon cameras is calculated on the basis of 25 watts per square foot of floor area. A typical example is Studio 3 of the

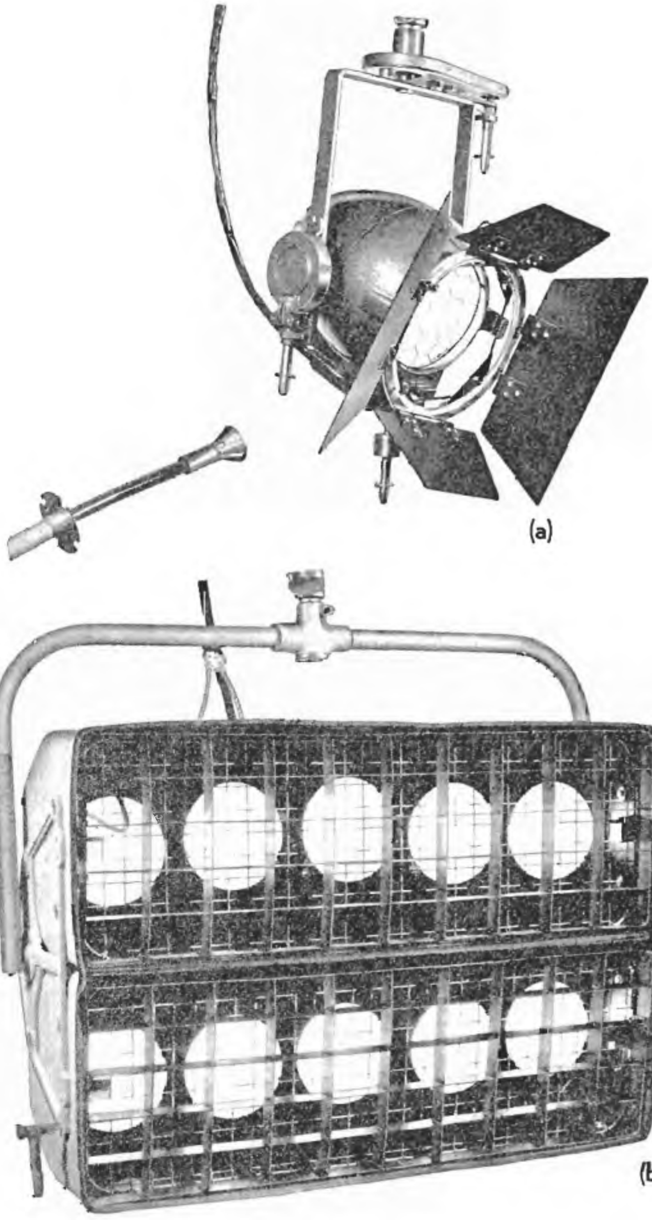


Fig. 3.12. Examples of light sources: (a) 500W PUP (b) 2kW 10 light

Television Centre where 200 kW is available for 8 000 square feet of floor area.

3.4 CAMERA TUBES

One method of converting brightness variations of a light source into electrical variations has been touched upon in Section 1.5.2, where it is stated that certain materials possess the property of releasing electrons when light falls upon them, the number of electrons released being proportional to the brightness of the light. This type of photo-electric effect is known as 'photo-emission' and a large proportion of the television camera tubes in use today operate on this principle. There are two other photo-electric effects known as 'photo-conductive' and 'photo-voltaic'. As the names imply, the first of these means that variations in light falling on a photo-conductive surface cause variations in its conductivity, whereas the second means that light generates voltages proportional to its brightness.

The photo-conductive effect (first noted in selenium many years ago) is now being exploited in a special type of camera tube known as the Vidicon. Compared with the photo-emissive camera tube the photo-conductive tube suffers from the disadvantage that it shows a time lag at low light outputs and this causes smearing with apparent loss of focus when the object or camera is moved. This can be overcome by using a high light intensity on the subject and it presents no difficulties when used in a television film projector. The photo-conductive camera tube can prove quite satisfactory on still pictures at low light levels.

The photo-voltaic effect depends on the release of electrons across a junction between dissimilar materials, such as copper and copper oxide, selenium and selenium oxide. This principle has not been exploited for television purposes but it is used for providing measurements of light intensity in exposure meters.

3.4.1 *The Principles of Photo-emissive Television Camera Tubes*

Photo-emission is dependent not only on the brightness of the incident light but also upon its colour, but this can be an advantage so long as the colour response is similar to that of the eye, because the electrical impulses will then give levels proportional to the brightness as seen by the eye. Early camera tubes suffered from the disadvantage that they discriminated in favour of colours at the red end of the spectrum. The result was that these colours were reproduced at too high a brightness level, and costumes and make-up had to be modified by reducing the content of red colours, for example by using yellow lipstick instead of red.

Developments in photo-emissive materials have now led to the production of camera tubes having colour responses approaching that of the eye, and special make-up and costume colours are not normally necessary. For television the image of the scene requires to be transmitted element by element and this was achieved in the earliest experimental apparatus by scanning a scene with a travelling spot of light. The light reflected from the scene was picked up by a bank of photo-cells with additive outputs which produced a series of electrical voltages directly proportional to the light reflected from the scanning spot. This method has two disadvantages: ambient light must be very low so that actors are performing almost in darkness, and sensitivity is poor because the incident light is passing so rapidly over the scene that the amount of light reflected is very small. In the 405-line system the light content of each element of the scene is only available for about 0·3 microseconds. An alternative method is to focus the image of the scene on to a plate consisting of very small photo-electric elements each insulated from each other. In the 405-line system at least 250 000 separate elements are required if picture detail is to be reproduced satisfactorily. Each photo-electric element forms a capacitance to the main signal plate and the continuous emission of electrons builds up a charge on each elemental capacitance. Regular discharge of this capacitance by means of a scanning device will produce a current pulse which in turn causes a voltage pulse across the series resistance. This voltage pulse is proportional to the charge, which is the product of the light intensity falling on the individual photo-electric cell and the time between each discharge. Such a system, known as charge-storage, is employed in all types of present day photo-emissive camera tubes and it increases the efficiency of conversion from light intensity to electric output by many thousand times over the scanning-spot system.

3.4.2. *The Emitron Camera Tube*

The first television camera tube used by the BBC was the Emitron iconoscope illustrated in Fig. 3.13, and it employed the charge-storage principle. The image of the scene to be televised is focused on a mosaic of small photo-emissive cells deposited on a mica backing plate. One the opposite side of the mica is a metal film known as the signal plate, which forms with the mica backing plate a capacitive connection to each photo-cell. The signal plate is connected to the electrode marked *second anode* by means of the resistance *R* across which the picture output voltage is developed.

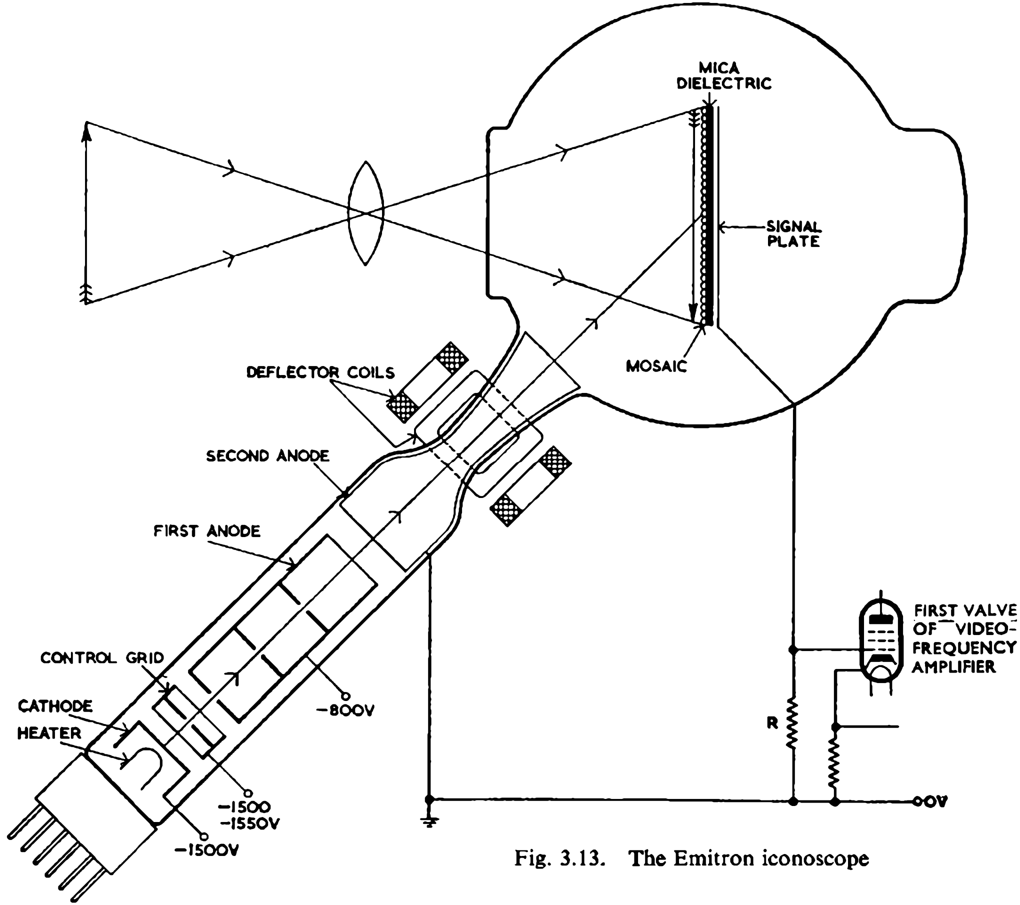


Fig. 3.13. The Emitron iconoscope

Light falling on the photo-sensitive mosaic releases a continuous stream of electrons which are attracted to and collected by the second anode. Each elemental capacitance between a given photo-electric cell and the signal plate builds up an increasing charge proportional to the light intensity falling on it. An electron beam is used to restore the electron deficiency on each photo-cell at regular intervals, and so discharge the elemental capacitance. A pulse of current proportional to the electron deficiency occurs round the circuit and a voltage proportional to light intensity and charge time is produced across *R*. The electron beam is arranged to scan the whole of the photo-electric area which is generally referred to as the target. The signal plate is opaque to light so that the electron beam and light must fall on the same side. In order to produce an oblique rectangular scan the scanning beam must have a gradually increasing line scan as it travels down the signal plate.

3.4.3. *The Image Iconoscope*

The next development of the Emitron iconoscope was the image iconoscope (super-emitron) which gives increased sensitivity by making use of a secondary image. A diagram of the tube is shown in Fig. 3.14. The photo-electric target of the iconoscope has now been replaced by a secondary image target, and the photo-electric plate known as the photo-cathode has been transferred away from the electron beam. The image is optically focused on this photo-cathode which is transparent and has the photo-emissive surface on the side away from the light; electrons released from this are magnetically focused to produce an electron image of the scene on the secondary-emitting mosaic. The photo-electrons falling on the secondary-emitting surface cause a greater number of secondary electrons to be released, and a charge is built up between the secondary-emitting mosaic and the signal plate in exactly the same way as occurred with the photo-electric target of the iconoscope. The sensitivity of the image iconoscope is greater than that of the iconoscope by the ratio of secondary electrons to photo-electrons, which may be of the order of 10–20 times.

In the iconoscope and image iconoscope the velocity of the scanning beam when it strikes the target is high and secondary electrons are emitted from the target to modify the charge-storage pattern so that it is no longer directly proportional to the light intensity falling on each cell. This tends to reduce sensitivity as well as produce strong spurious signals and no true black level. Camera tubes using special methods to reduce the scanning-beam velocity at the target to a low level were the next development.

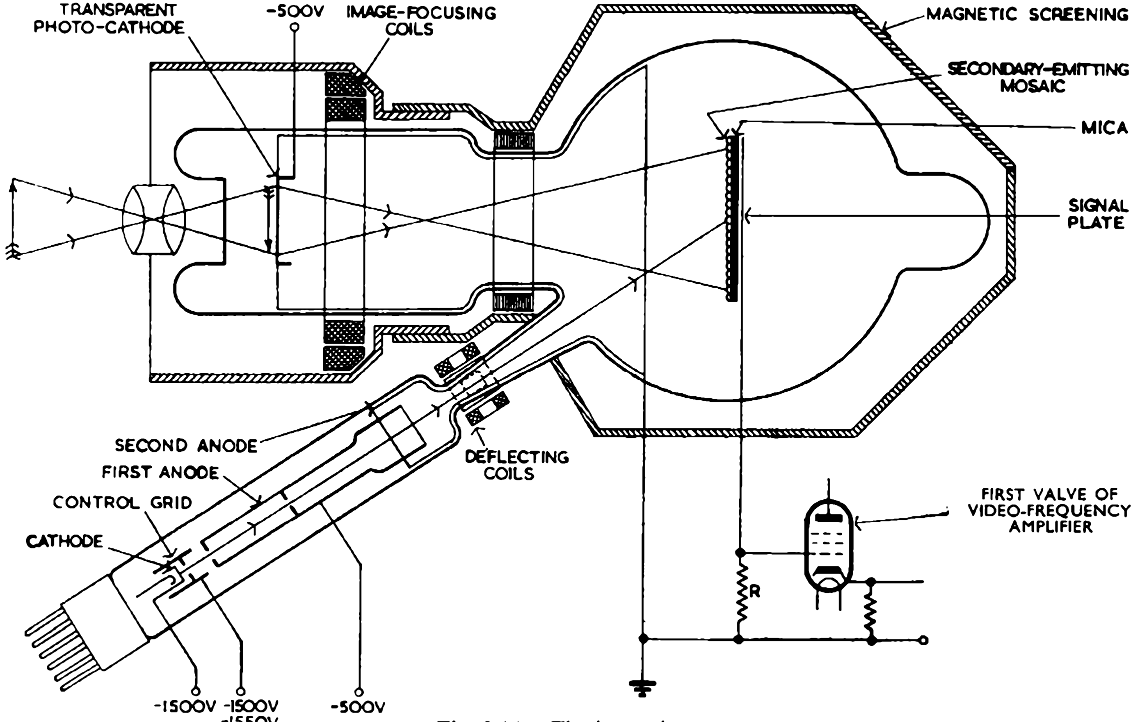


Fig. 3.14. The image iconoscope

They give a well defined black-level signal as well as increased sensitivity and have now replaced the high-velocity camera tubes.

3.4.4 *Low-velocity Camera Tubes*

The low-velocity tubes known as Orthicons use a target with a transparent signal plate and the image is focused on to the mosaic through the transparent signal plate and the dielectric. This does away with the need for a side tube containing the electron-gun assembly, and the scanning beam can strike the mosaic at normal incidence. This simplifies tube construction and scanning circuit design and also produces a physical shape which makes for easier mechanical design. For a low scanning-beam velocity at the target, the target must be at about the cathode potential of the scanning-beam electrode assembly and not, as in the high-velocity tubes, at the potential of the final anode. The term cathode potential stabilised (C.P.S.) is sometimes applied to these tubes and the first to be used by the BBC was the C.P.S. Emitron.

3.4.5 *The C.P.S. Emitron*

A sketch of the C.P.S. Emitron (orthicon-type) camera tube is given in Fig. 3.15. The target consists of a transparent conductive signal plate deposited on a transparent dielectric which has on its other face a transparent photo-sensitive mosaic. The latter must be transparent in order to allow the release of the photo-electrons from its free surface. A focus coil (labelled ' Field ' in the diagram) surrounding the whole tube carries a pre-determined direct current and produces an axial magnetic field for bringing the scanning beam to a focus at the target. The beam actually follows a helical path with several subsidiary focus points between the target and the electron-gun assembly. The wall anode potential also affects focus, and fine control is obtained by adjustment of this potential. The alignment coils around the electron-gun assembly ensure that the scanning beam is projected in alignment with the magnetic axis of the focus field coil. Deflector coils with axes mutually perpendicular across the tube cause the beam to scan the target in the normal way. With the highest attainable vacuum there is still sufficient gas left inside the tube to produce positive ions and these must not be allowed to reach the target where they could completely destroy the charge-storage pattern. An ion-trap mesh at a positive potential is interposed before the target to repel the ions. The electrons in the scanning beam travel up the tube at high velocity but are slowed down as they approach the target plate by the decelerator ring at cathode potential.

In the absence of light the target is at cathode potential and the scanning beam electrons are repelled and fail to land. When light falls on the target the photo-electrons are released to the wall anode and a positive charge pattern is produced over the target.

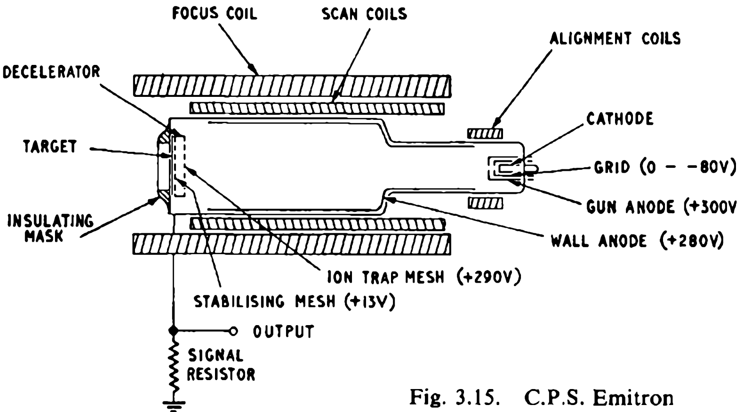


Fig. 3.15. C.P.S. Emitron

The electrons in the scanning beam are able to land and discharge the capacitance between signal plate and mosaic. In areas of high light intensity the positive charge is high and there is a danger that the electrons of the scanning beam will develop sufficient velocity to eject secondary electrons from the target. The released secondary electrons increase the positive charge and the effect is cumulative: instability results and to restore normal conditions the electron beam must be cut off momentarily. This difficulty has been overcome by including a mesh at about +13 volts above cathode potential and spaced 1 mm from the photo-emissive surface. The mesh collects some of the photo-electrons as long as the target potential is below that of the mesh and an excessive rise of target potential is prevented because as its potential approaches that of the mesh, photo-electrons are turned back to the target.

3.4.6 *The Image-orthicon*

An improvement in sensitivity can be obtained by including in the orthicon an image section similar to that used in the image iconoscope, and such a tube known as an image-orthicon is now widely used. To increase still further its sensitivity, a secondary electron multiplier is included. The image-orthicon can produce an electrical output for light levels which give very little output from the orthicon, but the reproduced picture under these conditions has a high noise level and is not suitable for a television broadcasting service. Higher light levels are necessary to produce a satisfactory signal-to-noise ratio, and the sensitivity for a given signal-to-noise ratio is of the order of five times better than that of the orthicon.

The construction of the image-orthicon tube is shown in Fig. 3.16. The face-plate of the tube is coated on the inside with a photo-emissive material, and the electron image is focused on a secondary emissive target consisting of a thin glass disk with a fine mesh mounted very close to it on the face-plate side. The mesh, designated target mesh, is maintained at a small positive potential with respect to the target so that when the photo-electrons cause secondary emission the secondary electrons are drawn off to leave a charge emission pattern on the target. The capacitance between the target and the mesh plays the more important part in the charge-storage action but that between the two faces of the target also has an effect. The target mesh prevents the instability effect described in 3.4.5 because any increase in target potential above that of the mesh causes the secondary electrons to return to the target. The focus and deflection arrangements are similar to those of the orthicon and need no further comment.

As with the orthicon, the electron beam supplies the electron deficiency at the target but an output is not provided by the resulting current pulse. Instead the returning beam minus the electrons restored to the target is deflected by electric fields into a series of secondary emission multipliers. At each dynode (secondary emitting surface) the incident electron beam releases more secondary electrons which then augment the main beam. The latter is finally collected at an anode containing in its external circuit a resistance across which the output voltage is developed. No mention is made of a returning beam in the description of the orthicon tube but the beam does in fact return and is collected by the gun anode but is not used for signal production. Secondary emission multiplication possesses the advantage of increasing the output voltage without adding to noise to the same extent as a valve amplifier would do. In the earlier versions of the image-orthicon tube the external diameter of the tube is about 3 in. but a larger version of approximately $4\frac{1}{2}$ in. diameter (and correspondingly larger target) is now being used by the BBC because it gives better resolution and signal-to-noise ratio.

All low-velocity tubes such as the C.P.S. Emitron and image-orthicon have a gamma (Section 1.9.2) of unity and gamma-correcting circuits have to be included if an overall gamma of unity is to be achieved with a picture-tube gamma of 2·5. The gamma correcting circuit is an amplifier stage having a non-linear relation

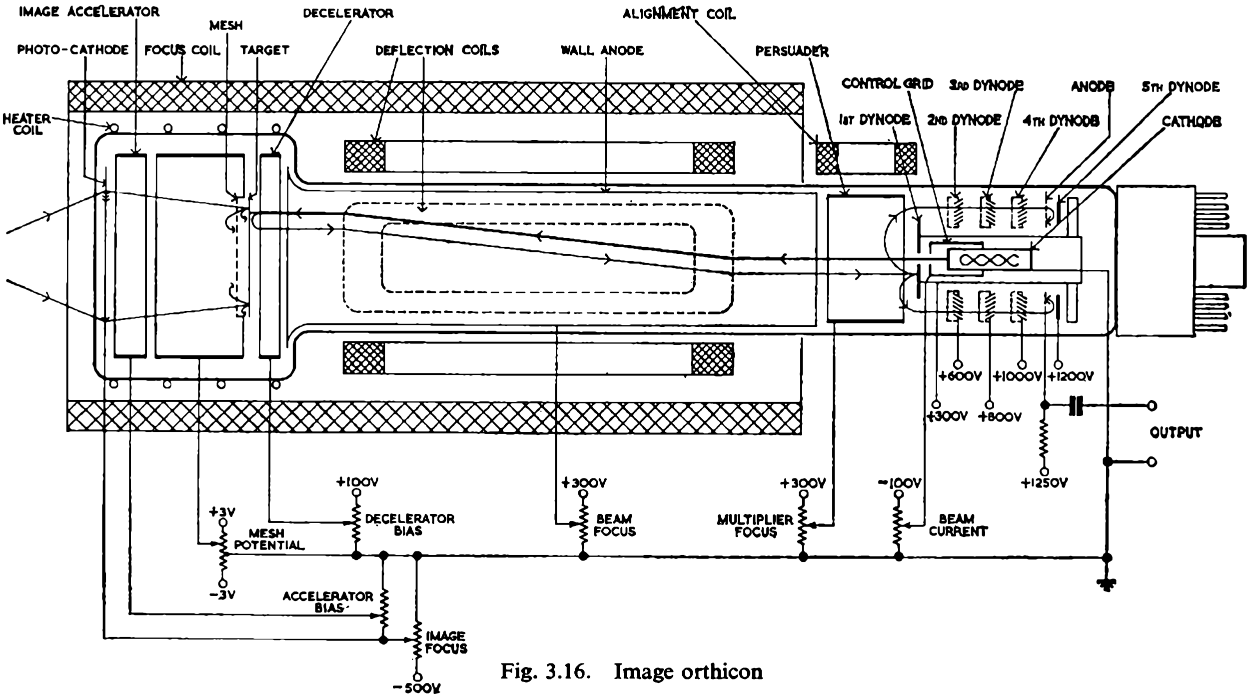


Fig. 3.16. Image orthicon

between input and output, and its amplitude-distorting characteristic is such that at input voltages corresponding to high light levels the amplification is less than at low light levels, i.e., output is proportional to $(\text{input})^{0.4}$.

3.4.7 *The Vidicon*

As stated in the introduction to this section the vidicon camera tube operates on the photo-conductive principle. A diagrammatic sketch of the tube is given in Fig. 3.17, and it is seen to have a simple electrode structure which provides an initial focusing action. The tube is small, about 1 in. diameter and 6 in. long, and has

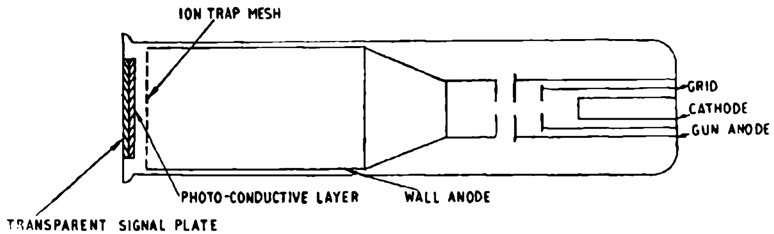


Fig. 3.17. Vidicon camera tube

the usual focus and deflecting coils similar to those for the image-orthicon. The target consists of a layer of photo-conductive material deposited on a transparent signal plate. The plate is biased positively with respect to the cathode. The photo-conductive surface has a very low surface conductivity and for all practical purposes is an insulator in this transverse direction. The conductivity through the surface is much lower and it is this that is affected by the light falling on the signal plate. The surface may therefore be regarded as a series of elemental capacitors paralleled by elemental conductances. Light increases the elemental conductivity and discharges the elemental capacitance, causing the voltage of the surface of the element to rise above cathode potential. The increase in voltage is proportional to the light causing the increase in conductivity. The scanning beam returns the voltage of the element back to cathode potential and in doing so sends a pulse of current through the resistor which is connected to the signal plate.

The current pulse is proportional to the loss of charge on the elemental capacitance and the charge is in turn proportional to the change in conductivity, that is, to the light which is falling on that portion of the target.

3.5 THE EQUIPMENT USED IN A TELEVISION CHANNEL

A typical studio television channel contains three main items of equipment besides the camera: the camera control unit in the Vision Apparatus Room, the vision mixer apparatus and the synchronising pulse generator. Certain studios have inlay, overlay and transparency facilities and this apparatus is generally housed in the Production Control Room.

3.5.1 *The Camera Control Unit*

The camera control unit for each camera used in the studio is located in the Vision Apparatus Room and it performs the following functions:

i. controls the power supplies to the complete channel;

ii. supplies to the camera via the camera cable the necessary timing pulses, the camera operating tube potentials, the picture signal for the viewfinder, and talk-back;

iii. accepts the picture signal from the camera and performs a series of operations to produce a standard signal at the output.

The action of the camera control unit can most easily be followed by reference to the simplified schematic diagram of Fig. 3.18, which shows all the essential parts but not necessarily in the order in which they appear in a particular channel. Four types of pulses are received from the synchronising pulse generator in the Central Apparatus Room, namely line drive, field drive, line and field blanking pulses and line and field synchronising pulses. Additional pulses and waveforms are derived as required. The camera blanking voltages and scanning voltages are derived from line and field drive. The drive voltages are rectangular pulses 8 microseconds wide for the line and 400 microseconds wide for the field. After amplification the video signal passes through the system blanking inserter which injects a blanking period of 18 microseconds every line period and of 400 microseconds during each field period. The blanking inserter is generally preceded by an aperture corrector which compensates for the loss of high frequency due to the finite width of the scanning beam in the camera tube. A camera correction unit is required to restore the h.f. loss in the camera cable.

Following the system blanking inserter is a limiter which establishes the black and peak-white picture limits. The line and field synchronising pulses are now added to produce the standard waveform which, after further amplification in a distribution amplifier is fed to the viewfinder, the picture and waveform monitor in the Vision Control Room, to the vision mixer and to the preview

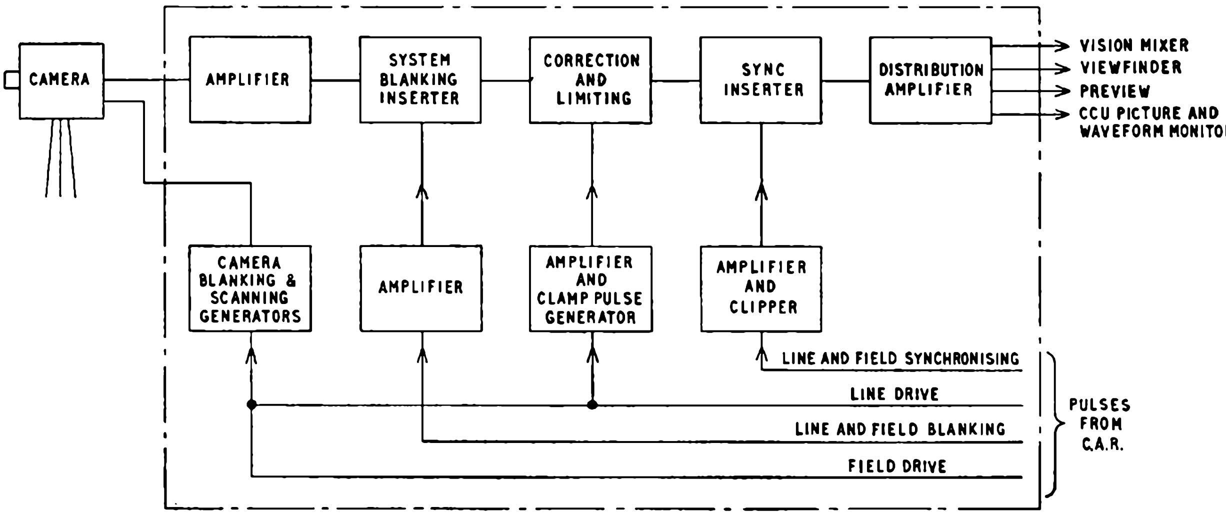


Fig. 3.18. Simplified block schematic diagram of the camera control unit

monitor in the Production Control Room. The initial setting up of a camera control unit is the responsibility of the maintenance section and the operator has normally only to adjust the following controls:

(a) Gain. This controls the amount of light reaching the camera tube by adjusting the iris setting.

(b) Lift. This adjusts the black level, insufficient lift causing crushing of blacks, and too much lift causing crushing of whites.

(c) Gamma. This adjusts the contrast range of the picture.

3.5.2 *Vision Mixer Apparatus*

The vision mixer apparatus must be able to accept and deal with several sources, e.g., studio cameras, telecine, special effects and outside broadcasts. Provision must be made for fading, cutting or mixing any of the sources, and for setting up accurately superimposed pictures when required.

The mixer equipment used by the BBC takes two different forms. In one there are separate fading and cutting controls for each source, and in the other two faders each having an associated row of cut-buttons, any source being available on both rows.

In some studios the equipment consists of two similar groups of seven channels, each channel having a cut-button and fader, and with this system both methods of control may be used. The groups are labelled A and B and connected as shown in Fig. 3.19. Each source distribution amplifier provides four outputs, A, B, Inlay and Spare, and after amplification the outputs of each group are passed on to a group control panel where either A or B group is selected. The group control output is amplified and clamped at black level before going to the Central Apparatus Room.

3.5.3 *The Synchronising Pulse Generator*

Synchronising, blanking, and drive pulses at line and field frequencies form an essential part of the television output waveform and must be made available at the camera and camera control unit. A simplified schematic diagram of a synchronising pulse generator is shown in Fig. 3.20. Since the field synchronising signal contains pulses at twice line frequency and has to begin halfway through the 203rd line on odd fields, it is necessary to use a master oscillator operating at twice line frequency, i.e., 20 250 c/s. The output from the master oscillator consists of rectangular pulses, which are fed

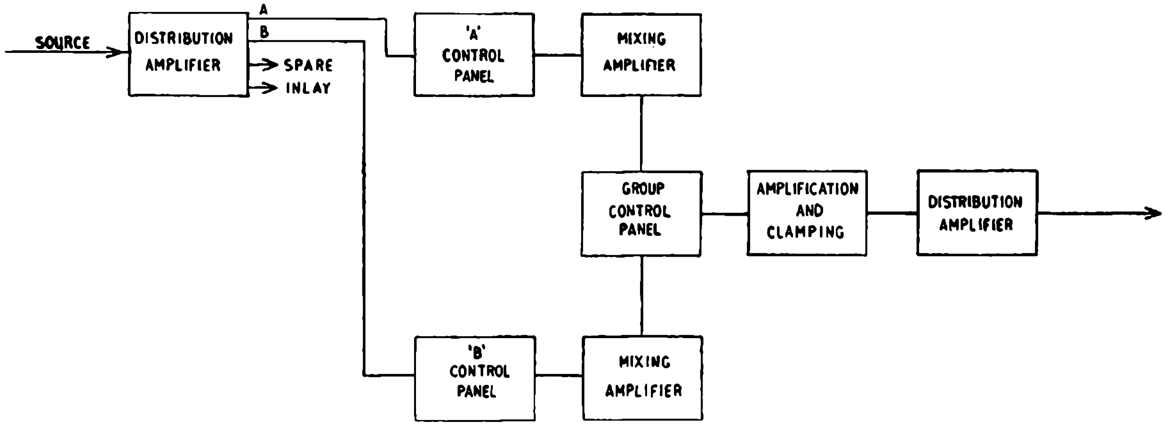


Fig. 3.19. Simplified block schematic diagram of the vision mixer

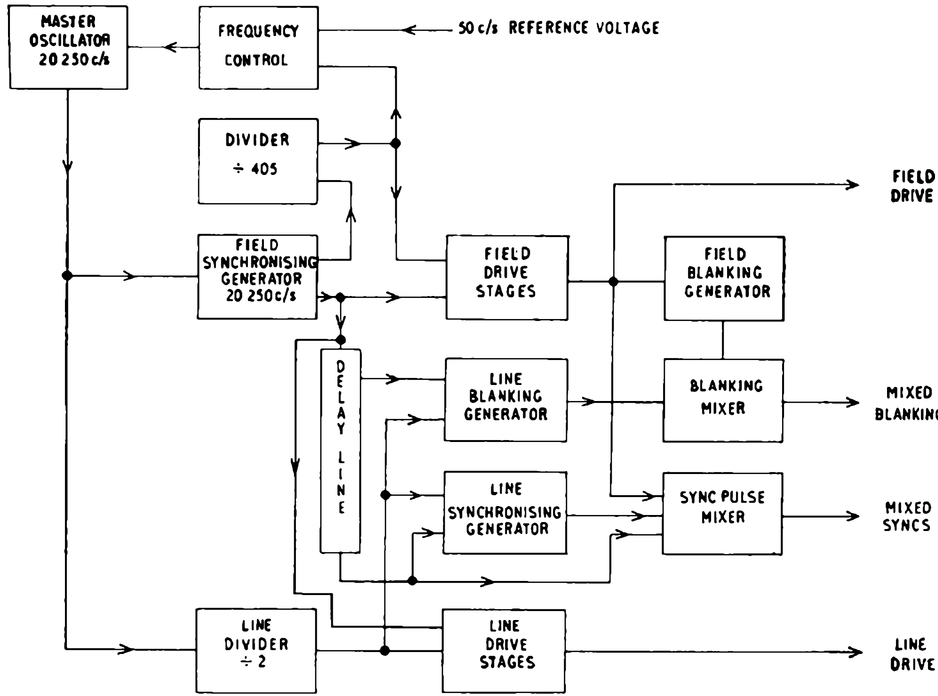


Fig. 3.20. Simplified block schematic diagram of the synchronising pulse generator

to the synchronising pulse generator and to the line divider. The field pulse generator converts the rectangular input pulses at twice line frequency into the 40-microsecond broad pulses required during the start of the field synchronising period, and it also provides an output for the divider circuit which controls the field drive. The 50-c/s pulses from the divider are compared against the 50-c/s mains supply; if these are not in step, the difference signal is used to operate a control to change the master oscillator frequency until a locked condition of operation is achieved. The divider output is connected to the field drive stage which gives a field drive output consisting of 400-microsecond rectangular pulses occurring 50 times per second. These pulses control the camera blanking and scanning generators as indicated in Fig. 3.18. Field drive pulses are connected to the field blanking generator and to the synchronising pulse mixer where they gate in the eight broad pulses at the start of the field synchronising period (Section 1.5.3). The field blanking generator converts the 400-microsecond field drive pulse into the 1 400-microsecond field suppression pulse.

The broad pulses from the field synchronising pulse generator are applied to a delay line giving 2·5 microseconds delay to the line blanking generator input. The line blanking output provides the 18-microsecond line blanking pulse required to form the front and back porches.

The line synchronising generator receives an input delayed by a further 1·5 microseconds and it produces the line synchronising pulses of 10-microsecond duration to give a front porch of 1·5 microseconds and back porch of 8 microseconds. The output of the line synchronising generator passes to the synchronising pulse mixer where it is gated out 50 times per second for 400 microseconds in favour of the broad pulses.

The line divider halves the frequency of the rectangular pulses from the master oscillator and these line frequency pulses provide line drive, and gate the line blanking and line synchronising generator to suppress every other pulse from the field synchronising generator, and produce from these generators pulses of line frequency.

The initial 2·5 microseconds delay between line and field drives and mixed blanking allows adequate time for the signals to pass up the normal length (about 600 ft) of camera cable and for the vision signal to return. For shorter or longer lengths of cable special arrangements are made in the camera control unit or the synchronising pulse generator to maintain correct registration.

Fig. 3.21 indicates the time relationships and shapes of the four waveforms which are available at the output of the generator for odd and even fields.

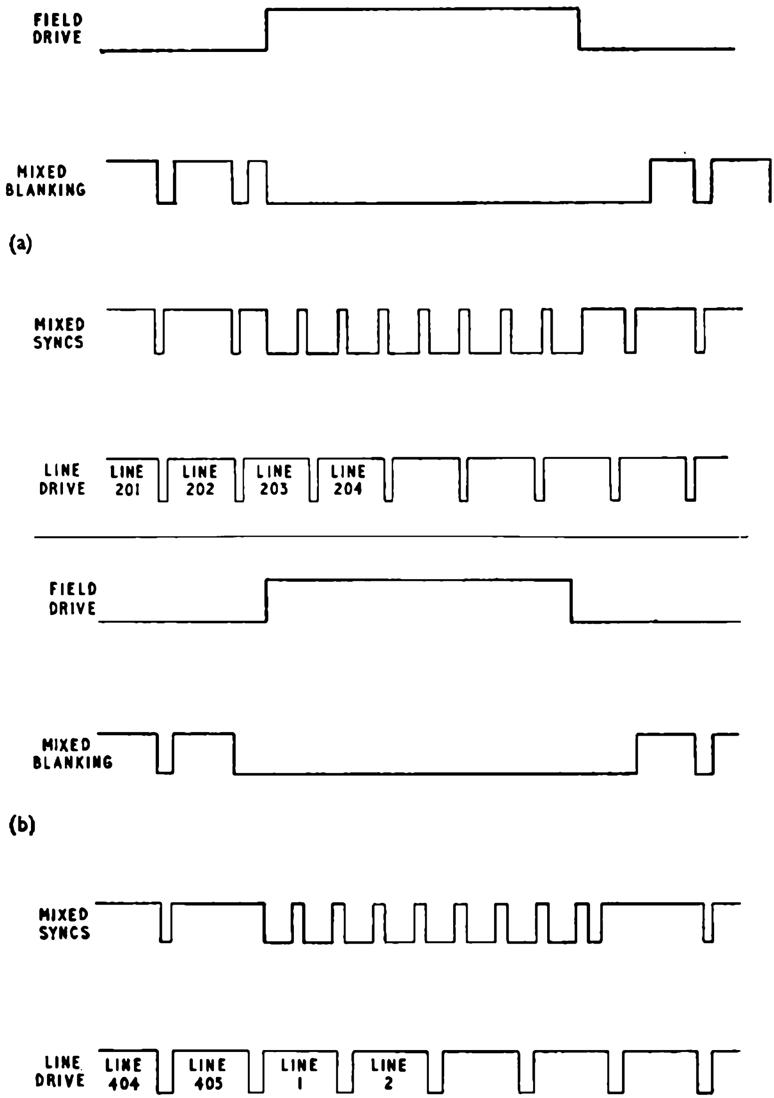


Fig. 3.21. Output waveforms from the synchronising pulse generator: (a) odd fields; (b) even fields

3.5.4 *Apparatus for Special Effects*

Genlock. The essential part played by synchronising signals in the vision waveform creates problems when picture signals from a remote source have to be mixed with those from a local source. Unless the synchronising signals for both pictures are locked, picture roll or break-up may occur during the switching operation. It is not often feasible to lock the remote source, and normal procedure is to lock the pulse generator in the Central Apparatus Room to the remote source generator by a system known as genlock.

Combined Studio Operation. It is sometimes necessary to be able at will to switch and control the outputs of two studios, and a combining mixer is included in the Central Apparatus Room with one studio acting as a master and the other as the slave. Both outputs are fed to the combining mixer, the faders of which are remotely operated by servo-control mechanism from the Vision Control Room of the master studio.

Back Projection. Certain types of production may require an outside scene to be reproduced in a studio and, to save the construction of an expensive set, back projection may be employed. The actors work in front of a screen on to the back of which is projected the required scene, which may be a 'still' from a slide or it may be moving and provided from a film. The film has to be synchronised by the field pulse so that the camera blanking occurs during the film change-over period. A high intensity of illumination is required and a carbon arc is used in the projector. To conserve studio space a mirror is used to 'fold' the light in a manner similar to that adopted for the folded telescopic lens described in 4.5.1. Great care has to be taken in lighting the foreground to prevent shadows falling on the screen or at an angle contrary to that suggested by the background scene, and so destroying the illusion.

Inlay. Inlay allows a composite picture to be obtained from two picture sources, a chosen area on one picture being replaced by an area taken from the other picture. Thus two people having a telephone conversation might be shown on the same screen. Inlay is also sometimes used for superimposing captions. The schematic diagram of Fig. 3.22 shows how inlay is achieved. A short persistence cathode-ray tube has field and line deflection synchonised with that of the cameras and it produces a 'flying spot'. A mask of opaque material, which has the specified area cut out, is placed between the cathode-ray tube screen and a photo-cell. The photo-cell receives a pulse whenever the flying spot starts to cross the opening cut in the mask, and the pulse is used to operate an electronic switch changing over from the output of camera 1 to that of camera 2. When the flying spot disappears at the opposite side of the mask opening, the resultant pulse switches camera 1 output back and cuts off camera 2 from the circuit. The size, shape, and placing of the inlay area is entirely controlled by the mask opening.

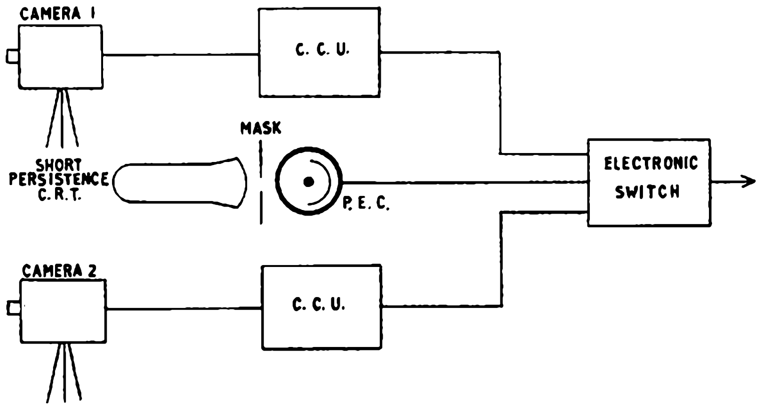


Fig. 3.22. Simplified block schematic diagram of inlay equipment

Overlay. Overlay involves a process very similar to inlay but without a mask, the switching pulse being derived from one of the picture sources. It is of particular value when a moving object is to be superimposed on another background or when its silhouette is to be filled in from another source: for example a trick effect may be needed in which a dancer appears as a newsprint cut-out. The moving object must contrast sharply with its own background (black against white or vice-versa) so that a silhouette pulse is produced for switching from the main scene either to the moving object or to another source, e.g., a picture of newsprint, which is required to fill in the silhouette.

3.6 SETTING UP AND TESTING A CAMERA CHANNEL

The setting up of a camera channel is the responsibility of the maintenance engineer and the procedure can be divided into three phases involving:

i. The correct adjustment of the picture and waveform monitor so as to display the televised picture and two field waveforms or two composite line waveforms. The waveform monitor time-base operates at half field frequency (25 c/s) or half line frequency (5 062·5 c/s).

ii. The use of test signals to line up the various stages in the camera channel starting at the output and moving progressively to the head amplifier.

iii. The adjustment of all camera-tube controls to provide a satisfactory picture of the object being viewed. The final touching up of the picture is completed by the vision control operator after the channel has been handed over.

The picture monitor can be checked with the aid of a test-card picture signal: brightness control is first adjusted to show the picture, and focus is altered until optimum over-all focus is obtained. It is sometimes possible to obtain a satisfactory focus by ensuring that the line structure of the raster is almost clearly delineated, but this will not be the best method if there is some astigmatism in the picture monitor. Line and field scanning frequencies are synchronised from, or driven by, the input synchronising signals, and their individual amplitudes are adjusted to fill limits inscribed on a protective plate over the picture tube. At the same time the line and field scans are centred in the picture area by use of the centering control. The final adjustment is of picture contrast by altering the gain of the video amplifier in the picture monitor. The waveform monitor has the usual oscilloscope controls of brightness, focus, and X and Y shift and amplitude. The sensitivity of the Y amplifier is adjusted so that the vertical deflection just reaches the horizontal calibration marks inscribed on the transparent screen over the front of the tube. These marks are calibrated against a 50-c/s input signal of 0·5 peak volts to the Y amplifier, and therefore represent a double-amplitude peak (d.a.p.) value of 1 volt at the input. The line-up of the various stages in the camera channel can now begin.

Test waveforms of three kinds are generally available, one producing a line saw-tooth picture signal from black to peak white, another known as a 'linearity grill' producing a chequer-board pattern, and the third a signal from a test card. The line saw-tooth is of value in displaying amplitude linearity and the effect of gamma control, and the linearity grid checks the linearity of the scanning system. The test card can provide information on frequency response, delay and phase distortion, ripple, defocusing at the edges of the picture, and scanning linearity. Loss of low-frequeny response shows up on a test-card signal in shading and streaking, a white horizontal rectangle perhaps shading from white to grey and being followed by a dark streak similar to a smudge. Loss of high-frequency response leads to loss of definition and a failure to resolve the 3 Mc/s and possibly 2·5 Mc/s bars. Phase distortion may produce a ripple following a sharp transition from black to white and vice versa.

Detailed procedure for lining up can best be followed by referring to the simplified schematic diagram of the camera control unit given in Fig. 3.18. The lift control on the system blanking inserter is turned to zero and the gain of the line and field synchronising pulse amplifier adjusted to give an output of 0·3 d.a.p. on the waveform monitor. This is the correct amplitude of the synchronising pulse for a video signal (peak white plus synchronising) of 1 volt d.a.p. The lift control in the blanking inserter is next increased until the amplitude of the video signal on the waveform monitor is slightly greater than 1 volt, say, 1·1 volts. The limiters in the limiting stage following the blanking inserter are adjusted until the picture part of the video signal is 0·735 volt (5 per cent greater than the normal peak-white amplitude of 0·7 volt). Due to the limiting action, transients could appear at the black and white limiting levels but transient suppressors are included in the limiting stage to remove these. The suppressors will not of course remove transients occurring at points in the waveform other than at the black and white limiting levels. The lift control is now returned to black level and a saw-tooth voltage (often locally generated) is applied to the input of the first video amplifier in the camera control unit The gamma control in the correction stage is now switched into circuit and adjusted to produce on the face of the waveform monitor tube a flattened saw-tooth output identical with the shape inscribed on the graticule; next a saw-tooth voltage is applied to the input of the head amplifier and an amplitude linearity check is carried out with the gamma control out of circuit.

The final stage in the procedure is an adjustment of the camera-tube controls. Except for the scanning voltage controls, which are set for maximum amplitude, all other controls are initially set at the mid-point of their travel. An illuminated coarse grill or test card is placed in front of the camera tube which has a 25-c/s square wave superimposed on its wall anode. If the beam is out of alignment, a twin picture will result. Alignment is altered until a single image is produced over most of the picture area. The square-wave voltage is removed and with a mesh over the camera-tube face the three scanning controls, centering, amplitude, and linearity, are varied until the mesh is accurately displayed within the limits inscribed on the picture tube. The initial over-scan setting of the controls produces black edges to the picture seen on the monitor and the scan amplitudes are decreased until these black edges just disappear. As a final check an illuminated test card is placed in front of the camera channel and a careful inspection made of the image on the picture monitor. No day-to-day check on over-all frequency response is undertaken unless a fault condition or poor frequency response has been reported. A frequency sweep of 0–4 Mc/s is then undertaken from head amplifier to output. The sine-squared pulse and bar test signal described in Section 6.9.1 may also be used.

3.7 THE TELEVISION SOUND SIGNAL

3.7.1. *Problems of Sound Quality*

It is much more difficult to obtain satisfactory sound for a television broadcast than it is for a sound broadcast, because television studios cannot be designed with only acoustical considerations in mind, and the microphone cannot be placed in the best position if in that position it or its shadow are obtrusive in the television picture. The television studio requires to have a low reverberation time (about 0·8 second) and has to be what is known as acoustically 'dead' so that noise caused by the necessary movement of studio staff and cameras is absorbed by the walls. For music productions artificial reverberation has to be applied to the sound signal in order to give an impression of liveliness.

Televisions studio sets have to be designed with a view to their visual effect and they can appreciably modify the characteristics of the sound picked up. One of the tasks of the sound supervisor is to know the acoustic properties of his studio and to recognise quickly poor quality due to scenery effects so that he can help his boom operators to avoid bad microphone positions. In sound broadcasting the positioning of the artists and microphones can often be closely controlled with a view to optimum sound quality. In the more static television production pictorial composition has generally to take precedence over sound quality, and in those productions in which movement is an essential part of the action, the microphone must follow as best it can while keeping out of the picture. The boom operator must be able to gauge the angle of view of the various camera lenses and the sound supervisor must ensure that the sound marries satisfactorily with the picture, i.e., a distant shot should not be combined with a 'close-up' voice at appreciable volume. To help in this the sound supervisor has two monitors, one carrying the preview and the other the transmission picture. For certain types of production, notably outside broadcasts, a microphone concealed about the person may represent the only solution, and an improvement in sound quality is sometimes achieved by employing special equalisers in the microphone circuit. As a rule camera and lighting requirements must take precedence over sound requirements though some modifications may be made to lighting to ensure that boom shadows are thrown out of the picture area.

3.7.2. *Microphones*

Microphones of the moving-coil, ribbon and electrostatic type similar to those used in sound broadcasting are employed in the television studios. Those with directional characteristics are generally preferred because it is necessary to discriminate against unwanted studio noise. The microphone most often used on the boom is the S.T. and C. Type 4033. This contains two separate elements, a moving-coil section and a ribbon section whose outputs

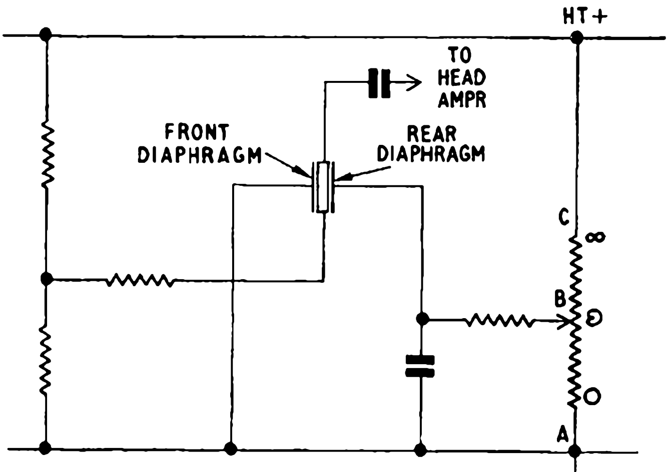


Fig. 3.23. Circuit diagram of the electrostatic microphone having variable directional characteristics

are added to produce a cardioid or heart-shaped characteristic. The S.T. and C. moving coil Type 4037, known as the 'stick' microphone because of its slender case, is unobtrusive and may be used in shot either held in the hand or in a special mounting. Ribbon microphones like the S.T. and C. 4038 are used generally in fixed positions; if they are mounted on a boom, care must be taken to avoid rumble and wind noises.

Electrostatic microphones having cardioid characteristics are sometimes used and one known as the AKG Type C12 of Austrian manufacture can have pre-set directional characteristics varying from omnidirectional through cardioid to bidirectional. Fig. 3.23 shows how this is achieved by varying the magnitude and polarity of the voltage on the back diaphragm relative to a central fixed plate. The front diaphragm is given a fixed bias voltage relative to the plate. In position B the back diaphragm has no voltage between it and the plate and it therefore makes no contribution to the output. The central plate is pierced by a series of holes from front to back through which the sound can penetrate and the length of this internal path is equal to that of the path round the outside of the microphone. Consequently the directional characteristic of the front diaphragm is that of a cardioid with near zero output to sounds immediately behind it. This results because sound from the back passes through the central plate in the same time as it takes to pass round the outside; thus a compression reaches the back of the front diaphragm at the same time as the compression reaches the front, and there is no effective movement of the diaphragm. Equally when it is energised the back diaphragm produces a cardioid directional response opposite to that of the front diaphragm. When the directional switch is set to A the polarities of the two diaphragms are in the same sense and their outputs add to give an omnidirectional pattern. When the switch is moved to C the polarities of the diaphragm are in the opposite sense and their outputs are in phase opposition so producing a figure-of-eight pattern with zero response to sounds produced at the sides at right-angles to the microphone axis. There are nine positions including A, B and C giving various types of directional pattern.

It is sometimes necessary to have a sharper directivity pattern than that of a cardioid and this is provided by a moving-coil microphone sealed in the end of a narrow 3-ft long tube, and known as the rifle microphone (Type MD82 of German manufacture). The far end of the tube is plugged, but along the barrel is a slot through which the sound enters. Sound from immediately in front of the microphone arrives at the microphone diaphragm in phase from the slot, but sound off the axis of the microphone arrives at the microphone diaphragm at differing phases and the response is appreciably reduced. The directional effect is frequency-dependent and at low frequencies very little directive effect is achieved. The microphone is therefore only of use over a restricted frequency range and is mainly used for effects purposes.

3.7.3 *Sound Control Equipment*

The apparatus used for controlling the sound signal from the television studios is to a great extent based on that used in sound

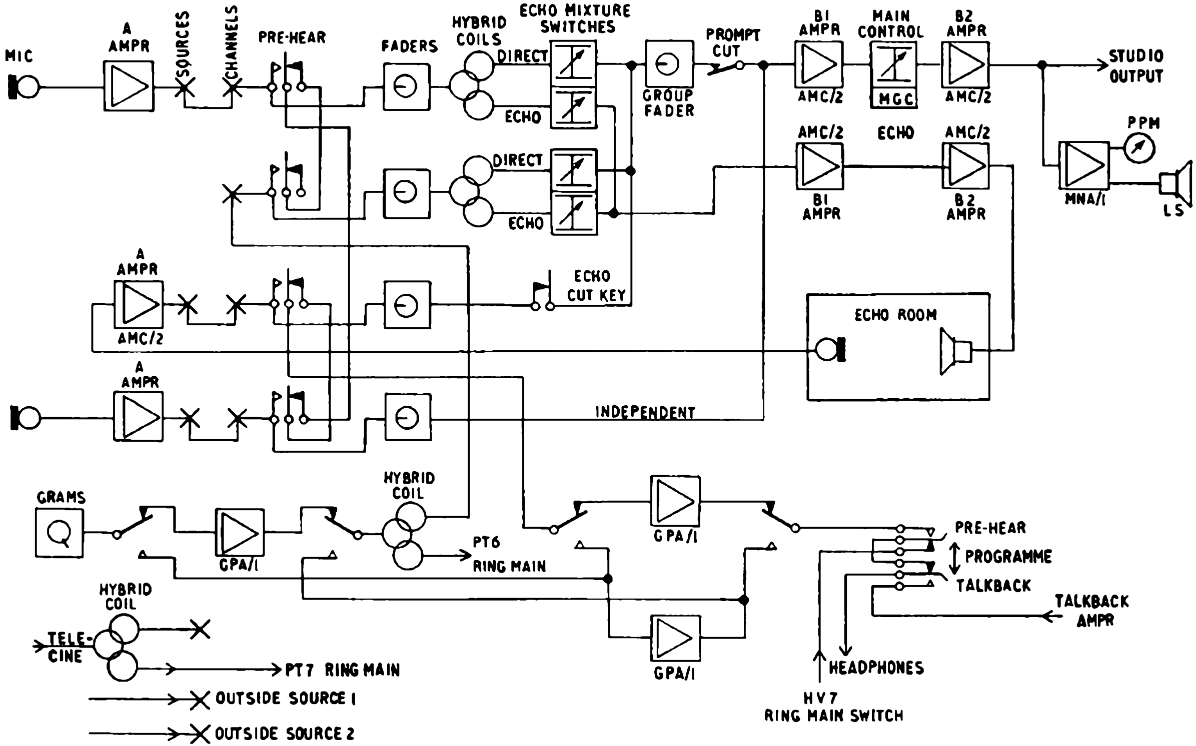


Fig. 3.24. Type A equipment modified for television sound

studios, and modified forms of the Type A and Type B equipments described in Chapter 2 are in use. Only the modifications will be considered in this chapter.

Type A Studio Equipment modified for Television Sound. The schematic diagram Fig. 3.24 shows the modifications needed to the Type A equipment used for controlling the sound accompanying the television programme. Pre-fade listening keys (in the Television Service called 'pre-hear') inserted between the A amplifier and the channel fader allow the supervisor to check that the various sources are connected to their correct channels without operating the channel fader. Pre-set balance controls adjust the input volume to be approximately the same to each channel fader, and it is not necessary for the operator's attention to be distracted by having a number of widely different fader settings.

Another additional facility is 'foldback' which allows a source, often a gramophone insert, to be connected to the studio loudspeaker while the microphones are faded up. This may be used for cueing or to give atmosphere on a studio set. It will be seen that the input to the group fader passes through the 'rest' contacts of the prompt-cut relay operated from the prompt switch. The prompt relay not only breaks the studio output but also inserts pre-recorded studio atmosphere into the sound chain so as to cover up the prompting break.

Type B Studio Equipment modified for Television Sound. Like the Type B equipment described in 2.5.3, there are two group faders, facilities for echo, clean feed and cue programme (included in the term foldback), and the modifications can be seen by comparing the simplified circuit diagram of Fig. 3.25 with that of Fig. 2.16. The main difference lies in the inclusion of pre-hear at the output of the microphone amplifier, foldback and public address feed after the channel fader, and a prompt cut key in the output line common to both group faders. Pre-set balance controls are included between the channel amplifier and fader as in the modified Type A. As with the Type A equipment there is a substitution feed of studio atmosphere when the prompt key is operated.

The arrangement of the controls on the main control panel is indicated on Fig. 3.26 which shows that quadrant faders replace the 270° knobs of the equipment used in the Sound Service. All the sources are plugged through a low-level jackfield and this allows complete freedom in the order of plugging sources to the two groups of 8 channels and to the two independent channels. The left-hand and right-hand groups are coloured and designated red and

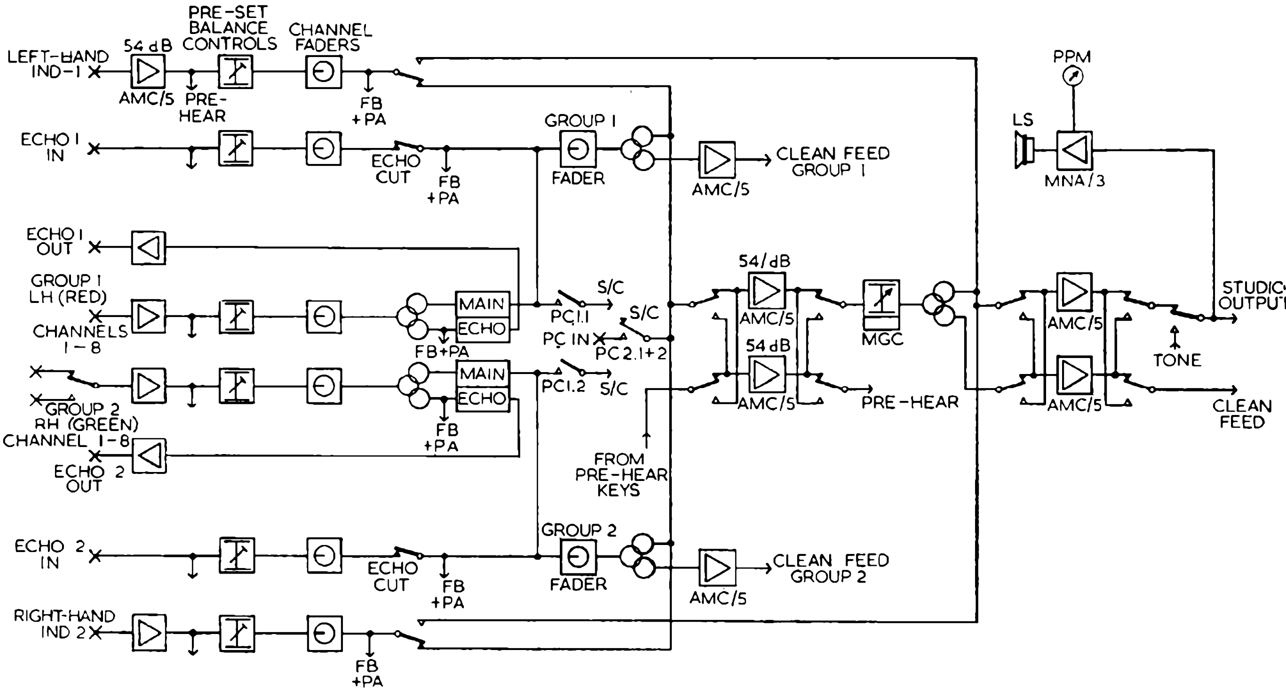


Fig. 3.25. Type B equipment modified for television sound

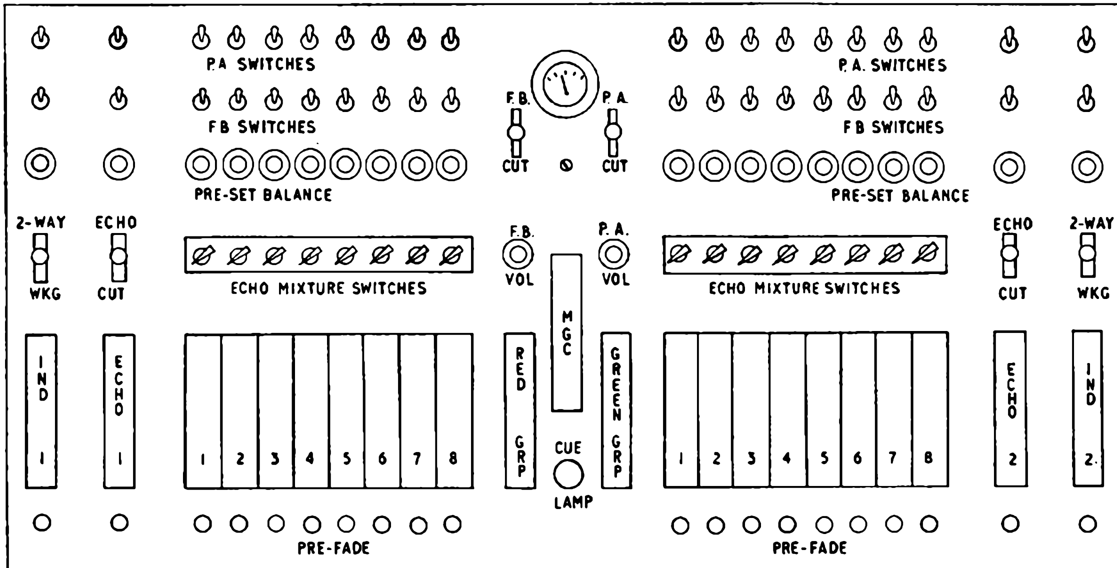


Fig. 3.26. Panel arrangement of the Type B equipment

green respectively. The pre-set balance controls for each channel are located immediately above the echo mix switches on each channel.

Echo facilities from an echo room and/or an artificial echo unit can be plugged to either group. The echo mix switches on each of the 8 channels allow the proportion of echo to signal to be pre-set. Foldback is taken from a point just beyond the channel fader of the two independent channels and on channels 1 to 8 from the echo feed after the hybrid coil.

Television programmes performed before studio audiences often require a public address or sound reinforcement system, and this is provided in the studio by loudspeakers arranged vertically one above the other to produce a line source which is directional, beaming the sound on to the audience and reducing any feedback to the microphones on the set. These line sources are controlled by the knob marked *P.A. Vol* shown on Fig. 3.26 above the green group fader. Control of the foldback gain is achieved by means of the *F.B. Vol* knob above the red group fader.

3.7.4. *Talk-back*

Comprehensive talk-back facilities are essential to the smooth running of any television production. For example the producer must be in close touch with the floor manager and the cameraman, and the technical operations manager must be able to speak to all members of the crew. The schematic diagram of a typical talk-back system given in Fig. 3.27 shows that the producer is in continuous contact with the production and operations staff. The talk-back is fed to the headphones of the camera crew via the camera cable, to the lighting console and at low level to vision and sound control rooms' loudspeakers, and throughout the studio on jacks marked *Prod. T.B.* It is also taken to any contributing source remote from the studio, e.g., telecine. The producer has available loudspeaker talk back to the studio floor by the closing of contact 1 but this is only used on rehearsal, for the contact is inoperable on transmission unless all studio microphones are faded out.

Since the floor manager must be free to move about, he must not be encumbered by long talk-back leads, and he is provided with a separate radio-link system. A v.h.f. transmitter modulated by talk-back is connected to an aerial in the studio roof and the floor manager is provided with a pocket receiver and headphones whose leads act as the receiving aerial. During rehearsal he may speak to the producer via the studio microphone but occasionally two-way communication is also provided by supplying him with a pocket transmitter similar in size to the receiver, the microphone lead acting as the aerial.

The technical operations manager can use the producer's talk-back system by closing contact 2. He can also speak to individual camera crews by closing contact 3 to the particular camera cable, and to the Vision Control Room by another circuit, not shown in Fig. 3.27. Through contact 4, he can use studio loudspeaker talk-back.

During rehearsal camera crews can communicate with the vision control supervisor and their associated camera control unit operator, and the lighting supervisor has a separate talk-back circuit to the

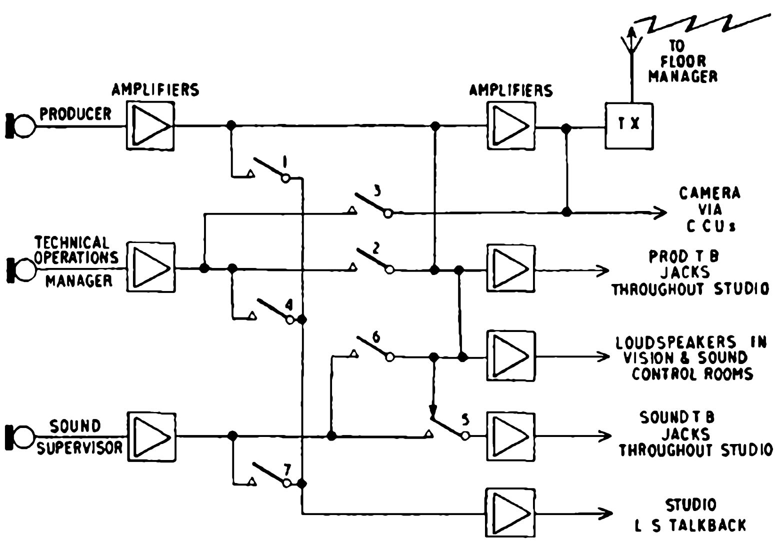


Fig. 3.27. Simplified diagram of the talk-back system

lighting gallery but for the sake of simplicity these circuits are omitted from Fig. 3.27.

The microphone boom operator and sound floor assistant can receive talk-back on headphones from the points marked '*Sound T.B*': these points are fed via contact 5 which changes over when the sound supervisor operates his 'sound' talk-back key. The operation of this key automatically injects a short burst of 1 000-c/s tone into the circuit to warn sound floor staff to stand by for the sound supervisor's instructions. He can also switch into the producer's talk-back system via contact 6 or into loudspeaker talk-back through contact 7. Reverse talk-back is provided from the principal microphone boom to the sound supervisor.

3.8 TELERECORDING OF TELEVISION PROGRAMMES

The advantages to be gained by recording television programmes are much the same as those listed in Section 2.9.1 for recording sound programmes. Occasionally a vision programme requires a rapid change of costume between one scene and the next with insufficient time for doing it, and pre-recording of one or the other of the scenes is necessary for the smooth running of the complete programme. There are two ways in which a recording of the vision part of the televised signal can be made, namely, as an optical image on photographic film or as a complete vision waveform on magnetic tape. Both systems have their own advantages and disadvantages. When a permanent recording or many copies are required film is preferable to magnetic tape but it is more expensive than magnetic tape for a single copy. Magnetic tape requires no processing and can be played back immediately but editing is more difficult.

3.8.1 *The Problems involved in the Recording of Television Pictures*

The procedures for recording television pictures are quite different from those used in making cinema films. A cinematograph film takes 24 pictures/second whereas the BBC (and European) television standards produce 25 pictures/second. Since the difference in picture repetition rate is only 4 per cent, the normal tolerances allow an interchange between the 24 pictures/second cinematograph film and the 25 pictures/second telerecordings from television pictures. The cinematograph film camera is presented with a complete picture for a given time, whereas the telerecording film camera receives its image from a picture monitor on which the image is being built up by a moving spot. The pictures taken by the cinematograph camera are separated by a time interval of 21 milliseconds during which the film is moved on and re-registered, but television fields are separated by only about 1·4 milliseconds which is very short for film pull-down and re-registering. This, coupled with the fact that the television image is made up of two interlaced halves separated by a time interval, creates the biggest problem in the recording of television pictures on film. If the relative movement of the object being televised is rapid the image on the film negative due to the second field will appear in a slightly different place from the image due to the first field so producing a double image; if the relative movement is slow a ghost image will not readily be discernible. Pre-exposure of the film to light from the first field renders the emulsion more sensitive to light, and the image due to the second field is often more clearly defined than that due to the first: this differentiation helps to make the effect less noticeable.

One of the major difficulties in telerecording is the movement of the film into position ready to take the next picture. If most of the picture information is to be retained, the film must be pulled down during the period between the end of one television picture and the beginning of the next, i.e., in about 1·5 milliseconds. A number of different alternatives have been tried. An early system used a comparatively long pull-down time by suppressing one in every three fields and using the 1/50 second so gained for pull-down purposes. Another used a continuous-motion film with tilting mirrors following the travel of the film and keeping the image of the spot in the correct position on the film. A later arrangement, known as the stored-field system and using a long-persistence picture monitor tube, allowed the two interlaced fields to be effectively on the tube together for 1/50 second, the remaining 1/50 second being used for pull-down. Originally it was thought that even if a satisfactory fast pull-down mechanism could be devised the rapid acceleration would cause the sprocket to tear the film, but in fact the film is well able to carry the strain and fast pull-down systems (in 2–5 milliseconds) are now available. The various methods of recording a television picture on film will next be detailed in order of development.

3.8.2 *The Mechau System*

This system made use of a specially adapted German film projector through which the film moved continuously. The image of the television picture was maintained in the same position relative to the film by an arrangement of fixed mirrors and eight tilting mirrors placed round the periphery of a rotating drum. The tilting mirrors, each of which reflected one complete interlaced television picture, were given the required radial and tangential tilts to register the picture correctly on the film. When one picture had been exposed the next mirror came into place already tilted at the correct angle to reflect the images of the next two fields and produce the succeeding picture. This method often gave very good results, but the mechanism was so complicated that maintenance caused many difficulties and this led to its abandonment.

3.8.3 *The Suppressed-field System*

The next development was known as the suppressed-field system. Every second field on the monitor was suppressed by a blanking pulse and during this 1/50 second the film was pulled down and re-registered in the gate for the next exposure period. Since only one field was recorded, the picture contained only half the total number of lines and spot wobble had to be adopted on the picture tube to try to reduce the coarse line structure. On reproduction, scanning restored the customary appearance of the picture in terms of the number of lines but the second field was identical with the first. In spite of this defect, the recorded pictures often gave quite satisfactory results. A standard 35-mm intermittent-motion picture camera was used with the shutter removed and the blanking pulses of field duration were derived from a device coupled to the camera drive system, whose motor was synchronised with the mains frequency, mechanical phasing control being available.

3.8.4 *The Stored-field System*

The stored-field system at present in use is a development of the suppressed-field recorder. It is used with equal exposure and pull-down times of 1/50 second. A long-persistence picture tube delays the 'die-away' so that both interlaced fields are present together on the end of the tube. Hence the term 'stored-field'. Since the brightness of each line decays exponentially, each field would normally have a different brightness level and there would be vertical shading of the picture. This defect is overcome by applying a compensating brightness modulation to the picture tube, and during the pull-down period with the camera shutter closed the spot is given a progressive reduction of brightness from the starting line to the end of the finishing line of the first field. The second field is reproduced while the film is exposed and if there were no afterglow no brightness modulation of the spot would be required. With afterglow the light content to which the film is exposed is in effect a product of the average brightness of a given point multiplied by the time of exposure, and the first lines of the second field, even though at the same brightness as the last lines, would give a greater effective brightness because of the longer exposure time. During the second field therefore the spot must be brightened as it approaches the last line of the field. The necessary spot-brightness modulation waveform is derived from a beam of light directed on to a photo-electric cell through a rotating mask, whose edge is finally shaped by trial and error to give the correct waveform. The decay characteristics of the spot should be consistent over the whole of the screen of the picture tube and the e.h.t. of the latter must be stabilised to prevent any variations occurring due to the change of load when the beam is modulated. Any variation of e.h.t. voltage would produce changes in picture size, and stabilisation to within 0·1 per cent is necessary.

3.8.5 *Fast Pull-down Telerecording Systems*

There are two versions of fast pull-down telerecording apparatus, one for 16-mm film and the other for 35-mm. The fast pull-down mechanism for the 16-mm apparatus uses a claw to engage the sprocket hole when the shutter has closed and it is actuated by a

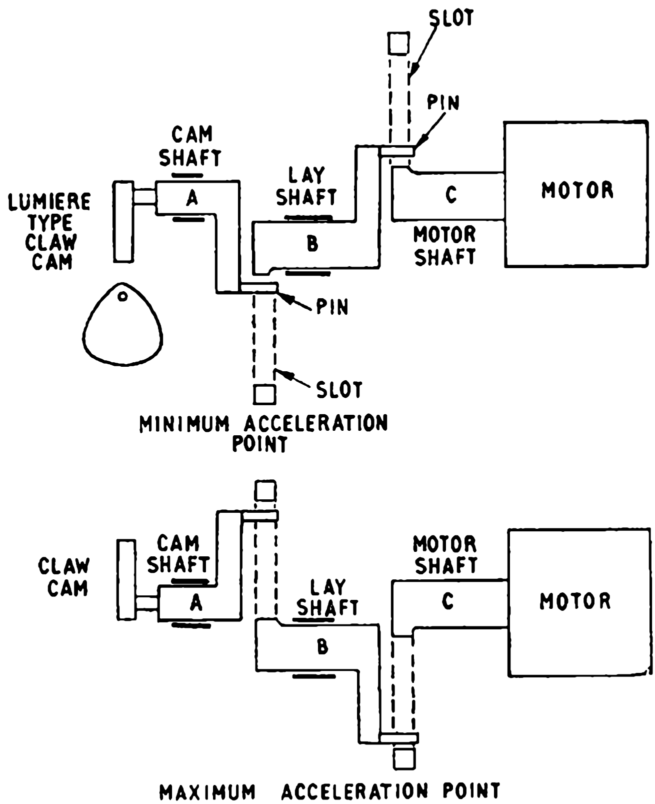


Fig. 3.28. Fast pull-down mechanism for 16-mm film recording

mechanism which reduces the initial strain on the film by imparting a gradually increasing acceleration to the claw. The rapid acceleration of the claw engaging the sprocket holes of the film is obtained by interposing pin-in-slot accelerators between the traction motor and the cam operating the claw, as shown by the diagrammatic sketch of Fig. 3.28. The film is pulled down and registered in the gate during the 2-millisecond interval while the shutter is closed so that the exposure period of approximately 1/25 second is slightly reduced by an amount equivalent to a total loss of about 12 lines of picture in addition to the 28 lines lost in the field flybacks. The magnification of the camera lens system is increased so that the recorded information occupies the normal picture size, and the results obtained from this system are very satisfactory.

In the 35-mm system the shutter-closure time is somewhat longer (4·5 milliseconds) because of the larger picture size, and it is achieved by the 'maltese cross' accelerator shown in Fig. 3.29. This increased pull-down time would normally lead to a loss of an additional 62 lines and to prevent this the picture tube has a phosphor with sufficient persistence to allow the camera to register the afterglow of the lines which would otherwise be lost. The maximum period for which any line is stored is less than 5 milliseconds and the decay in brilliance during storage is much more rapid than in other storage telerecording methods and is simpler to correct. The correction is achieved by a graded neutral-density filter placed in front of the picture tube. The filter gives the afterglow lines the same exposure as the remainder which are

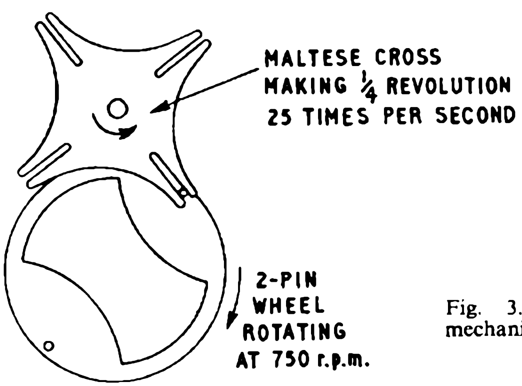


Fig. 3.29. Fast pull-down mechanism for 35-mm film recording

scanned after the shutter has opened. Grading is also necessary at the bottom of the picture, since closing of the shutter reduces the afterglow contributions from the end lines. Pull-down is only necessary between complete pictures, i.e., after every pair of fields, but the camera shutter is operated after every field so that the neutral density filter has the same effect on both fields. An advantage of the filter is that it gives a reduction in flare. The latter arises due to internal reflection at the glass-air surface of the picture tube and it is reduced by filling the space between neutral-density filter and the tube surface with glycerine which has very nearly the same refractive index as the glass. Little internal reflection occurs at the glass-glycerine junction and most at the filter-air surface. During reflection back through the filter and its return by scattering, the light causing flare is twice attenuated by the filter and its visibility is much reduced.

3.8.6 *Film Traction Motor Synchronisation*

It is desirable (and sometimes essential) that a film telerecording system should have synchronism between film traction and the

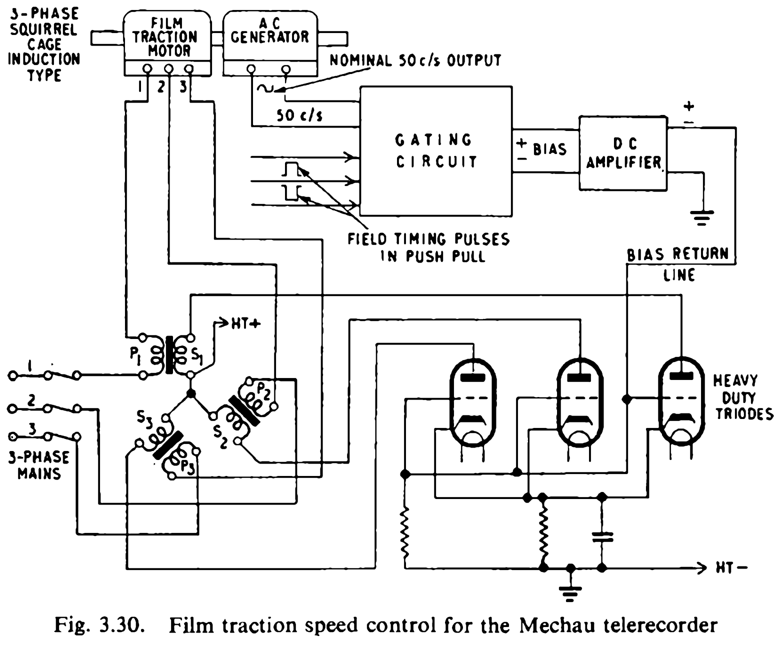


Fig. 3.30. Film traction speed control for the Mechau telerecorder

field timing pulses. There are a number of ways in which this may be arranged and one of the simplest (used in the Mechau telerecording system) is shown in Fig. 3.30. Film traction is provided by a three-phase squirrel-cage induction motor. On the motor shaft is a small 50-c/s generator whose output is applied together with the field timing pulses to a gating circuit. The gating circuit gives no output when the field timing pulses occur at the nodal point of the 50-c/s wave. When the latter moves out of synchronism, a pulse is produced at the output and its polarity depends on which side of the nodal point it occurs. Rectification followed by d.c. amplification provides bias for three triode valves acting as a load on the secondary of a three-phase transformer whose primaries are in series with the film-traction motor. Bias control on the triodes alters the effective primary inductance in series with the motor in such a way as to bring the speed of the motor back into synchronism.

3.8.7 *The Ampex Videotape Recording System*

The problem of recording video signals on magnetic tape is made difficult because a very wide frequency spectrum is involved: for the British 405-line system it is from 0 to 3 Mc/s, or with d.c. restoration it is effective from about 20 c/s to 3 Mc/s, a range of about 17 octaves. In recording audio signals on magnetic tape an octave range of about 9 is involved. Some means must therefore be found for reducing the octave range of video frequencies and this can be done by using a carrier system. Thus if a carrier of 4 Mc/s and vestigial amplitude modulation were employed, the frequency range would be from about 3 Mc/s to 7 Mc/s, an octave range less than 2. Unfortunately it is impossible to avoid slight random variations of permeability along the tape and of contact between tape and heads: these appear as random variations of amplitude of the reproduced signal, and are of no serious consequence in audio reproduction but they can seriously mar a reproduced picture. This difficulty can be overcome if the video signal is used to frequency modulate a carrier because there is then no information in the reproduced amplitude, which can be passed through a limiting amplifier to remove all random amplitude variations. After this has been done the frequency-modulated carrier must be converted back to an amplitude-modulated signal before it is detected. The frequency-to-amplitude converter must have a linear characteristic and its output will be frequency- and amplitude-modulated but the detector ignores the frequency change and registers only the amplitude change.

This is the method used by the Ampex videotape recorder, peak white corresponding to approximately 6·75 Mc/s, blanking level to 5 Mc/s and synchronising level to approximately 4 Mc/s. The sidebands produced by the frequency modulation extend beyond 4 and 6·75 Mc/s but in practice, due to head limitations, the recorded frequency range is from about 1·75 to little more than 6·75 Mc/s.

In order to record these high frequencies satisfactorily the speed of the tape past the recording head must be high, and this is achieved in the Ampex system by recording the modulated vision signal transversely across 2-in. wide magnetic tape with the aid of a 2-in. diameter rotating drum carrying 4 equally-spaced recording heads. Fig. 3.31 shows how the heads are arranged around the drum and also how the tape is held in position by means of a vacuum device as it passes the rotating heads. The heads are fed in parallel and record the vision signal in a series of transverse tracks across the width of the tape which itself travels at 15⅝ inches per second. The drum carrying the recording heads rotates at 250 revolutions per second to give the very high head-to-tape speed of 1 570 inches per second. The recording-head gap width of 2 microns (0·002 mm) equals the wavelength of a recorded frequency at 19·5 Mc/s so that the maximum high frequency (about 9 Mc/s) which it is desired to accommodate should be satisfactorily recorded. About an hour's programme is contained on a spool of 12⅝-in. diameter.

Each recording head sweeps out a 114° arc over the tape, and the next head commences to sweep before the first has finished, giving an overlap of information towards the end of one track and the

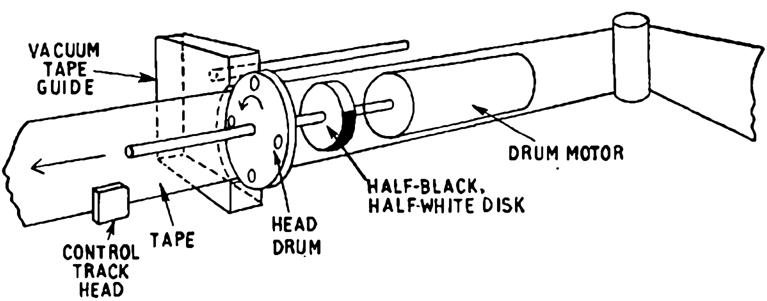


Fig. 3.31. The Ampex videotape recording head system

beginning of the next. Advantage is taken of this duplication when switching from one track to another during reproduction. The four heads provide a thousand tracks across the tape each second (Fig. 3.32). One television picture of 405 lines is recorded in about 40 tracks each of which contains 12 lines of television information with an overlap of about two lines. On reproduction, switching takes place at the end of the 10th or 11th line. Each field occupies about 5/16 in. of the length of tape and each picture ⅝ in. There are two longitudinal tracks on the tape, the top one carrying the sound associated with the picture. The bottom track, consisting of a 250-c/s control signal with pulses marking the end of each field, is recorded at the same time as the vision signal, its purpose being to maintain synchronisation when reproducing. The field marker pulses are used when editing is required. Space for the sound track is found by wiping off some of the overlap vision information contained in the transverse tracks, but the 250-c/s control track is recorded over unwiped tape and unwanted

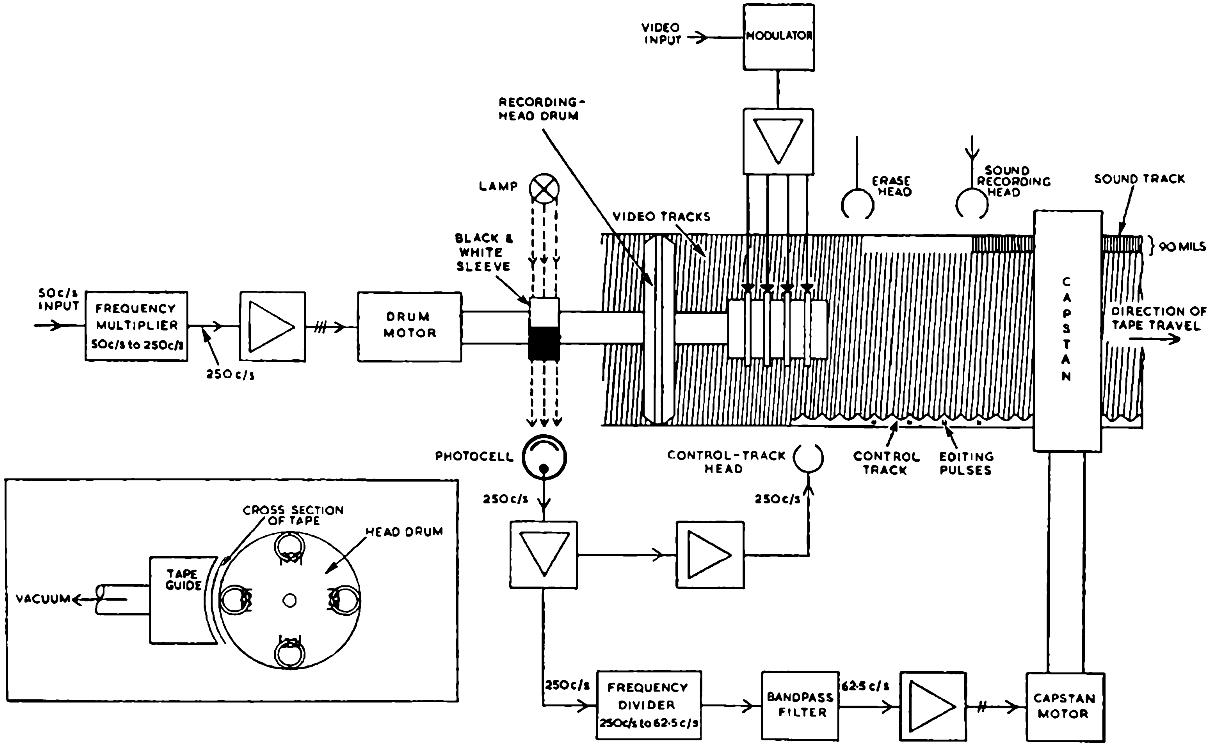


Fig. 3.32. A schematic diagram of the Ampex videotape recorder

vision signal. For reproduction the same rotating drum head is used, a switching unit selecting the outputs of the heads in correct sequence and at the correct time instant. The f.m. output is applied to a limiter and a frequency-to-amplitude converter, followed by a detector. A signal-to-noise ratio of at least 30 dB and satisfactory resolution with a high contrast ratio are readily obtained.

Ampex Speed Control System. During recording and reproduction an exact relationship must be preserved between the rotation of the head drum and that of the tape-drive capstan, Fig. 3.32. The head-drum motor is driven by a 250-c/s source provided by an amplifier fed through a frequency multiplier (5 times) from the 50 c/s supply derived from the field synchronising. Light reflected from a half-white, half-black sleeve on the drum axle is used to generate a wave of 250-c/s frequency when recording the vision signal. This 250-c/s wave output is amplified and recorded as the bottom longitudinal control signal. It is also divided by four and passed through a band-pass filter giving a 62·5-c/s output which, after suitable amplification, is used to drive the tape-drive synchronous motor. When the machine is being used for reproduction, the control-track 250-c/s frequency is compared against the 250-c/s output of the photo-electric cell and the error signal is used to bias a reactance valve controlling the frequency of a 62·5-c/s oscillator feeding the tape-drive synchronous motor. The reproducing-head drum is initially adjusted to centre on the tracks and is maintained in that position thereafter by operation of the control signal. The 250-c/s waveform from the photo-cell is also used to initiate the switching from one head to the next.

Editing and Splicing. When editing has to be done the cut must be made so that the possibility of 'roll-over' is reduced: the most suitable points for cutting are during or just after the field blanking period, and the marker pulses on the 250-c/s control signal track enable these points to be found. They are made visible by placing the recorded tape in a solution of carbonyl iron, when the iron particles adhere to the tape according to the magnetic pattern made by the recording. The tape is then placed in a jig and cut transversely at the correct point. The iron particles are wiped off and splicing is effected by sticking a patch to the back of the join.

3.9 TELEVISION FILM REPRODUCTION (TELECINE)

Before the introduction of the vidicon camera, which is able to hold an image until scanned, the reproduction of all cine films was carried out with the film in continuous motion. The image from the moving film is optically compensated so that it remains focused and stationary on the photo-cathode. Three basic types of continuous-motion film telecine apparatus have been used by the BBC, namely:

(i) the Mechau flying-spot;
(ii) the Cintel and E.M.I. flying-spot; and
(iii) the polygonal prism.

3.9.1 *The Mechau Flying-spot Telecine*

The Mechau flying-spot telecine uses as a light source a cathode-ray tube whose spot is deflected horizontally and vertically to produce a raster having the same line and field frequencies and aspect ratio as the normal television picture. The film is in continuous motion and rotating tilting mirrors are used to keep the raster image registered correctly on the film. Another tilting mirror focuses the light emerging from the other side of the film on to the photo-cathode of an electron multiplier, the output of which gives a vision waveform corresponding to the information contained on the film. This type of apparatus has the advantage that a single stationary frame can be displayed and the picture be 'brought to life' as the machine is started up. The Mechau telecine is now being superseded by other methods requiring much less mechanical maintenance.

3.9.2 *Cintel and E.M.I. Flying-spot Telecine*

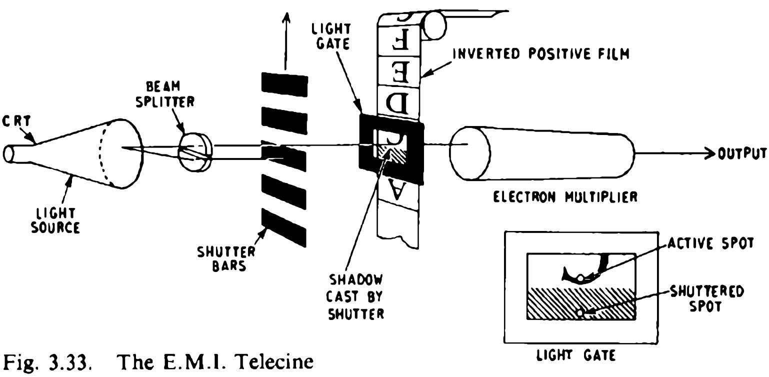


Fig. 3.33. The E.M.I. Telecine

The Cintel and E.M.I. flying-spot telecine are very similar in principle and the general arrangement of the E.M.I. equipment is shown in Fig. 3.33. The light-source is provided by a raster of aspect ratio compressed to $4 \times 1\frac{1}{2}$ and displayed on a short-persistence cathode-ray tube. The light from the flying spot of the raster is passed through a beam-splitter which creates two inverted images of the compressed raster one above the other.

Between the beam-splitter and the film there is a shutter in the form of a series of bars which move continuously upwards at the same rate as the inverted film moves downwards. One of the

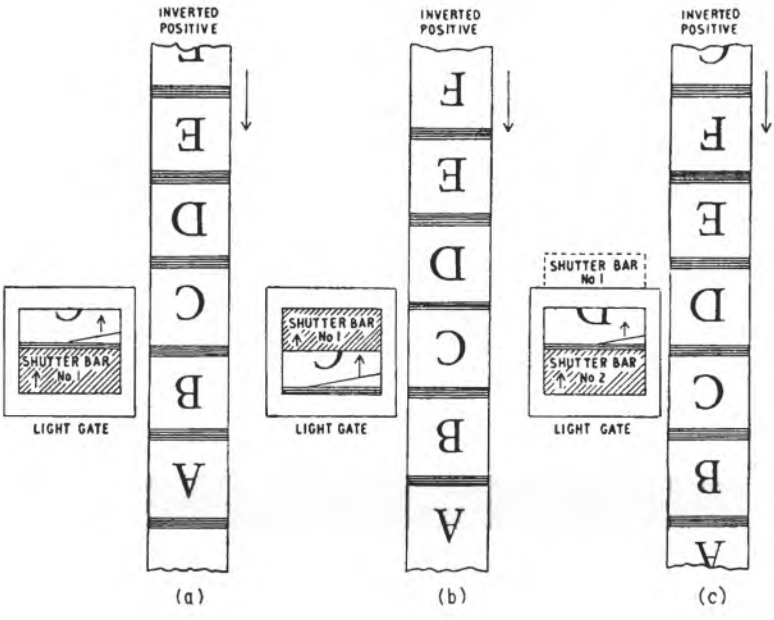


Fig. 3.34. The film and shutter mechanism of the E.M.I. Telecine

twin images (the top one in Fig. 3.34 (a)) from the beam-splitter falls on the downward-travelling film and passes through to the photo-cathode of an electron multiplier. The output from the latter represents the vision signal without line and field synchronising pulses, these being inserted later in the chain. The other twin image is intercepted by a shutter bar moving in the opposite direction to the film, and as the bar moves upwards it covers the upper twin image and uncovers the lower which takes over and scans the same picture once again. Thus a film frame receives an odd line scan of normal aspect ratio as it passes through the top half of the light gate and an even line scan as it passes through the bottom half.

The action is illustrated in Figs. 3.34 (a), (b) and (c). In Fig. 3.34 (a) shutter bar 1 shuts off the lower split image and the spot image begins to scan film frame C. During the next 1/50 second the film moves steadily downwards and the bar upwards until the trailing edge of frame C reaches the top of the light gate: during this same time the image of the flying spot tracing out the odd line field has travelled up from the centre of the light gate to the top. Thus film frame C has experienced a complete odd-line scan of normal aspect ratio, even though the raster has a compressed aspect ratio of $4 \times 1\frac{1}{2}$. At the end of the 1/50 second (Fig. 3.34 (b)) the spot returns to its half-line starting point ready for the even-field scan. The shutter bar obscures the top twin image and reveals the lower one, which proceeds to scan frame C once again on an even-field scan. One-fiftieth second later (Fig. 3.34 (c)) shutter bar 1 has moved away and bar 2 has take its place to cut off the lower twin beam. The upper beam begins the odd-line scan of film frame D and the process is repeated every 1/25 second. The gamma of the photo-multiplier is unity and this is reduced to the normal transmitted value of 0·4 by gamma-correcting circuits.

Satisfactory operation depends on the film traction being synchronised with the field timing pulses and on the film speed being maintained constant. The latter is not easy to achieve because the film is sprocket-driven and irregularities in the sprocket holes tend to make the traction uneven. One method uses flywheel-loaded pulleys to carry the film through the light-gate, and between these and the sprockets are interposed two spring-loaded jockey pulleys. The inertia of the flywheel-loaded pulleys and the compliance of the spring tensioning the jockey pulleys provides a filter to smooth out any speed variations due to the sprocket holes.

Another problem is film shrinkage which changes the height of the film frames. To compensate for this, the separation between the split twin images must be changed. One way to achieve this is to lace the film round a spring-loaded jockey pulley between two sprocket wheels, leaving a given number of film frames between the sprocket wheels. As the film shrinks the loop decreases in size and the jockey pulley moves nearer the sprocket wheels. The jockey pulley is mechanically coupled to the two halves of the beam-splitter so that a change in its position automatically brings the twin images closer together to give a spacing suitable for the shrunk film.

3.9.3 16-*mm Polygonal Prism Telecine*

This machine is another example of the optically-compensated flying-spot system similar operationally to the 35-mm flying-spot Mechau telecine in that it can exhibit a still picture from a stationary film, can be brought to life and need not be rigidly locked to the scanning cycle. The machines of this class used by the BBC are for 16-mm gauge film, and the optical compensator takes the form of a 30-sided rotating prism. The scanning process is initiated (as for the 35-mm flying-spot Mechau) by a 4 × 3 aspect ratio raster on a cathode-ray tube and as the prism is rotated the image of this raster is caused to 'slip'. The optical slip produced in this way maintains the raster image exactly in step with the continuously

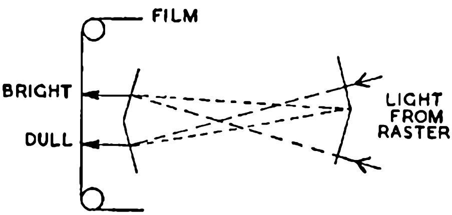


Fig. 3.35. The action of the polygonal prism telecine

descending film at the light-gate; thus, there is no *relative* motion between the successive film pictures and the image raster scanning them. After passing through the film, the light-spot forming the image raster impinges on the cathode of a photo-cell, and the vision signal is thus initiated. As the prism rotates there will be times during transition between film-frames at the light-gate when portions of more than one prism face are in the light path.

The light path is split by the angular difference between adjacent facets (see Fig. 3.35) into the two beams (generally of different light intensity) which are arranged to match up with successive film frames so that as each film frame is travelling down the light-gate it is accompanied by its own individual image of the scanning-raster. The reproduced picture at such a time is a composite of two frames simultaneously scanned, but since the versions of the action portrayed on two adjacent film frames are usually very nearly identical no undesirable results occur. By this means, the transition from each frame of the film to the next is a form of mix or dissolve, and the machine can be run at any speed for which mechanical provision is made in the drive system.

3.9.4 *Vidicon Telecine*

In this system, an orthodox intermittent film projector is caused to throw the picture images into a television camera. Normally such an arrangement would give rise with the C.P.S. Emitron to undesirable effects because it is very difficult to make the intervals between successive television field scans coincide either in moment or duration with the period of closure of the projector shutter. The vidicon type of photo-conductive television camera has a long persistence due to charge storage, but unlike the image-orthicon, there is no sticking of the image. The output voltage of this type of tube is unaffected by the position of the projector shutter and no detail is lost when the shutter operates during the normal scanning time.

The photo-conductive camera has a good inherent signal-to-noise ratio but, due to the smallness of its target and the difficulty of obtaining a sharply-defined scanning beam of small cross-section, the higher frequencies of the vision signal have to be 'boosted' to obtain satisfactory reproduction of fine detail. This is practicable, but is unfortunately only effective in the horizontal direction; in consequence the vidicon-type camera as used operationally has less definition of fine detail in the vertical direction. Another result of the small target is that any blemishes on it, or in that portion of the glass envelope which is in the light path, receive a large effective magnification.

A typical installation consists of two projector and camera assemblies at right-angles to each other, so that the projector beams cross; commonly one projector is for 35-mm film and the other for 16-mm film. A central mirror at the crossover point of the projector beams can be swung to determine which projector serves either camera; such a layout is known as a 'crossfire' installation.

3.10 RECORDING AND REPRODUCING THE SOUND SIGNAL

In the Ampex system the sound associated with the vision signal is recorded magnetically on the vision tape and the principles of magnetic sound recording have already been described in Section 2.10.2. On film systems, the sound may be recorded either optically or magnetically. With optical recording the sound-track is photographed on one side of the picture track; the track may be produced by varying the density or by varying the area of the black portion. The disadvantage of variable density is that separate processing for vision and sound information is sometimes required and this increases costs and preparation time. The BBC uses the variable-area method for which the track is either opaque or transparent, and simultaneous development of picture and sound can be carried out. A duplex method of recording is employed and the track appears very similar in shape to a modulated wave. This is achieved by focusing via a mirror two wedge-shaped light beams through a narrow slit on to the sensitised film as shown in Fig. 3.36. The mirror is attached to a galvanometer actuated by the sound signal and when the mirror vibrates, the dark triangle between the two wedge-shaped beams is moved across the slit image on the film. The envelope variations of the darkened section have a waveshape corresponding to the pressure variations of the original sound.

For reproducing the optically-recorded sound, light is focused through a narrow slit on to the optical sound track. The emerging light, which is modulated by the variation of the opaque area, is applied to the cathode of a photo-cell, the output current of which

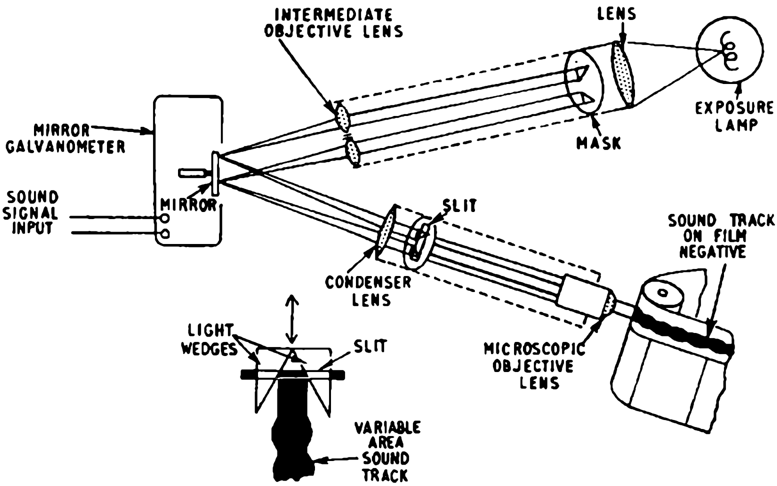


Fig. 3.36. Optical sound recording with Duplex track

is directly proportional to the light falling on it. The current variations are changed to voltage variations by passing the current through a resistance before being amplified. For maximum output the slit must be perpendicular to the direction of film travel; an extinction frequency occurs when the slit width equals one wavelength and its value is given by

$$f_e = \frac{\textit{film velocity}}{\textit{width of slit image}}$$

To prevent a fall in high-frequency response the slit width must be not greater than half the recorded wavelength of the highest audio frequency to be reproduced.

CHAPTER 4

TELEVISION OUTSIDE BROADCASTS

4.1 HISTORICAL REVIEW

TELEVISION Outside Broadcasting began in Great Britain in May 1937 with an Outside Broadcast (O.B.) of the Coronation of King George VI and Queen Elizabeth, when three cameras were employed. For the Coronation of Queen Elizabeth II in 1953 the BBC used a total of twenty-one cameras, five in Westminster Abbey and sixteen along the route of the procession.

In the two years before the second world war the only Television O.B. Unit (consisting of two mobile control rooms each of three cameras and associated equipment) was based in London, but after television broadcasting restarted in 1946, Outside Broadcast facilities began to spread throughout the country and by 1953 three other Units based in Birmingham, Bristol and Glasgow had been formed. The Birmingham Unit was mainly responsible for programmes originating in the Midland region but it also shared with the Scottish Unit responsibility for programmes emanating from North Region. The West of England and Wales were catered for by the Bristol Unit. By 1955 North Region had its own Unit based in Manchester, and Wales was provided with a Unit in Cardiff. In the meantime the number of mobile control rooms in the London Unit had been increased to four (one being of the Roving Eye type described in 4.5.6) making a total of nine complete equipments in operational use within the United Kingdom. A tenth was added in 1960 with the formation of the Northern Ireland Unit based in Belfast, where the first of the two-channel mobile control rooms was brought into service.

4.2 THE DUTIES OF O.B. STAFF

Some of the problems encountered in outside broadcasts are common to television studio operation and maintenance but there are many additional ones, e.g., the apparatus is mobile and an interconnection has to be made with the television network, the type of programme may not permit the use of normal television lighting, and cramped and difficult conditions of work may have to be accepted.

The duties of the technical staff of the Outside Broadcast Unit in London are different from those of the O.B. staff in the Regions because staff in London is engaged full-time on outside broadcasts. Each Regional Unit is responsible for operating and maintaining the equipment in the main and subsidiary studios of the region as well as the O.B. equipment. In order to ensure economic working O.B. staff in the Regions must be prepared to undertake the duties associated with either O.B. or studio productions. Clearly, when working on outside broadcasts, the engineer must be able to locate and correct a fault in apparatus since space in the vehicles is restricted and spares must be limited; when he is engaged on studio work, the engineer may have adequate spares easily available and fault correction may not be so urgent.

The staff complement varies to some extent from one region to another since each establishment has been drawn up to meet local programme requirements. As a general rule an outside broadcast crew consists of a Senior Television Engineer (S.Tel.E.) who is in charge of the mobile control room and responsible for the technical planning of programmes and in some instances for their lighting as well: the normal number of cameramen is three although a fourth may be provided if the programme requires it: there will be vision and sound control engineers each with an assistant technician: there will always be a team of rigger-drivers and if the programme requires lighting in addition to that already present there will usually be a Lighting Supervisor and lighting electricians. Normally vision mixing is carried out by a member of the production team. The rigger-drivers are frequently used for camera tracking.

The crew required to operate a small television interview studio would be no more than four, consisting of a Senior Television Engineer, cameraman, vision control engineer and sound control engineer.

A base maintenance section staffed by maintenance engineers under a Senior Television Engineer accepts responsibility for all the sound and vision equipment of the Unit and also for the cameras and the equipment used by the Regional Film Unit.

4.3 PROGRAMME CONTRIBUTIONS

Programme contributions from outside broadcasts or from the regional studios may be either for insertion into the National television network supplying the majority of the transmitters or for use as regional items only. The Region is said to 'opt out' from the network for the period during which it is originating its own programme. All regional news bulletins are examples of the opting-out technique. Should a region wish to put out a programme when there is none on the network, it can do so; the contribution is termed 'ex-network' and goes to the local regional transmitters only. The output from the London O.B. units is normally distributed throughout the television network. The majority of regional contributions will also be taken by the network, the exceptions being those which are of local interest only.

4.4 THE TECHNICAL REQUIREMENTS OF OUTSIDE BROADCASTING

The requirements for equipment to undertake an outside broadcast at a site are similar to those outlined in the previous chapter on Television Studio Operation but since the equipment must be mobile, space considerations are all-important. The complete unit generally comprises three vehicles, that is, Mobile Control Room, an auxiliary tender carrying the cameras and microphones and a cable tender for carrying the interconnecting cables, camera dollies, etc. When the outside broadcast takes place far from any suitable entry point to the television contribution network, a radio link will be necessary to provide a vision connection. A number of additional vehicles is then required, one for housing each set of link apparatus and others carrying extendable towers on which the aerials may be mounted. If an electricity supply is not available an additional trailer-mounted generator is towed behind the radio link vehicle to the radio link site.

4.4.1 *The Vision Equipment*

The most important item of outside broadcast equipment is the Mobile Control Room (M.C.R.) which contains all the vision control apparatus, sound equipment and the technical facilities required for production. It fulfils a function equivalent to that of the control gallery and the sound and vision control areas of a television studio. Great care has had to be exercised in the layout in order that full use should be made of the limited space (approximately 17 ft × 7 ft × 7 ft) available in the vehicle. A schematic diagram of the vision equipment installed in a mobile control room employing three cameras is shown in Fig. 4.1. The outputs from the three cameras are fed to their respective control units each one of which has its own waveform and picture monitor. The three-camera control unit (CCU) outputs are taken to a vision mixing unit (VMU) which allows the selection of any one output or a combination of any two outputs. Thus not only is it possible to 'cut' from camera to camera but cross-fading between two, or superimposition of one upon another, can be achieved.

In the newer type of mobile control room, provision is made for accepting as many as eight inputs, of which four may be from

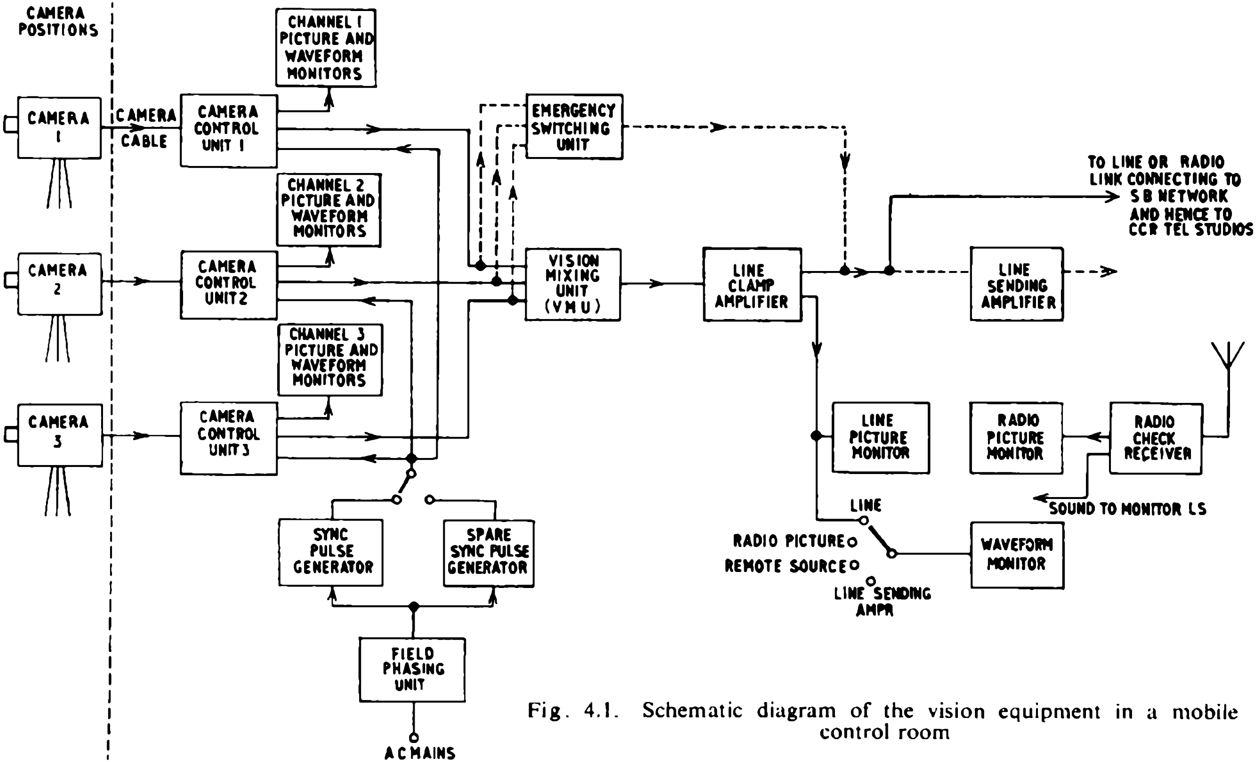


Fig. 4.1. Schematic diagram of the vision equipment in a mobile control room

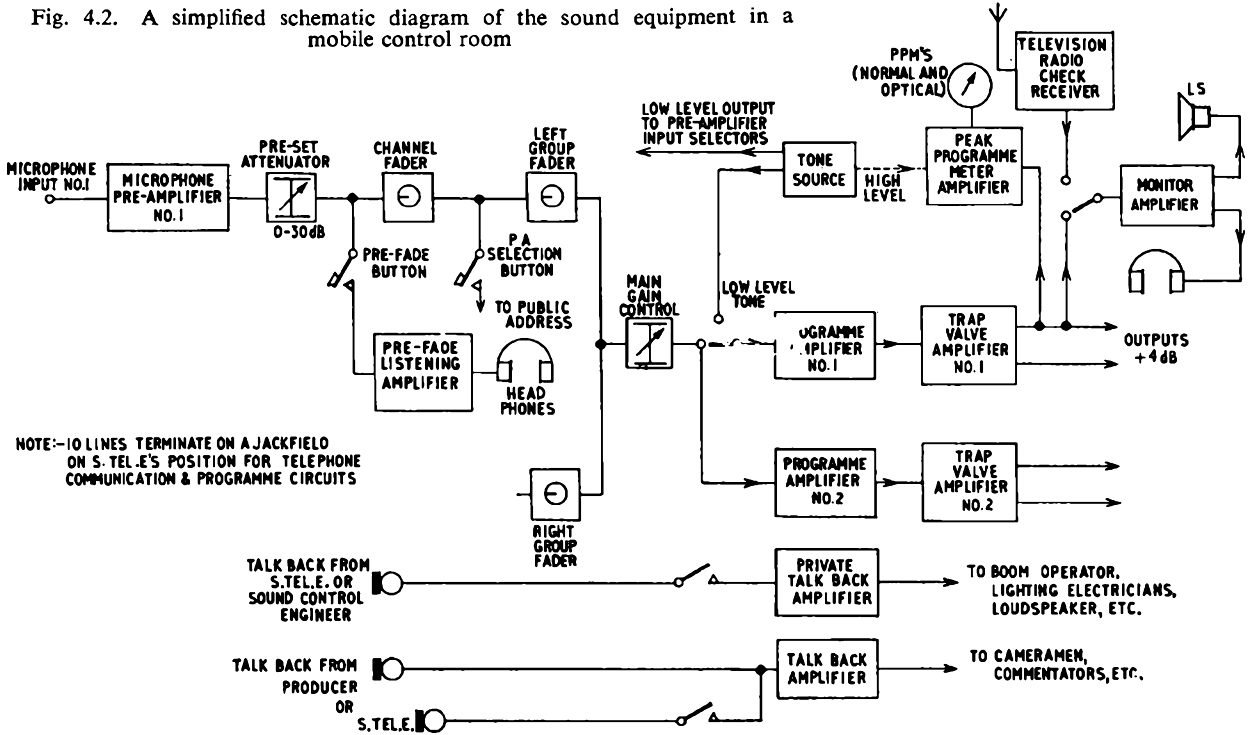
non-synchronised remote sources. An example of remote-source operation is provided by a motor or horse-racing programme which may require a camera or cameras to be located on the far side of the course. The special problems involved are described under Remote Camera Operation in Section 4.5.4. The output from the vision mixing unit is connected to a picture monitor and also to the line-clamp amplifier, which fixes black level, removes the synchronising signals and inserts new synchronising signals or pre-inserts the original ones after processing. A waveform monitor, connected to the line-clamp amplifier output is used to ensure that the waveform leaving the outside broadcast point is correct in all respects. A high-quality television receiver ('radio check') is used to monitor the signal from the nearest television transmitter, the picture from this frequently being used for cueing purposes. If a coaxial-type cable connects to the radio-link apparatus the output is taken direct from the line-clamp amplifier but if a balanced cable is employed, a line-sending amplifier must be included to convert the unbalanced output to a balanced one.

The field frequency of the synchronising signals locally generated in the synchronising pulse generator is held in step with the mains supply by means of a mains-hold circuit. The phase of the O.B. field-synchronising signals is brought into step with the field-synchronising signals in the Central Apparatus Room (3.1.3) so as to prevent roll-over when the Central Control Room switches from studio to O.B. The synchronising-pulse generators can be arranged to transmit test waveforms for line-up purposes prior to the broadcast. In this way a comprehensive check can be undertaken on the complete chain between the outside broadcast site and the television switching centre in Broadcasting House, London, or one of the regional switching centres.

4.4.2 *The Sound Equipment*

Without resorting to the auxiliary mixer, ten microphone outputs or other programme sources can be mixed together on the sound console in the mobile control room, six being connected under one group fader and four under another. The system of high-level mixing (as described in 2.6.1) is employed, each source having its own pre-amplifier giving a gain of about 65 dB which can be reduced to accommodate microphones having outputs greater than about -70 dB. The simplified schematic diagram of Fig. 4.2 shows one of the ten microphone channels. To accommodate the different kinds of microphone which may be used, each microphone pre-amplifier may be switched to have an input impedance of either 30 Ω or 600 Ω. It is sometimes possible to make use of a feed from

Fig. 4.2. A simplified schematic diagram of the sound equipment in a mobile control room



equipment covering the same event for the Sound Service and to cater for this a third position on this switch brings in a 60-dB attenuator which allows a high-level input from a sound O.B. amplifier or another mobile control room to be accepted. Pre-set gain controls make possible a rough balance of the levels delivered to the channel faders which are in quadrant form.

The two group faders are linked in such a way that channel inputs 1–6 may be faded up as channels 7–10 are faded down or vice versa, and in the fader mid-position both groups are faded up. Pre-fade listening facilities on each channel allow monitoring before the channel fader is opened and provision is made for the output of each channel or a group to supply local public address equipment.

The mixed programme output is controlled on a main fader and passed through programme and trap-valve amplifiers before being sent to line at the usual level of +4 dB. By means of selector switches, the programme meters and monitor loudspeaker may be connected across any of the existing trap-valve amplifier outputs. The operation of another switch enables sound from the radio-check receiver to be fed to the loudspeaker for cue purposes at the start of the programme.

When the outside broadcast demands the use of more than 10 channels, an auxiliary low-level mixer accommodating an additional six sources may be used. This is in-set in the desk in front of the sound-control engineer and has its own group control. Its output is amplified before coming under the control of the right-hand group fader on the console. The tone source shown in the diagram can be used for checking the programme and trap-valve amplifiers but its principal function is to enable line-up tone to be sent to line prior to transmission. Under this condition the spare programme and trap-valve amplifiers can be brought into service if the rehearsal must continue. The tone source also supplies a low-level test input to the microphone amplifiers as well as a high-level calibrating signal for the peak programme meter.

Talk-back equipment (T.B.) is included so that the producer and Senior Television Engineer can give instructions to the crew during operations, but talk-back is also possible between sound supervisor and boom operator, Lighting Supervisor and lighting electricians, etc., without interfering with the normal production talk-back to the cameramen. The producer has facilities for switching talk-back, programme, or radio sound to the commentator's head-phones. The operating crew receive talk-back and programme sound together.

A number of reserve facilities exist in the equipment: for example the amplifier used for pre-fade listening may be switched to replace one of the programme amplifiers should this become faulty, and the one used in the talk-back system is a switchable spare for the second programme amplifier. The PPM amplifier, tone source and monitoring amplifier are also duplicated so that fairly comprehensive protection is given against breakdown of the important parts of the equipment. An alternative power supply is also available and its

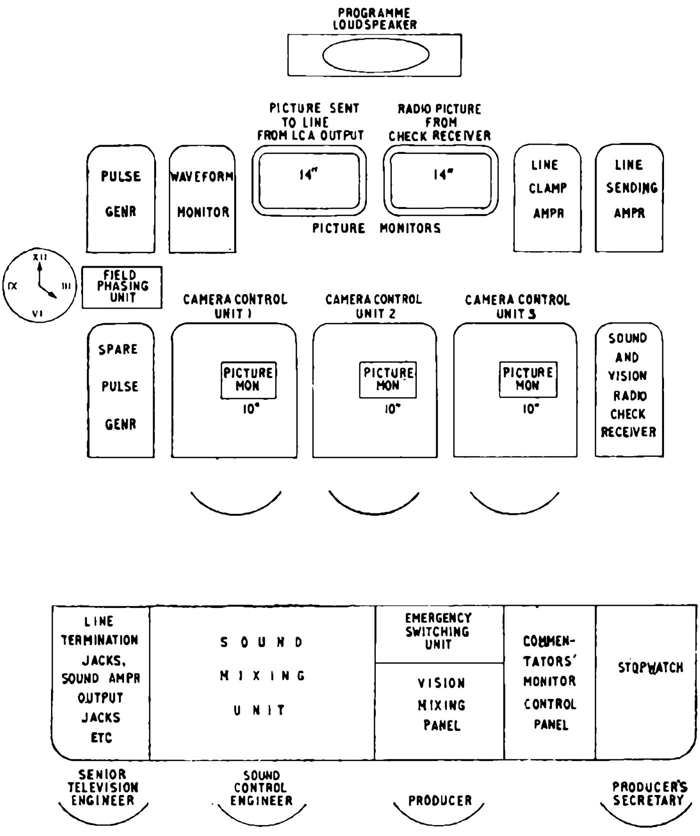


Fig. 4.3. Interior layout of a mobile control room

output is sufficient to maintain five of the channels and the talk-back communication units in operation. It is a vibrator unit, obtaining power from a 24-volt d.c. source and should there be a mains or local generator failure, it can enable the programme to be continued for a limited period on sound only.

An interesting feature is the use of illuminated channel indicators above each fader; when the channel is ready for use but is not connected to the main chain the indicator light is white and it changes to red if a channel or group fader is opened and the main control is also up. Arrangements exist for simultaneously operating an external cue light. The channel indicators can be marked to act as source identification labels, so that the sound control engineer can see at a glance to which channels sources are connected and which are faded up. The sound-control console carries a 40-way jackfield for the termination of all lines associated with the programme and patching cords are provided to enable calls to be routed to the producer and his secretary, who are supplied with lightweight telephone headsets.

4.4.3 *The Complete Equipment*

Fig. 4.3 shows the layout of the equipment in the vehicle. The top half is an elevation which shows the disposition of the main vision equipment. There are three sets of camera control equipment normally operated by two vision control engineers. The left-hand top picture monitor carries the programme output from the mobile control room, and the right-hand one the output from a check receiver tuned to the nearest television transmitter. This monitor is used for cueing purposes as well as for checking that the programme is being received satisfactorily. The bottom half of the layout of Fig. 4.3 is a plan view of the console at which the producer, his secretary, the Sound Control Engineer and the Senior Television Engineer sit. As a rule the producer does his own vision mixing. The Sound Supervisor is responsible for seeing that the sound output is satisfactory in quality and balance and also that cross-fades from one microphone to another are done at the appropriate time and in the correct manner. The Senior Television Engineer exercises general overall supervision of the vision and sound output, and acts as liaison between producer and technical staff.

4.5 PROBLEMS ASSOCIATED WITH THE CAMERA AND ITS POSITIONING

4.5.1 *O.B. Cameras and Lenses*

The image-orthicon tube is used in the O.B. camera because of its high sensitivity and satisfactory operation even with low light intensity. It only differs from the type used in studios and described in Chapter 3, in that a wider spacing is used between target and mesh so that higher sensitivity may be obtained. The newest mobile control rooms use 4½-in. tubes, but older ones, the Roving

Eye and two of the regional studios employ 3-in. tubes. Vidicon cameras (1-in. size) are used in the smaller interview studios.

Problems encountered on outside broadcasts differ markedly from those occurring in a television studio and one effect they have is on the range of lenses used with the O.B. camera. Thus when a close-up shot is required in a studio programme it is usually possible to track the camera forward towards the scene to achieve it. This

TABLE 4.1

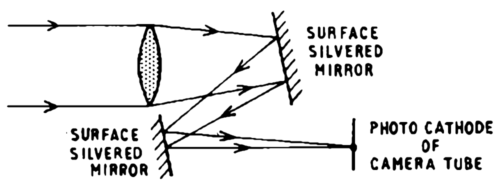
Chart Showing some Typical Lens Complements Used

Nature of Programme	*Camera No.*	*Lenses Employed*
Cricket	1 2 3	Zoom on 8″–40″ range 2″, 4″, 8″, 17″ 4″, 8″, 12″, 17″
Theatre excerpt	1 2 3	Zoom on 4″–20″ range 4″, 8″, 12″, 25″ } or a second 4″, 8″, 17″, 25″ } zoom lens
Golf	1 2 3 4	5″, 12″, 40″ 5″, 12″, 17″, 25″ 5″, 8″, 17″, 24″ Zoom on 8″–40″ range
Boxing	1 2 3	Zoom on 8″–40″ range Zoom on 4″–20″ range 5″, 12″, 40″
Basketball	1 2 3	4″, 5″, 12″, 17″ 2″, 4″, 8″, 12″ 4″, 5″, 17″
Rugby	1 2 3	2″, 4″, 5″ Zoom on 4″–20″ range 12″, 40″

facility is rarely available at an outside broadcast because the camera is generally in a fixed position. Again, the working length of the largest BBC studio is only about 100 ft, and the studio camera is often operating within a few feet of the scene, whereas the O.B. camera may be required to produce an enlarged image of action at a distance of, for example, 400 yards.

The increased distances and the fixed camera positions encountered on outside broadcasts mean that a different range of lenses must be available and they must be changed more often if production requirements are to be met satisfactorily. Lenses of focal length varying between $1\frac{1}{2}$ in. and 40 in. are held by each O.B. unit and it is from these that the producer with the assistance of his cameramen makes a selection for a particular programme. Choice depends on the positions of the camera with respect to the action and the extent of the area to be covered. The exact movement within that area is also important for it is relatively simple to hold a close-up of a platform speaker on a long focal length lens but it becomes an entirely different problem to hold the same size of image with the same lens if the subject is for example a player running hard for the line in a rugby match. In the latter instance a wider angle lens would be preferable in order to relate pictorially the player to members of the opposing team, the goal posts, the touch line or a combination of all three. The horizontal angle of view of O.B. lenses varies between 1°50′ and 49°48′. The first is achieved by a lens of 40-in. focal length and the second by a 1½ in. lens. Table 4.1 gives an indication of the lens types required for typical O.B.'s.

Fig. 4.4. Folded telescopic lens



In order to obtain a close-up of a distant scene a long focal length is necessary, and in a simple lens system the greater the focal length the longer must be the lens.

In television cameras as in photographic and cine cameras there is a limit to the length of the lens system which may be used not only on account of handling difficulties but because it must not project into the field of view of any of the other lenses on the lens-changing turret. One solution to these difficulties lies in the telephoto lens, which has already been described in Section 1.3.3, and is illustrated in Fig. 1.12. This consists of a convex convergent lens followed by a concave divergent one. The introduction of the divergent lens reduces the rate of convergence of the light rays to that which would be obtained from a single convergent lens of much longer focal length as shown in Fig. 1.12. The photo-cathode of the camera tube is placed at the focal plane (Fig. 1.12). This principle is used in the 12-in., 17-in. and 24-in. lenses. When lenses of very long focal length are required, even the telephoto type proves to be too long and cumbersome, and 'folding' by means of mirrors is resorted to as shown in Fig. 4.4. The Dallmeyer 25-in. and 40-in. lenses are of this type.

There are many occasions during the televising of outside events when programme value can be considerably increased if the viewer is given the impression that the camera is moving towards or away from the scene. A televised football match can provide many examples of the need to be able to change rapidly from a wide angle distant view to a narrow angle close-up. Such changeovers could be effected by quick cuts to different cameras having lenses of the desired focal length but even if time were available for this the dramatic impact is much greater if the situation is met by a smooth change from distant to close-up shots. To achieve this a lens of variable focal length is required. This causes the angle of view and the apparent size of the image to alter, image size being increased as the angle of view is narrowed. Such a system is known as a 'zoom' lens. When 'zoom-in' is effected the focal length increases, the angle of view decreases and the image size increases. The variable focal-length property of the zoom lens has also an important application in enabling the cameraman to establish quickly the exact angle of view for covering a particular scene prior to the producer selecting the picture for transmission.

There are a number of different types of zoom lens designs and the one illustrated in Fig. 4.5 is due to Messrs. Taylor, Taylor and Hobson. This figure gives the lens components and their positioning for the extremes of long and short focal length. The three lens components are (1) a front positive convergent lens, (2) a centre negative divergent lens, (3) a back positive convergent lens. The power of the negative lens is greater than those of either positive ones, so that in combination with either lens 1 or 3 the over-all result is a negative lens. In the long focal length position (Fig. 4.5 (a)), the centre lens 2 is moved backwards close to the back convergent lens 3 and the optical arrangement is that of the telephoto lens already shown in Fig. 1.12 (a). A single lens producing the same convergence would need to be placed at C. Its position is determined by the intersection of the parallel rays (produced forwards) entering lens 1 from the object and the convergent rays (produced backwards from lens 3).

The equivalent optical arrangement of the long focal length position is a convergent lens followed by a divergent one as shown in Fig. 4.5 (a). For the short focal length condition Fig. 4.5 (b) the centre lens is moved close to the front lens 1 and the reverse telephoto arrangement is produced with a reduced size of image.

The equivalent optical arrangement for the short focal length position is a divergent lens followed by a convergent one as shown. The position of the equivalent lens is at C′ and though its size is reduced the ratio focal length/diameter (*f*/number) and therefore its aperture are unchanged. This means that the brightness of the image is independent of the zoom action—a very necessary condition.

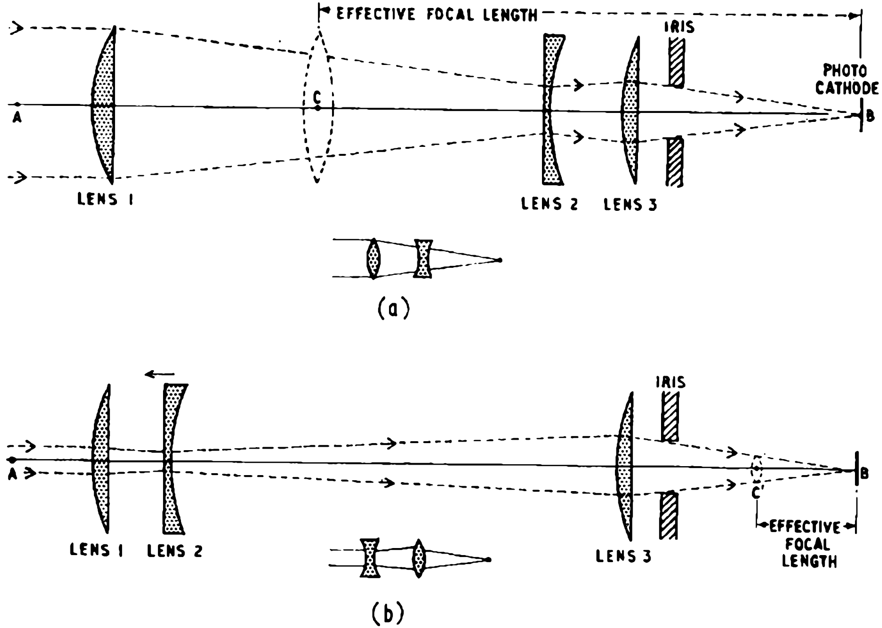


Fig. 4.5. The zoom lens

In the diagram the iris is shown for simplicity outside lens 3 though in fact it is contained within this member. The aperture setting of the iris may be adjusted remotely to suit the prevailing light conditions. The correct action of the zoom lens depends on lenses 1 and 2, producing a virtual image at a fixed position such as A and to maintain this condition lens 1 has to be moved for positions of lens 2 intermediate between those it takes up for the extremes of long and short focal length. The depth of field obtained for any setting of the zoom control is similar to that which is achieved by a lens of equal focal length. Correct focus will automatically be maintained during zooming as long as the object in focus remains at a fixed distance from the lens. When the object is moving towards or away from the lens it has to be kept in focus by the zoom focus control which alters the position of lens 1 relative to its carrier.

In order to keep the over-all aberrations small it is necessary to limit the extent of movement of lens 2 and with the present design techniques the over-all zoom ratio is about 5 : 1 giving focal lengths of 4 in.–20 in. which corresponds to angles of view of approximately 23°–4° respectively. It is possible by changing the lens 3 for another convergent lens of different power to alter the range of focal length to one of 8 in.–40 in. (angles of view approximately 11°–2°).

The latest type of zoom lens (Taylor, Taylor and Hobson) allows a change of range to be effected by a lever operating on the back component which is a small auxiliary zoom within the main lens. A front attachment may be added to halve the focal length ranges to 2 in.–10 in. and 4 in.–20 in. so that the full O.B. range of focal length from 2 in. to 40 in. is covered. The zoom can therefore be used to replace any combination of lenses normally used on a turret. The zoom lens in the long focal length position suffers from the same defect as the normal fixed telephoto lens, namely, it produces a perspective different from that to be seen by the eye placed at an equivalent position. For example if at an outside broadcast of a cricket match a view is taken from behind the bowler by telephoto or zoom lens in the long focal length condition, the pitch appears much shorter and the batsman much closer to the bowler than if the eye were viewing the scene from a position giving the same size of bowler.

4.5.2 *Camera Siting*

The siting of the camera for an O.B. programme is ultimately a decision for the producer but certain factors, technical as well as artistic, must be taken into account. From the technical point of view the area of action is very important, since all camera cables must be taken back to the mobile control room. The cameras can normally operate with as much as 1 000 feet of camera cable, but some have been modified to be suitable for lengths up to 2 000 feet. If this distance is exceeded the complicated linking arrangements associated with remote camera operation (4.5.4) must be introduced. The height of the cameras above ground and the range of lenses necessary will have to be estimated. Siting of the cameras in relation to the sun so as to avoid direct sunlight falling on the lens will also have to be considered. The location of the cameras to meet production requirements is all-important. For example cameras are not normally located on opposite sides of a sports stadium because confusion would be caused to the viewer when a cut is made from one camera showing direction of play from right to left to another which apparently suddenly reverses it.

4.5.3 *Scaffolding Towers for Cameras*

On the televising of many sporting events the cameras are required to be at an appreciable height above ground and though a suitable platform, e.g., a race-course grandstand roof, is sometimes available it is more often necessary to erect a scaffolding platform. These may vary in height from approximately 10 to 70 feet and their construction requires considerable skill, because the platforms must be rigid as well as safe if smooth panning while maintaining focus is to be achieved in all conditions of wind or weather. The height of the camera platforms is very important, since it determines the kind of coverage the camera gives. If it is too low the picture will be oblique and spectators may block the field of view. If it is too high, a bird's eye view is obtained and a very considerable area round the platform cannot be covered by the camera because its movement in the vertical plane is limited to an angle of about 70° to the horizontal. The use of the towers need not be restricted to cameras and cameramen and they often provide crow's-nest view positions for commentators on platforms above or below the cameras. They may also be used for siting highly directional microphones or for the erection of aerials when a radio link is used.

Constructions of this kind require special safety precautions to be observed. Climbing ladders have to be securely lashed and should preferably be placed inside the tower. Guard rails must be erected at each platform about 3 feet above the floor boards and a vertical 'kicking' board must be included round the edges of the platform to prevent small items such as headphones and lens boxes blowing off the tower. The rails and the boards offer almost complete protection to the cameraman, who is rarely in a position to observe how near he may have come to the edge when he is looking into his viewfinder. Safety nets must be placed below each camera position to catch any item which might fall from the platform.

A pulley-wheel mounted at the head of the tower is generally employed in rigging the camera and commentary positions. Guide ropes have to be attached to equipment being raised or lowered to prevent it striking the structure because even heavy items can swing considerably in a high wind. Although scaffolding towers used for outside broadcasts do not usually exceed a height of 60 or 70 feet, producers are not limited to siting at such levels and many have used cameras at much greater heights. For example a dockyard crane at a height of 165 feet has been used to record the launching of a ship and a camera has been operated from the top of a span 300 feet above the water for a programme on the Forth Bridge.

4.5.4 *Remote Camera Operation*

There are many occasions in O.B. working when at least one camera must be located at too great a distance from the mobile control room to permit the satisfactory transmission by normal means of all the necessary operating waveforms. This remote camera must then have its own synchronising pulse generator and it will return the complete vision signal plus synchronising pulses to the mobile control room by means of a radio link or a specially installed P.O. cable. To prevent field slip when the producer switches over to the remote camera output, correctly-phased control signals must be sent from the mobile control room to keep the remote synchronising pulse generator in synchronism. The technical difficulties are increased if a commentator accompanies the remote camera for then his microphone output must be returned to the mobile control room and he must be able to receive instructions from the producer; hence two more circuits have to be found. In addition the engineers at either end must be able to communicate with each other.

The following facilities have therefore to be provided:

1. Vision circuit from remote point to M.C.R.
2. Sound/music circuit from remote point to M.C.R.
3. Production talk-back from M.C.R. to remote point.
4. A two-way technical control channel.
5. Locking signal circuit.

These five circuits may be accommodated in a 7-pair cable or be transmitted over multi-channel radio links as shown by the schematic diagram in Fig. 4.6. In the example shown the vision signal is

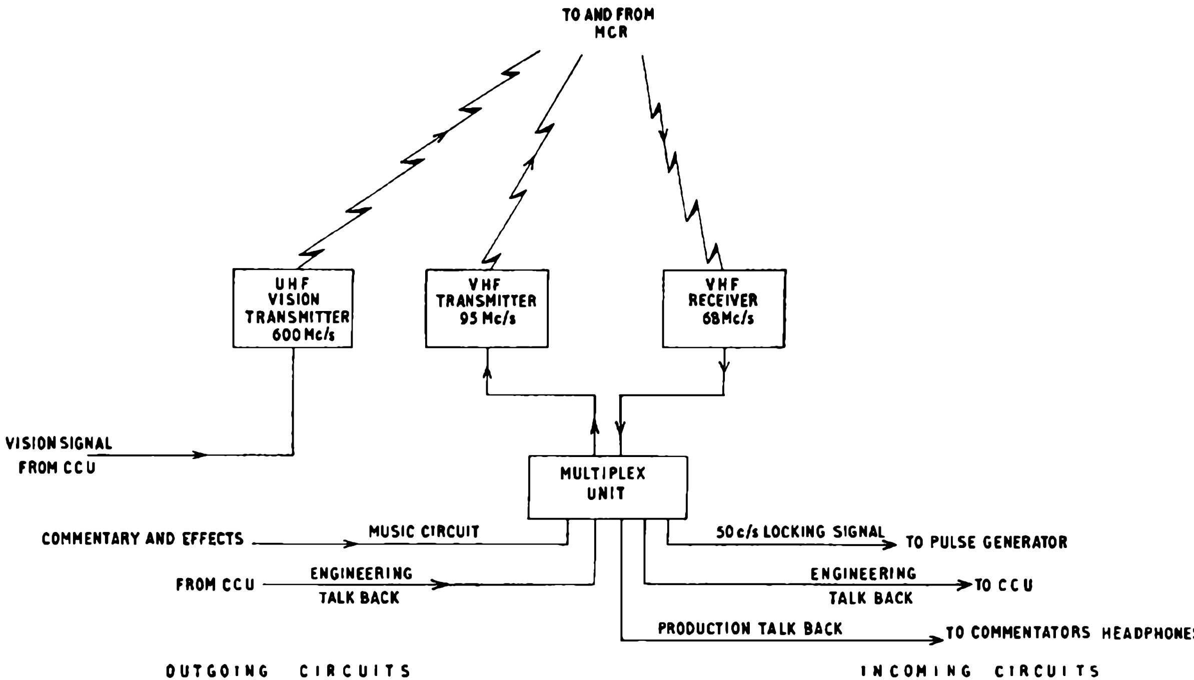


Fig. 4.6. Remote camera linking arrangements

transmitted by means of a u.h.f. transmitter at about 600 Mc/s and the commentator's vision and engineering control signals are used to modulate in multiplex a v.h.f. carrier of about 95 Mc/s. Reception of the locking signal, producer's instructions, and technical control information is afforded by another v.h.f. link.

4.5.5 *The Radio Camera*

For certain types of picture—for example, a low level shot of a putt on the green during a golf match or from behind the goal posts during a football match—the normal type of camera is not very practicable, and for this purpose a lightweight portable camera complete with control unit, sychronising pulse generator and transmitter has been designed. It is known as a Radio Camera, the camera itself being no bigger than one used for amateur cine work. On account of its small size and weight it proves very convenient for mounting in motor boats, light aircraft, etc. It is easily carried in the hand while the associated apparatus contained in a pack-set may be worn by the cameraman on his back or be carried by an assistant.

The camera unit comprises a 1-in. vidicon tube equipped with any one of the standard 16-mm lenses or a small zoom and an optical viewfinder. It weighs only 5 lb and a schematic diagram is given in Fig. 4.7. The camera control unit, waveform generator and transmitter together weigh about 55 lb, the weight having been kept down by transistorising the power supply unit and the pulse generator. The vision signal is used to frequency-modulate a Band V transmitter giving a power output of 100 mW which is satisfactory over a range of about half a mile. Future radio cameras may make use of an s.h.f. link on about 7 000 Mc/s to transmit the vision signal. The power consumed is about 90 watts and is derived from two 12-volt 20-ampere-hour batteries which have a life of several hours.

Two aerials are normally erected for the vision receiver; one has highly directional properties and may be panned to follow the camera while the other gives good all-round coverage. The receiver can be switched to whichever aerial gives the better signal and the output from the receiver is fed to the local mobile control room. A low-power frequency-modulated sound transmitter (power output of 10 watts) operating at about 95 Mc/s, is used to carry the talk-back from the producer in the mobile control room and from the engineer in the control vehicle to the cameraman who receives it on a lightweight pocket-size receiver. A locking signal is also carried by this link. A radio microphone is provided to enable the cameraman to communicate with the producer and control engineer.

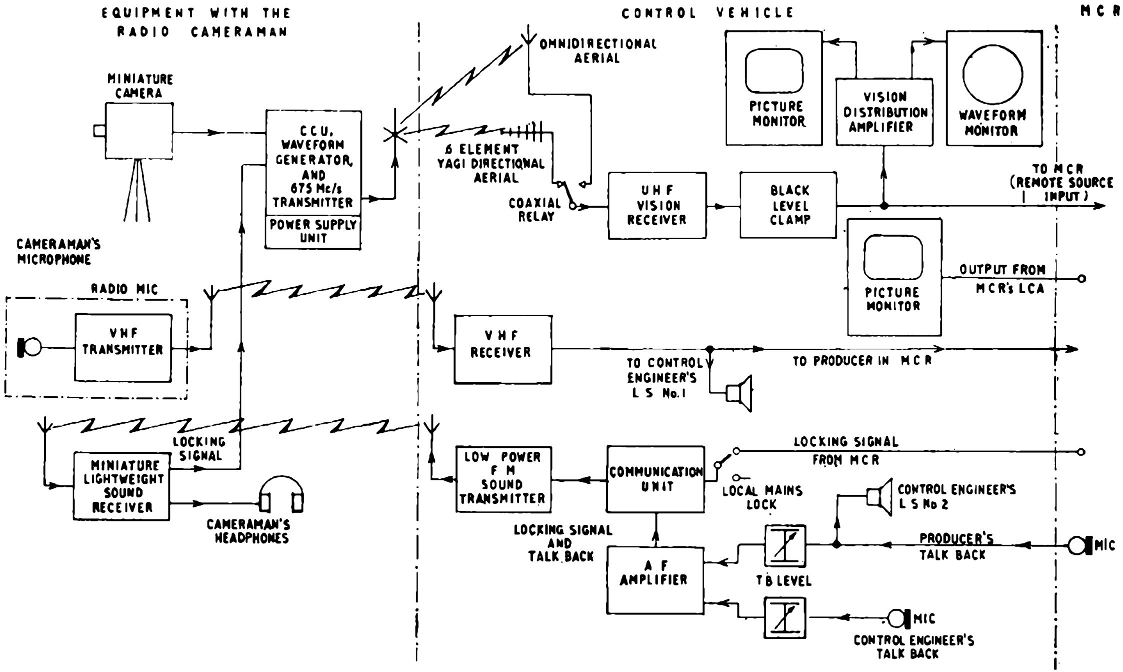


Fig. 4.7. Schematic diagram of the radio camera

4.5.6 *The 'Roving Eye'*

It sometimes happens that a programme may have to portray action taking place over too large an area to be covered by fixed cameras and for this a mobile camera vehicle is required. The 'Roving Eye' has been designed for just such a programme; it consists of two cameras, control apparatus, microphones and radio equipment mounted in a vehicle from which pictures and the accompanying sound can be transmitted back to a stationary base vehicle and hence to the network, whilst the Roving Eye itself is moving.

The power for the electronic equipment is derived from a petrol-electric generator. The transmitting aerial is directional and special arrangements are made to maintain it on the correct bearing for transmission back to the receiving point. Standard 3-in. image-orthicon cameras are used rather than the 4½-in. versions because of their smaller size and lighter weight.

The Roving Eye can also be used as a stationary two-camera mobile control room and there are a number of occasions—such as short previews of exhibitions, snooker and boxing matches—where all the necessary O.B. facilities can be provided more economically by this smaller vehicle. When the vehicle is used from a fixed position, additional height may be gained for the vision transmitting aerial by the extension of a telescopic mast built into the vehicle body. The aerial is raised in about two minutes by compressed air. At its maximum height of 42 feet it clears most buildings in suburban areas. A multiplex unit is used for superimposing the necessary music and control circuits on to the radio link provided for the Roving Eye.

4.6 POWER SUPPLIES FOR MOBILE CONTROL ROOMS

The power requirements of a mobile control room vary according to the time of the year because apart from technical needs power may also be wanted for air-conditioning plant and for space heaters. The technical equipment accounts for about 6–10 kW and the ancillary equipment an additional 3–6 kW. Allowance has therefore to be made for a power supply of about 15 kW when the needs of the BBC radio link or G.P.O. vehicle are taken into consideration. Should the outside broadcast call for artificial lighting, power consumption may be increased by an amount depending on the area to be covered; it might be as low as 5 kW or well in excess of 100 kW. There will be less difficulty in obtaining the power if the outside broadcast is from a factory or large theatre but when it is required, for example, in a country house or small church, a special temporary installation and mobile generator may be necessary. In any case it is unlikely that a suitable existing power socket will be available and special arrangements will have to be made—usually with the local electricity board—for a direct connection through suitable switches and meters. It is essential to avoid making connection to existing switches controlling other loads.

Each modern mobile control room is equipped with an automatic voltage control unit to compensate for and smooth out variations in supply voltage which could affect the operation of the equipment. The control unit ensures that any supply between 170 and 250 volts can be accepted. Voltages near the lower limit are however avoided whenever possible, but when such conditions are met, step-up transformers are often included in the circuit. When no mains supply is available portable generators have to be provided. For example in the Boat Race transmission from the launch 'Everest' two 7½-kVA diesel generators are needed to power the two cameras. 15-kVA generators are provided when power is not readily available for the mobile control room and its associated link.

4.7 LIGHTING FOR TELEVISION OUTSIDE BROADCASTS

Television outside broadcasts call for a specialised lighting technique which has been described elsewhere[1]. There are however some points of general interest which should be considered here. From a lighting point of view O.B. work can be divided into three types, characterised by the means of lighting as follows:

1. Artificial, e.g., theatre excerpts, military tattoos, boxing, light entertainment.

2. Daylight or direct sunlight, e.g., all outside events televised during day-time.

3. Mixture of artificial and daylight, e.g., morning church services, day-time programmes from swimming baths, ice rinks, etc., having glass roofs.

When artificial lighting is required, the lighting supervisor has to plan the structure to which he will attach his lamps. This may be a simple system involving only half-a-dozen scaffolding tubes distributed on the walls as required or it may be a major construction in which either self-supporting lighting towers or a lighting grid covering walls and ceiling are used. The lamps, cables and any other equipment are erected to the lighting supervisor's plan by a team of electricians. If existing lighting equipment can be used, as it would be in a theatre or ice rink, the lighting problem is eased for it is then only necessary to install the augmenting equipment. If the O.B. comes from a low-ceilinged room or corridor, considerable difficulties are experienced in finding a suitable and unobtrusive form of lighting.

When a programme takes place out-of-doors in daylight the vision control operator has to compensate for changes in lighting levels, and to this end the modern mobile control room provides him with remote control of either the iris or a neutral density filter in the television camera lens system. In rapidly changing weather and daylight conditions almost continuous control may have to be exercised on the light reaching the photo-cathode of the camera tube, if best results are to be achieved. To cope with very bright sunlight conditions most of the cameras are equipped with 1 per cent and 10 per cent fixed-rating neutral density filters, which can be rotated into position in front of the camera tube as required. Colour filters are of value in O.B. work; for example a yellow (minus blue) filter is a help in penetrating haze, and under foggy or smoky conditions can produce a relatively clear television picture.

The type of indoor programme for which daylight coming through windows is augmented by artificial lighting presents many difficulties to the lighting technician. Daylight not only varies in intensity but if the day is sunny, also changes direction during the day. It is generally impossible to exclude it by any economic form of blackout and to do so would often be artistically undesirable, hence a balance must be found between the natural and artificial lighting and it will be clear that any rehearsal involving lighting should if possible take place at the same time of day as that for which the programme is scheduled.

4.8 SOUND FACILITIES

4.8.1 *Microphone Positioning*

The microphones for indoor events are similar to those in use in the television studios and for outdoor work are largely similar to those used on sound O.B.s and the same principles apply. The problem of placing microphones is more difficult because, if possible, sound and vision perspectives have to be matched. To convey atmosphere it may be necessary to use a highly directional distant microphone to bring out, for example, the crack of a ball on bat in a cricket match. The microphone may be placed at the focus of a parabolic reflector which will then have to be moved to follow the play. The reflectors have to be limited in diameter to about 3 ft and they will therefore only be satisfactory for picking up sounds which contain frequencies above about 200 c/s. Another form of super-directional microphone is the 'rifle' type described in Chapter 3.

It is light in weight and may be easily tilted and panned on its mounting to follow a moving object. Spectator reaction as conveyed by crowd noises, if used judiciously, can help to heighten the impact of an occasion. It is however important to ensure that such effects do not mask a commentary or render it difficult to follow.

4.8.2 *The Commentator's Microphone*

For some outside broadcasts requiring running commentaries the commentator does not appear in the picture. Occasionally he is in a separate studio or vehicle with a picture monitor in front of him, and the problem is then no different from that of a small studio. More often he is accommodated in a special stand from which he can see the whole action only a part of which is displayed on his picture monitor. He may then have to use the lip ribbon microphone which discriminates against crowd noise in favour of the commentator's voice. A switch (see Fig. 4.8) is included in the mobile control room to allow either the outgoing vision or the output from a television check receiver to be viewed on the commentator's monitor. The output of the receiver is given to the commentator just before the programme commences in order that he may obtain a visual cue in addition to the aural cue received over his headphones from the producer, and this makes for smoother continuity. Once the programme is being transmitted the switch is returned to the line output because there the picture quality is at its best and the picture itself is independent of the local station to which the receiver is tuned.

A breakdown at the local transmitter might cause embarrassment to the commentator by removing the picture from his monitor and this could affect the programme on the other transmitters which are receiving it satisfactorily. An exception to this rule occurs when the programme involves telecine inserts or is a composite one involving other O.B. sites as well. The commentator must then be given the check receiver output in order to follow the sequences. The liaison between commentator and producer must be very close. A skilful commentary from one who can see all the action may guide the producer to redirect his cameras and select a more dramatic situation. If the area of action to be covered is large, a number of commentators will be required and very careful planning and accurate cueing will be needed.

4.8.3. *The Radio Microphone*

There are many occasions in outside broadcasting when an interviewer must carry a microphone with him and its trailing lead can

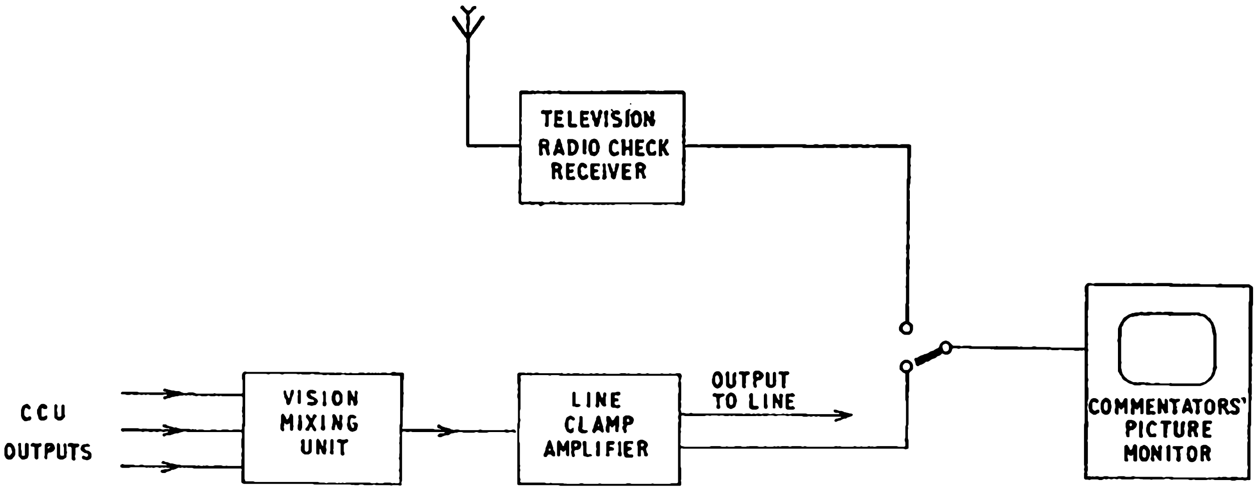


Fig. 4.8. Switching circuits for the commentator's monitor

be a serious disadvantage. A further disadvantage is that attention will be drawn to the microphone and its lead, and the viewer may be distracted by its appearance in the picture. A radio microphone has been developed by the BBC Designs Department to overcome these difficulties. It usually consists of a small lapel-type crystal microphone (other types can be used) associated with a pocket radio transmitter attached to an aerial concealed about the person. The commentator has free use of his hands and can wander about unencumbered. It is normal practice to arrange for a reserve microphone to be worn to guard against a possible fault developing.

A schematic diagram of the equipment is given in Fig. 4.9. The transmitter, which uses frequency modulation, operates in the range 45–60 Mc/s and has a power output of about 250 mW, the power being derived from a 90 V/1·5 V pocket-size battery capable of giving about two hours' operational use. The flexible insulated-wire aerial, one quarter of a wavelength long, is generally concealed inside a trouser leg. Associated with the miniature transmitter is a receiver normally situated inside the mobile control room and the output from this receiver is connected to one of the channels in the sound console.

The quality of the sound output when the lapel microphone is used is not as good as that from the normal O.B. or studio microphone but this disadvantage is offset by its convenience. An improvement in quality can be achieved by using a special miniature microphone suspended on a lanyard round the neck or by using the 'stick' microphone held in the hand by the commentator.

The receiver usually makes use of a directional 'H' aerial in order to increase the sensitivity and several of these aerials located in different positions may be needed to maintain adequate signal strength as the commentator moves around. The pick-up range is dependent on the conditions of operation and it will be greatest when the radio microphone is used out-of-doors. With a clear path between transmitter and receiver it will work satisfactorily over a distance of 100 yards but even greater ranges have been found practicable. In reinforced-concrete and steel-framed buildings the range will be considerably reduced owing to the screening effect of the building on the signal.

4.9 THE VISION SIGNAL LINK TO THE MAIN TELEVISION NETWORK

Although there are some occasions when a sound O.B. programme is recorded at its originating point, more often than not the programme has to be connected into the S.B. network at a studio centre. This is effected by a temporary line hired from the G.P.O. The

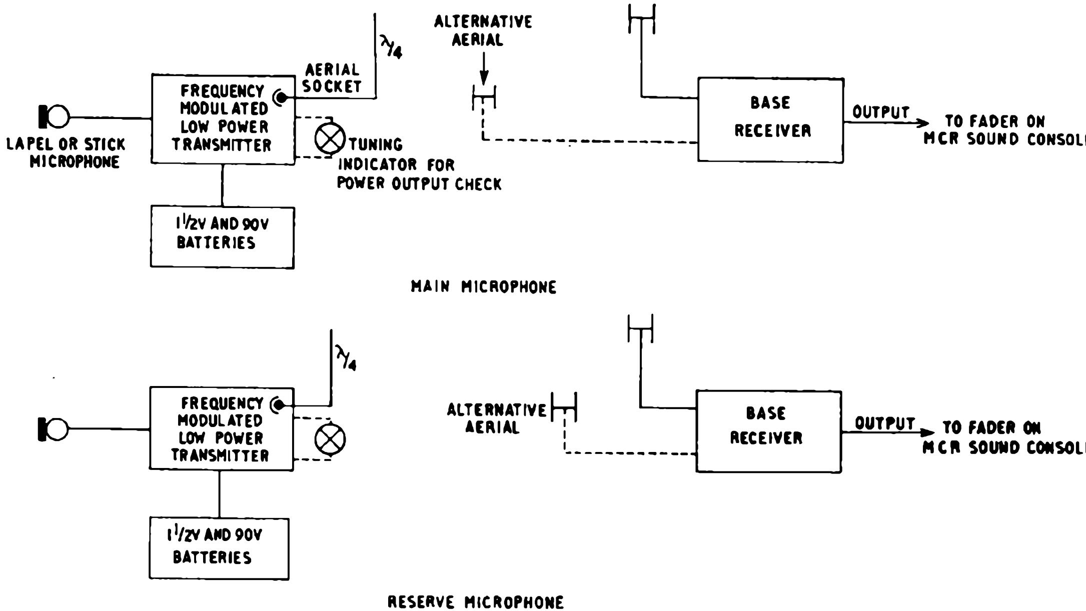


Fig. 4.9. Schematic diagram of the radio microphone

same arrangement can be made for the sound contribution of a television O.B. but ordinary telephone lines using normal transmission techniques are unsuitable for carrying the much wider range of frequency components making up the picture signal. However, by using short lines and special equaliser circuits[2] the ordinary telephone line can prove extremely useful as indicated on page 363. The more common method, however, is to transmit the vision signal by radio link. Sometimes it is impossible to have the transmitter close to the mobile control room because the site is too restricted (it may be in a built-up area) or because it is in a deep hollow with poor line-of-sight transmission possibilities. When this is so, the services of the G.P.O. may be sought to provide a temporary cable link between the mobile control room and a suitable transmitter site (Section 4.9.2). The cable may be as much as a mile or more in length.

4.9.1 *The Radio Link Equipment*

Two kinds of equipment are available for providing the radio link for the vision programme; both use a frequency-modulated carrier, one operating in the u.h.f. range and the other in the s.h.f. range of frequencies.

Frequency-modulated U.H.F. Transmission Link. The equipment uses frequency-modulation and the final carrier frequency is 660 Mc/s. A schematic diagram of the apparatus is shown in Fig. 4.10. The video signal is used to control the bias of a reactance valve modulator (Section 1.7.2) which varies the frequency of a 60-Mc/s oscillator a total of about 2 Mc/s from the troughs of the synchronising pulses to peak white. The f.m. signal together with the second harmonic of a crystal-controlled 80-Mc/s oscillator is applied to a frequency changer and the sum frequency 220 Mc/s is extracted. It would be feasible to multiply the original 60-Mc/s f.m. signal by four to bring it to about 220 Mc/s and this would have the advantage of multiplying the deviation frequency by four but it would at the same time multiply any variation in mean carrier frequency by the same amount. A frequency tripler following the mixer multiplies up to the final carrier frequency on 660 Mc/s and at the same time multiplies the deviation frequency and therefore the modulation content to about 6 Mc/s.

The multiplication of modulation content when an f.m. signal is applied to a multiplier represents an important advantage of frequency modulation over amplitude modulation. It is not possible to amplitude-modulate a carrier frequency before multiplication since multiplication essentially involves distortion of the amplitude

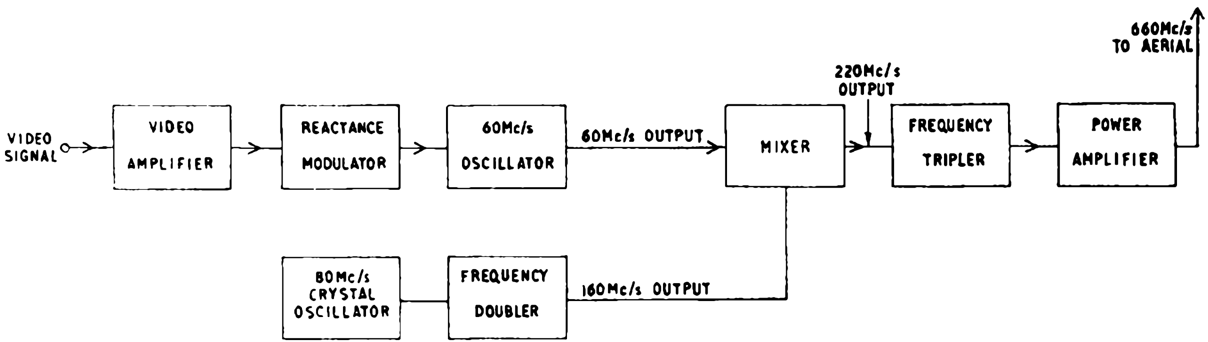


Fig. 4.10. Schematic diagram of a u.h.f. radio link transmitter

which contains the information. The amplitude of an f.m. signal can be completely distorted without in any way affecting the modulation content. The transmitter output of 18 W is delivered to a dipole aerial in a corner reflector or a six-element Yagi array, and a range of about 40 miles may be obtained over flat country when the transmitting aerial is mounted on a 40-foot mast.

Frequency-modulated S.H.F. Transmission Link. Equipment operating within the band 4 500–4 800 Mc/s is still being used for providing the radio link, but a change to the 7 000-Mc/s band is gradually being made. Quite often the O.B. point is too far from a suitable receiving point in the television network to allow the use of one transmitter, and a series of equipments is required to relay the picture. A schematic diagram of a combined receiver-transmitter is given in Fig. 4.11. Frequency modulation using a frequency deviation of 6 Mc/s is employed. The signal sent out from the s.h.f. transmitter at the O.B. location is received at an intermediate point, where the video signal is extracted in a superheterodyne receiver.

In the i.f. amplifier of the receiver the signal amplitude is limited before being applied to the frequency-to-amplitude converter. The converter provides a d.c. output which is zero when the receiver is correctly tuned to the incoming signal but is either positive or negative when there is a tuning error. The amplitude of the d.c. voltage is proportional to the degree of error, and it is used to vary the frequency of the receiver local oscillator in such a way as to reduce the error, i.e., automatic frequency correction (a.f.c.) is achieved. The video signal from the converter is fed to the transmitter section where it is used to frequency-modulate a Klystron s.h.f. oscillator, the output of which is fed to the transmitting aerial. The video signal is continuously monitored on a picture and waveform monitor. A test signal can be substituted when desired and this provides a check between the local transmitter and the receiver at the next link point. Thus each link in the chain can be separately checked.

A radio receiver is tuned to the nearest television station to serve as a check on overall programme continuity and a radio-telephone link is included for engineering control purposes because normal telephone circuits are rarely if ever, available between sites. This communication channel is all important and is in constant use during the setting-up and testing of the link as well as during programme transmission. The complete equipment may be supplied from a mobile diesel generator if no existing supply is available.

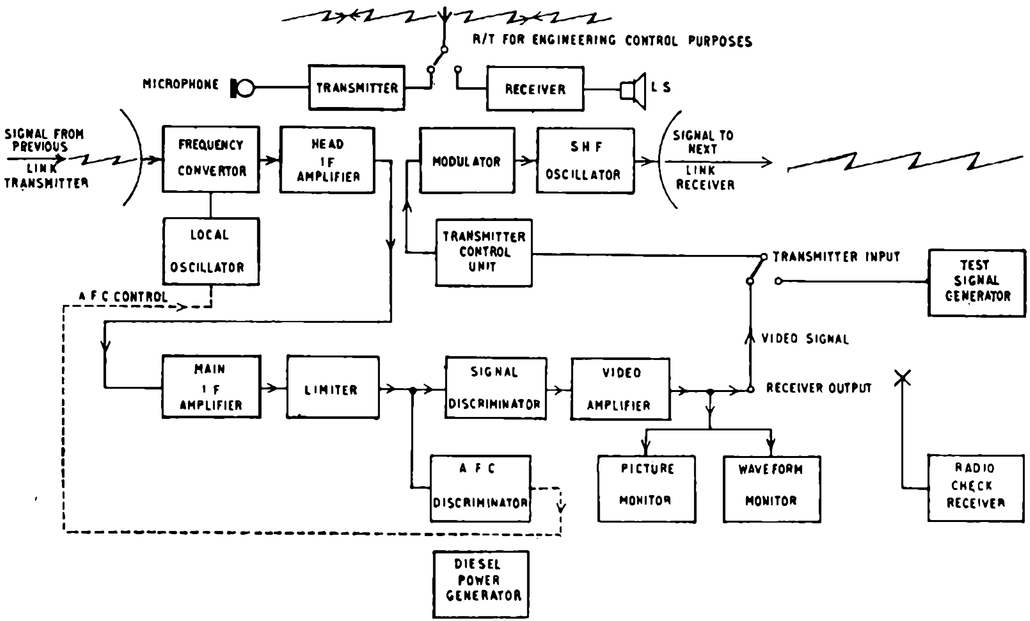


Fig. 4.11. Schematic diagram of the apparatus for a s.h.f. link

Since the wavelength of the s.h.f. signal is so small (7 cm) a high-gain parabolic reflector aerial can be used and ranges of up to 50 miles have been successfully achieved with a transmitter power of 3 W. Since the parabolic reflector has a beam width of only about 5° communication is by means of 'line of sight' and great care has to be exercised in setting up the aerial. The transmitting aerial is first set exactly on a bearing calculated from map readings of the position of the transmitter and receiver. A 'search' is carried out at the receiving site by moving the receiving aerial a few degrees on either side of the bearing and this should reveal the signal if a line-of-sight path exists. During the final 'trimming' the transmitting aerial is panned and tilted until the receiving site reports maximum signal. The radio telephone engineering control link is invaluable at this stage when the link is being established.

4.9.2. *The Entry Point to the Main Television Network*

The O.B. vision signal has to be 'injected' into the permanent television network at some convenient point and the way in which it is done will depend on the location of the O.B. site in relation to the vision distribution/contribution system. In the centre of London for example a balanced-pair cable permanently links places such as Earls Court, Olympia, Whitehall and the Albert Hall with the BBC Switching Centre at Broadcasting House. An O.B. radio receiving station on high ground at Highgate in North London provides an ideal reception point for O.B. link transmissions from many points in the Home Counties. It is permanently connected to the Switching Centre and to Alexandra Palace. In the Midlands, North, West and Welsh Regions use is made of the existing television network which consists of a duplicate coaxial cable with repeater stations at regular intervals between London and the regional high-power television stations. One cable distributes the programme from London to the transmitters and the other in the opposite direction exists for contributions from the Regions.

There are eleven repeater stations in the P.O. link between London and Birmingham, sixteen between Birmingham and Manchester and twenty-three between London and Bristol and any one of these may be used as an injection point for an O.B. programme. An example of such an insert is illustrated in Fig. 4.12—motor racing from Castle Coombe. The O.B. site is about four miles from the repeater station at Upper Wraxall on the London/Bristol/Wenvoe coaxial cable and the vision signal is transmitted from the O.B. by radio and is then introduced into the contribution circuit for transmission back to the Central Control Room in London.

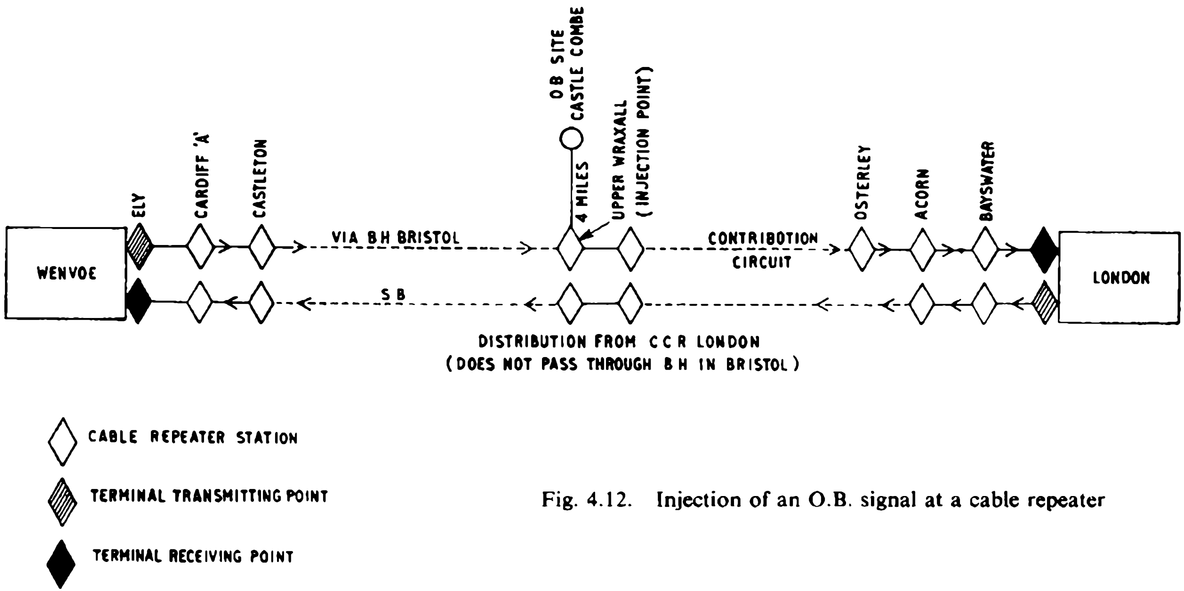


Fig. 4.12. Injection of an O.B. signal at a cable repeater

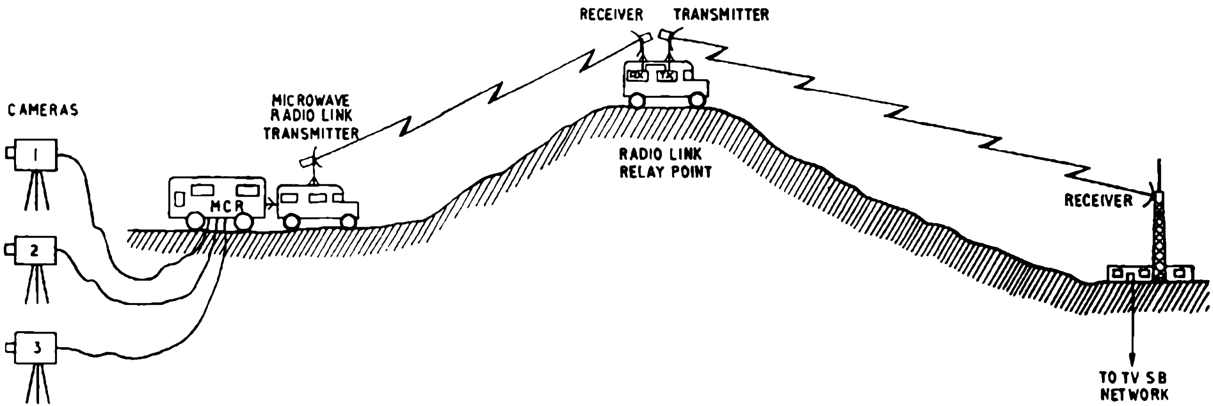


Fig. 4.13. A simple radio link to a high-power transmitting site

The vision distribution chain between Manchester and Kirk O'Shotts (also two-way) is by radio (s.h.f.) through eight intermediate relay stations, which serve as possible injection points for O.B. signals from the North of England and Scotland. The distribution and contribution vision links are both extended to the high-power (and some medium-power) BBC television transmitters so that each of these affords a convenient injection point.

On each transmitter mast a s.h.f. aerial with parabolic reflector is installed at a high level for receiving O.B. transmissions as illustrated in Fig. 4.13. A frequency changer, integral with the aerial assembly, converts the incoming signal frequency to 115 Mc/s, and the signal

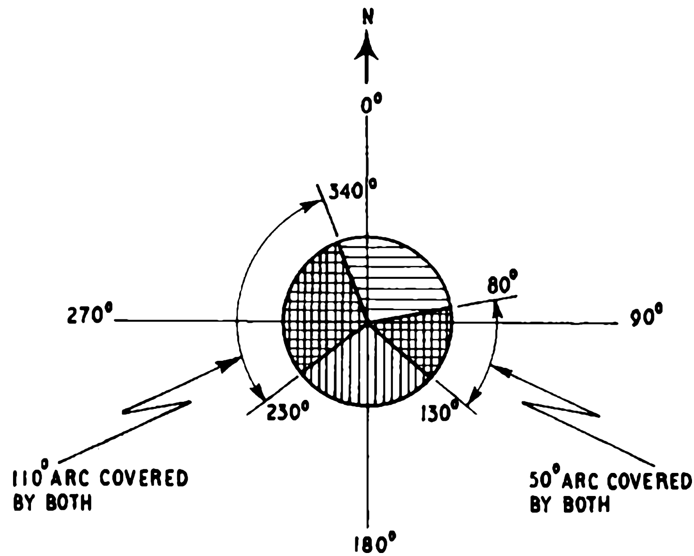


Fig. 4.14. Coverage by s.h.f. mast-head receivers at Kirk O'Shotts

is then conveyed by coaxial cable down the mast to the remainder of the receiver situated in the transmitter building. After demodulation the resulting video signal can be injected into the London-going contribution circuit. In order that signals may be picked up from any given direction the parabolic aerial must be capable of being panned by remote operation from the ground. A calibrated control dial showing the bearing from the station, allows an initial search to be made. The final position at which the aerial is locked is determined by that which gives the strongest signal. Since it is not possible to obtain all-round coverage from a single parabola outrigged from the mast two separate paraboloidal aerials and two separate s.h.f. receivers are used. A considerable area of overlap exists as in Fig. 4.14, which represents the coverage obtained at the Kirk O'Shotts transmitter. The overlap means that in certain directions the second set of s.h.f. equipment is a spare for use in an emergency, and at Kirk O'Shotts it is so arranged that signals from the areas, Glasgow and Edinburgh, most likely to originate programmes, can be accepted by either mast-head aerial. This method of gaining access to the television network is a most important facility since the transmitter station masts are invariably sited on high ground. Thus at Kirk O'Shotts the s.h.f. aerial receiving point is 1 500 feet above sea level and at Holme Moss it is 2 300 feet above sea level.

Some idea of the complexity of an O.B. link is given in Fig. 4.15 which shows the complete chain involving the use of a specially equalised G.P.O. cable between the mobile control room and first link transmitter, followed by a 10-mile and a 25-mile s.h.f. 'hop' to the BBC high-power station at Wenvoe. The Post Office provides the apparatus and the link between Wenvoe and the BBC switching centre at Broadcasting House, London, from which the vision signal is taken to the Central Control Room.

Sometimes a number of possible injection points offer themselves as illustrated by an outside broadcast from a site in Aberdeen shown in Fig. 4.16. A u.h.f. transmitter may be used to carry the vision signal to the first s.h.f. relay point on high ground 4 miles south of Aberdeen; from there it may be conveyed by s.h.f. to Bruxie Hill, 17 miles away, where a second s.h.f. transmitter passes it on to Craigowl Hill, 32 miles further on. From here there would appear three possible injection points into the network, namely, the Kirk O'Shotts transmitter mast-head equipment or the G.P.O. relay stations at Blackford Hill or Black Castle Hill. The line of sight to the Kirk O'Shotts mast head is actually obscured by a range of mountains, and the Black Castle Hill site is unlikely to be satisfactory because it is over water, which has a high reflection coefficient. Variations in direct or reflected path conditions when the reflected ray strikes a water surface can cause 'drop outs' during which the signal falls to a very low value. Hence the Blackford Hill site might be chosen as the injection point for this particular O.B., or Kirk O'Shotts if a further intermediate relay point can be set up.

For certain types of broadcast such as the Queen's Christmas Day speech it is essential to have a reserve radio link and Fig. 4.17 shows how this has been carried out. The London and Regional Units

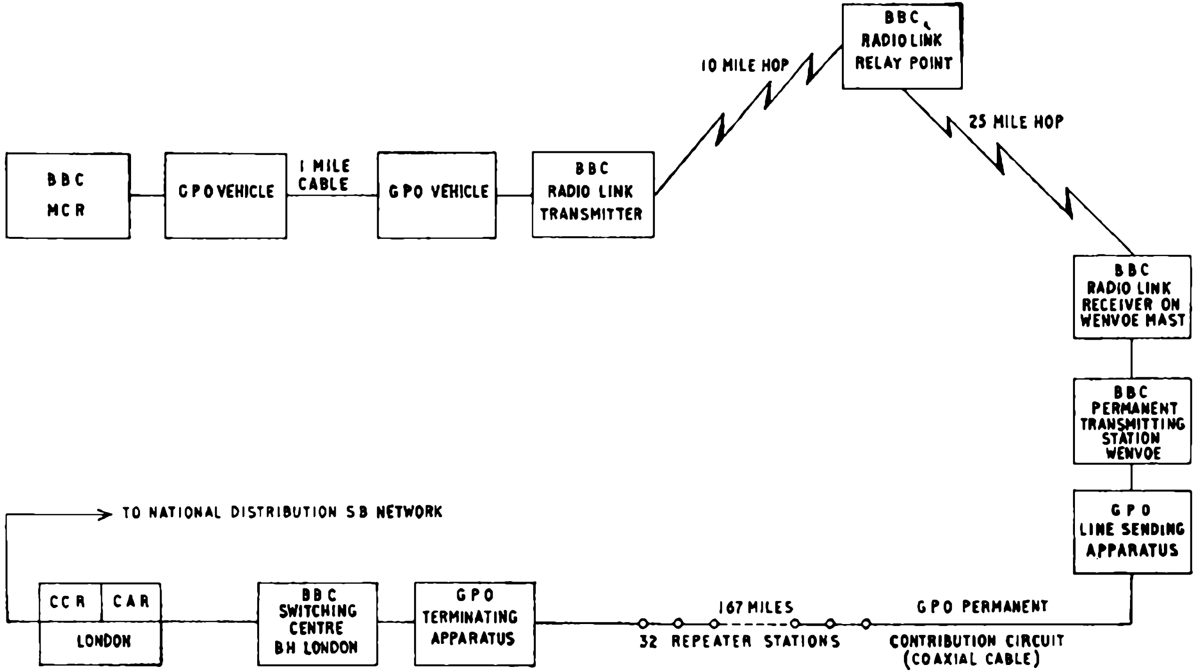


Fig. 4.15 Arrangements for an outside broadcast using a G.P.O. cable and a 2-hop radio link into a high-power transmitter site

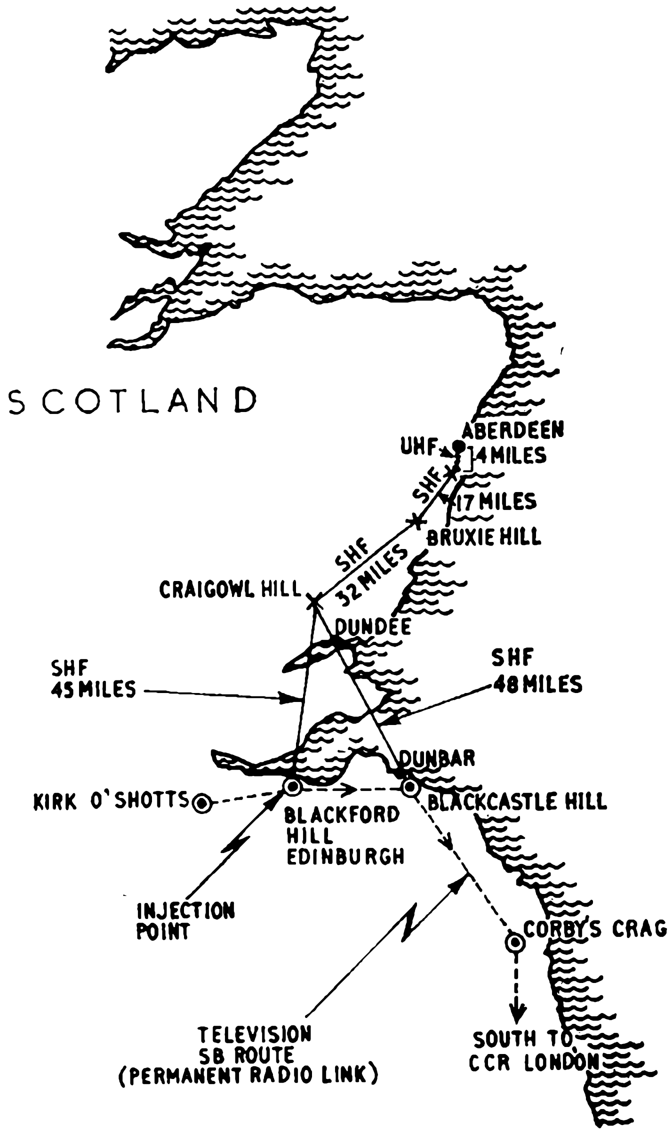


Fig. 4.16. The route followed by a radio link from Aberdeen to the main television distribution network

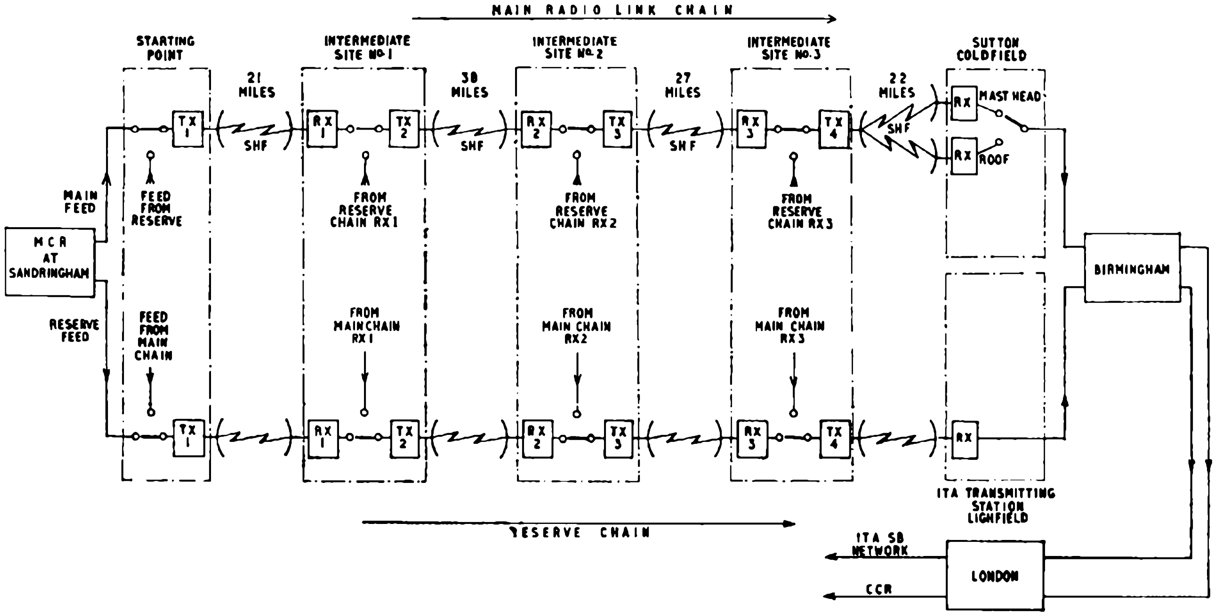


Fig. 4.17. Typical radio link arrangements for the Christmas Day broadcast from Sandringham

co-operate to provide the staff and apparatus for each section of the duplicate link, which in effect makes two completely separate vision chains. One uses the Sutton Coldfield masthead as the injection point to the distribution network and the other feeds to the ITA station at Lichfield, from which there is a reserve line through the Birmingham G.P.O. to the BBC switching centre in Birmingham. The distribution and contribution two-way cable between Birmingham and London takes the vision signal to the Central Control Room, London. Facilities exist at Birmingham and London for changing over from the main to the reserve link so that the maximum flexibility is obtained throughout.

4.10 SPECIAL PROBLEMS

The problems involved in arranging the placing of cameras and microphones and of getting the vision and sound signals to a suitable injection point in the television distribution system have already been outlined, but there are at least two others, namely parking and the weather, that may complicate an O.B. It may be very difficult to find room in a built-up area for five large vehicles such as the mobile control room, auxiliary tender with cameras, microphones, monitors, etc., cable tender, radio-link vehicle and aerial-tower vehicle none of which is less than 20 feet long and all of which must be located within easy reach of each other. Even when a sufficiently large area has been found it may not be possible to park the vehicles in the most space-saving way because the placing of the mobile control room is governed to a large extent by the positions taken up by the cameras and by the location of the nearest power supply. A long power cable should be avoided as it is likely to cause a voltage drop which varies with the load.

The weather can also cause serious embarrassment to O.B. teams on outside events. Excessive sunlight on cameras may raise the internal temperature of the apparatus and affect adversely the resolution of the camera tube. Rain falling on camera lenses causes defocussed spots to appear on the picture. Heavy mist or rain may occasionally affect s.h.f. propagation causing reduced signal strength and on exposed sites strong wind accompanied by rain may force water into the apparatus. Wind can affect the stability of the camera and of the parabolic reflectors used in the radio-link equipment so that great care must be taken to see that this type of apparatus is fastened as securely as possible. Wind can also disturb microphone operation and wind shields may be necessary to counter this. The particular procedure which is to be followed in any given circumstances is usually a matter of common sense and experience.

4.11 EUROVISION

Events taking place in foreign countries often have interest outside their country of origin and to the BBC belongs the credit for pioneering the direct exchange of programmes between European countries. In August 1950 it injected television pictures from France into its own television distribution network. Out of the experiment has grown 'Eurovision' and a television network which allows the exchange of programmes between fifteen European countries. The planning of the technical facilities and the co-ordination of programme material for these is carried out by the European Broadcasting Union office in Brussels. The BBC has set up its own Continental Control Point (C.C.P.) in Broadcasting House, London, to centralise the control of both vision and sound signals of television programmes going to and from Europe. For programmes originating in the United Kingdom facilities exist at the central control point for the simultaneous relay by line of a number of commentaries in different languages. Since the sound facilities of the normal mobile control room cannot cater for these, a separate vehicle, the Foreign Commentary vehicle, is used at the programme site. It has control, cueing and monitoring equipment and can handle up to six commentaries. When the foreign commentator cannot be present at the programme site he may give the commentary at the destination from the received pictures displayed on a monitor, and sound effects may be relayed for superimposition on the commentary.

Outgoing vision signals are routed (see Fig. 4.18) through Continental Control Point by cable to Tolsford Hill near Folkestone from which the signal is sent to Lille on the French side with intermediate relay points at Fiennes and Cassel. The G.P.O. in conjunction with French P.T.T. is responsible for the two two-way radio links operating at about 4 000 Mc/s between Tolsford Hill and Fiennes.

Since three different line standards are employed in Europe, namely, 405 (British), 625 (Continental) and 819 (French) it is necessary to arrange for conversion to different line standards when programmes are being exchanged. Conversion always has to be undertaken when the BBC is receiving programmes from the Continent and this is done at Tolsford Hill by staff and equipment provided by the BBC. When the outgoing signals are destined for 625-line countries the conversion from 405 lines is also often undertaken by the BBC at Tolsford Hill, but when the transmission is for the French 819 lines the conversion is undertaken in France itself. The method of conversion is basically simple. An image-orthicon camera tube is set up in front of a specially adjusted

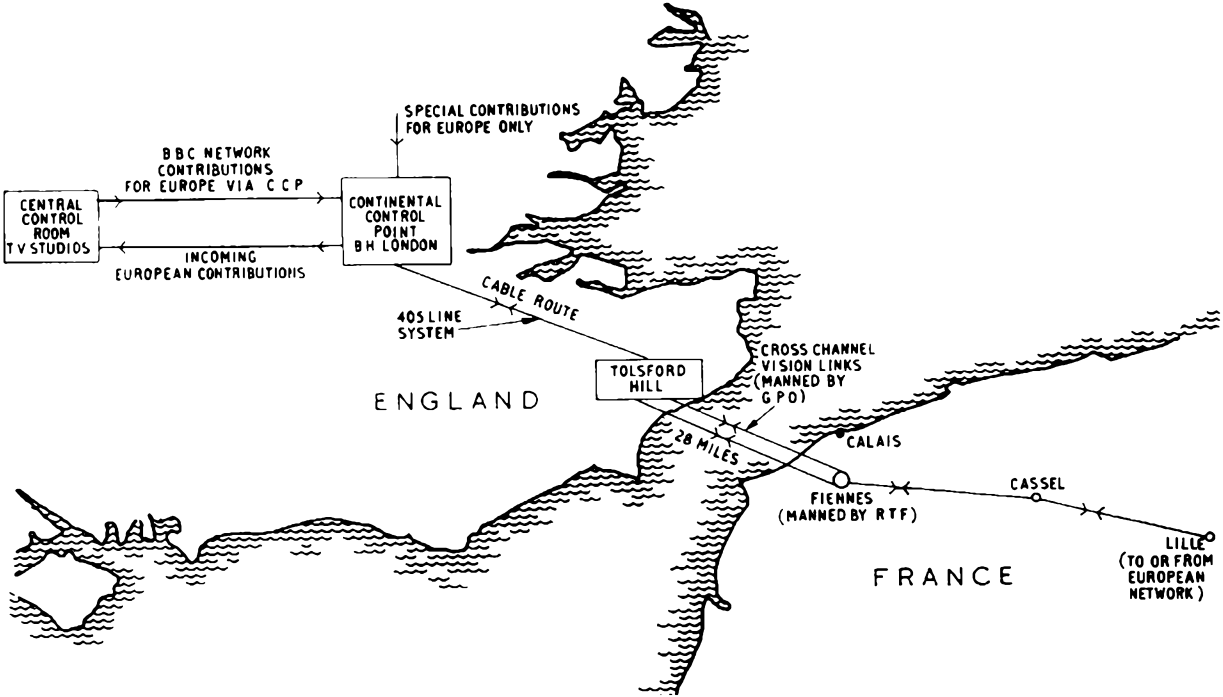


Fig. 4.18. The Eurovision link to the Continent

picture display monitor which is capable of operation on any of the three standard line systems. Image-orthicon tubes (4½-in. target) are used and the conversion adds very little distortion to the picture.

REFERENCES

1. Mayhew, H. E. H., 'Lighting for Television Outside Broadcasts', *BBC Engineering Training Supplement No.* 11.
2. Rendall, A. R. A., 'Temporary Linkages for Outside Broadcast Purposes'.
3. Anderson, W. N., *Proc. Inst. Elec. Engrs.*, *99*, No. 18, Part IIIA, p. 328 (1952).

CHAPTER 5

THE RADIO-FREQUENCY TRANSMISSION OF SOUND AND VISION PROGRAMMES

5.1 INTRODUCTION

THE aim of any broadcasting system is to give the greatest possible coverage within a given (usually national) boundary, and BBC transmitters operating at low, medium and very high frequencies are situated in different parts of the country to ensure that the sound and vision programmes shall be brought to the maximum number of people in Great Britain and Northern Ireland. In addition there are four high-frequency transmitting stations for radiating our overseas programmes to other countries; there are also some low- and medium-frequency transmissions of overseas programmes from Great Britain. The only transmitting and receiving station operated by the BBC outside the United Kingdom is at Tebrau near Singapore, and it acts as a relay for the overseas programmes directed to the Far East and Australia, as well as a relay of Australian programmes to the BBC.

Programme origination and control may take place hundreds of miles from the transmitters and the General Post Office is normally responsible for providing the lines or radio links which carry the programme to the transmitting station. The programme voltage, which even at its maximum never exceeds a value of about 1 volt when received at the transmitting station, has to be amplified and is then used to modulate one of the two characteristics (amplitude or frequency) of a r.f. carrier voltage. The latter is generated by a master oscillator and suitably amplified to the required power. The modulated carrier is applied to an aerial generally designed to radiate in all directions equally; the main exceptions are the high-frequency aerials at the overseas stations for these are 'beamed' to countries for which the programme is intended, and the aerials at certain television stations which, to accord with international agreements or domestic requirements, give reduced radiation in certain directions.

The purpose of this chapter is to describe the essential features of the transmitting equipment necessary to produce and radiate the modulated carriers. To facilitate this, three basic types of transmitters will be considered:

1. High-power transmitters, typical of those that operate at low and medium frequencies carrying the Home, Light and Third and Network 3 programmes, or at high frequencies carrying the many overseas programmes.

2. Transmitters operating at very high frequencies carrying the Home, Light and Third and Network 3 programmes.

3. Transmitters operating at very high frequencies carrying the vision and sound of the Television programmes.

The transmitters listed under 1 and 3 all use amplitude modulation but the v.h.f. transmitters carrying sound programmes (listed under 2) employ a different kind of modulation in which carrier frequency instead of carrier amplitude is varied.

5.2 LOW- MEDIUM- AND HIGH-FREQUENCY TRANSMITTERS

5.2.1 *The Radiated Signal*

The internationally-agreed designations and frequency ranges for low-, medium- and high-frequency broadcasting in Europe are listed below:

Designation	*Frequency Range*
Low-frequency Broadcasting	150–285 kc/s
Medium-frequency Broadcasting	525–1 605 kc/s
High-frequency Broadcasting	6, 7, 10, 12, 15, 18, 21 and 26 Mc/s

Although of different mechanical construction, these transmitters are electrically similar and produce the same type of amplitude-modulated output signal. With no audio-frequency input voltage the transmitter output is a radio-frequency carrier of constant amplitude as shown in Fig. 5.1 (a). Tests are often carried out on a transmitter using a 1 000 c/s audio-frequency tone modulation, Fig. 5.1 (b), instead of programme, and the carrier then varies in amplitude as in Fig. 5.1 (c). The programme signal has a much more complicated waveshape (Fig. 5.1 (d)) and its effect on the carrier is indicated in Fig. 5.1 (e).

5.2.2 *Schematic Diagram of a High-power Amplitude-modulated Transmitter*

Two types of modulation have been employed, namely low-level and high-level. In low-level modulation the final a.f. amplifier is of comparatively low power and its output is used to modulate a low-power carrier in a r.f. modulated amplifier. The modulated output is then amplified in a number of stages before being passed to the aerial; a typical block schematic diagram is shown in Fig. 5.2. Low-level modulation was used in the early transmitters, but because it tends to a low over-all efficiency, all sound transmitters in

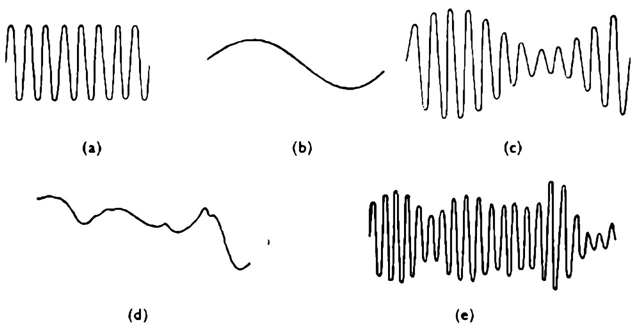


Fig. 5.1. Amplitude modulation of an r.f. carrier wave

normal service are modulated at high level. With this system the final audio-frequency stage modulates the transmitter final amplifier and the output from this amplifier is fed direct to the aerial system, Fig. 5.3. No attempt has been made in Fig. 5.2 or 5.3 to include

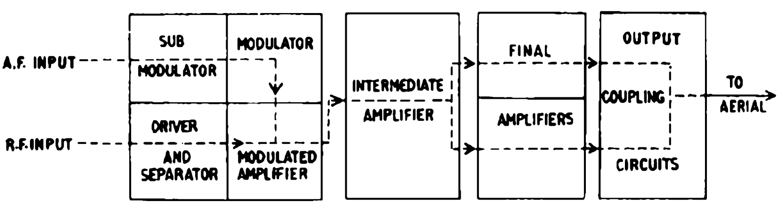


Fig. 5.2. Schematic diagram of a low-level modulated transmitter

the power supplies which are an essential part of a transmitter installation (see Sections 5.2.8 and 5.2.10).

5.2.3 *The Carrier-frequency Drive Unit*[1,2]

The individual units shown in Fig. 5.3 will now be considered in more detail, starting with the drive unit. For synchronisation reasons, BBC medium- and low-frequency (and some high-frequency) transmitters are required to operate at a carrier frequency which must be maintained within a very close tolerance figure (better than the internationally accepted ± 10 c/s), and the carrier frequency error for medium-frequency transmissions is normally kept within $\pm 0{\cdot}05$ c/s, representing an accuracy of the order of $\pm$ 5 parts in 100 million. It is not possible to maintain such a high degree of frequency constancy with a simple *LC* circuit, and the frequency control is effected by means of a quartz crystal.

The quartz crystal is a very stable frequency-control device almost independent of changes that may occur in the external circuit. It is, however, essential to prevent variations in its temperature, and the crystal is usually placed in a constant temperature oven. A schematic diagram of a typical crystal-oscillator unit (Type COU/4) is shown in Fig. 5.4. A valve supplies the power which

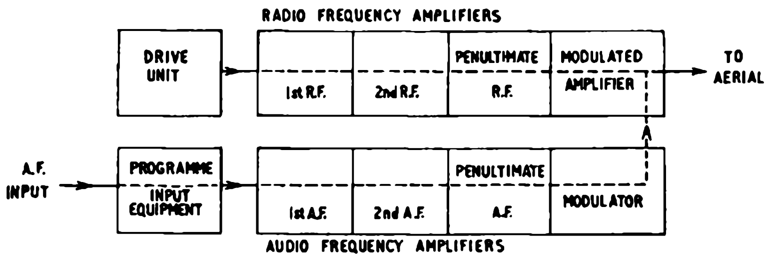


Fig. 5.3. Schematic diagram of a modern high-level modulated transmitter

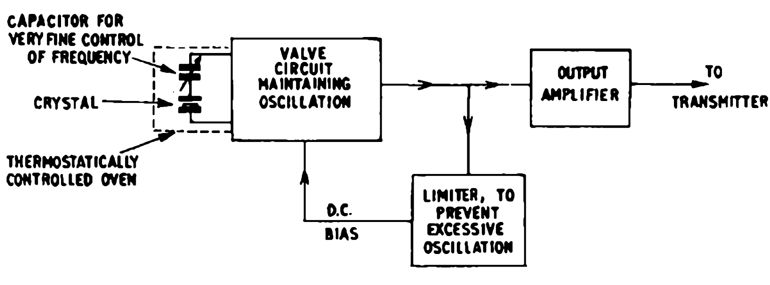


Fig. 5.4. Schematic diagram of a crystal-oscillator drive unit

maintains the crystal in oscillation and some form of limiting circuit is necessary to prevent excessive oscillation amplitude which might cause fracture of the crystal. Crystal control is not at present used to any extent for the drive circuits of high-frequency transmitters because the carrier frequency has quite often to be changed to suit the prevailing ionospheric conditions, and a variable-frequency oscillator using *LC* circuits is employed. Frequency stability is not as high as for the medium-frequency crystal drive, and is of the order of ± 10 parts in one million. A schematic diagram of the variable-frequency oscillator Type VFO/4 is shown in Fig. 5.5. The oscillator covers from 0·7 to 1·4 Mc/s in four separate ranges (for clarity only one *LC* circuit is shown in Fig. 5.5)

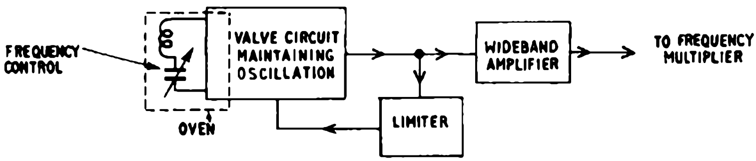
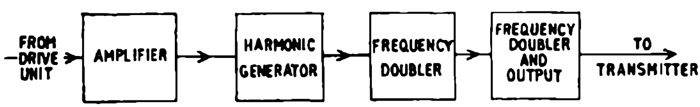


Fig. 5.5. Schematic diagram of a variable-frequency drive unit

and the required carrier frequency is obtained by the use of a frequency multiplier, in which multiplication by 4, 8 or 16 can be selected. The Harmonic Generator Multiplier HGM/4 illustrated in Fig. 5.6 is an example of this. Frequency calibration charts for



Input frequencies	× 1	× 2	× 2	Output
0·7 to 1·4 Mc/s	× 2	× 2	× 2	frequencies
	× 4	× 2	× 2	2·8 to 22·4 Mc/s

Fig. 5.6. Schematic diagram of a harmonic generator multiplier

the oscillator permit a close approximation to the desired frequency to be selected, and final adjustments are made by comparing the selected frequency with an output from a frequency monitor checked against the very stable carrier frequency of the BBC's 200-kc/s transmission from Droitwich.

5.2.4 *Programme Input Equipment*[3]

Programme input equipment consists of a series of amplifiers connected between the incoming line and a.f. input of the transmitter. There are many different types of equipment in use and the schematic diagram shown in Fig. 5.7 is typical of that used at low- and medium-frequency stations.

The repeating coil is a simple transformer used to isolate the amplifiers from the line. As shown in Chapter 2, lines attenuate high audio frequencies more than the lower frequencies and an equaliser having reverse characteristics attenuating the lower frequencies more than the higher frequencies is required between the line and amplifier to restore a flat over-all frequency response up to a frequency of about 8 kc/s. The output from the equaliser is at a very low level and amplification is necessary. This is usually achieved by a general purpose amplifier (GPA/1) having a two-valve

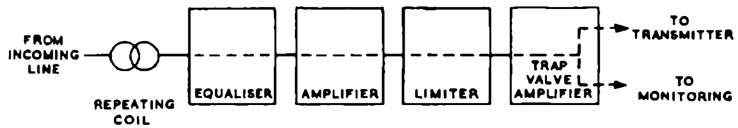


Fig. 5.7. Diagram of programme input equipment for a m.f. transmitter

circuit, a coarse gain control (35, 50, 65 or 80 dB can be selected) and a fine gain control by 2 dB and 0·5 dB steps over a range of 18 dB.

Serious signal distortion and possible damage to the transmitter may occur if an a.f. voltage greater than that necessary to produce 100% modulation is applied to the transmitter, and the programme input often includes a limiter to prevent this. The limiter is essentially a variable-gain amplifier, whose amplification is reduced if the signal exceeds a predetermined voltage. The output from the limiter is usually taken to what is often called a trap-valve amplifier, i.e., an amplifier of low gain (about 0 to +4 dB) providing 2 or more separate outputs. One output is connected to the transmitter and the others are used for monitoring or distribution purposes.

When provision is made for monitoring programmes aurally and visually the arrangements are generally as shown in Fig. 5.8. With aural monitoring a signal voltage is taken from the output of the transmitter or from the aerial to a check receiver or a modulation monitor unit connected to an amplifier and loudspeaker. Monitoring can be carried out at other points in the programme chain to aid rapid fault location. A monitoring amplifier (MNA/1), is included and it may be switched to the input or output of the limiter. A meter indicating programme volume is incorporated and it functions in a similar manner to the Peak Programme Meter (PPM) already described in Chapter 2. The peaks indicated by the PPM during programme depend upon the nature of the programme, news, drama, music, etc.

Fig. 5.8 also shows a Modulation Monitor Unit (MMU/1) which registers the percentage modulation of the transmitter on a meter calibrated from 0 to 100: it depends for its operation on making a comparison between two d.c. voltages, one derived from the carrier, the other from the modulation. The monitoring loudspeaker is normally left connected to the modulation monitor but as shown it can be switched to the output of the line amplifier, limiter or check receiver.

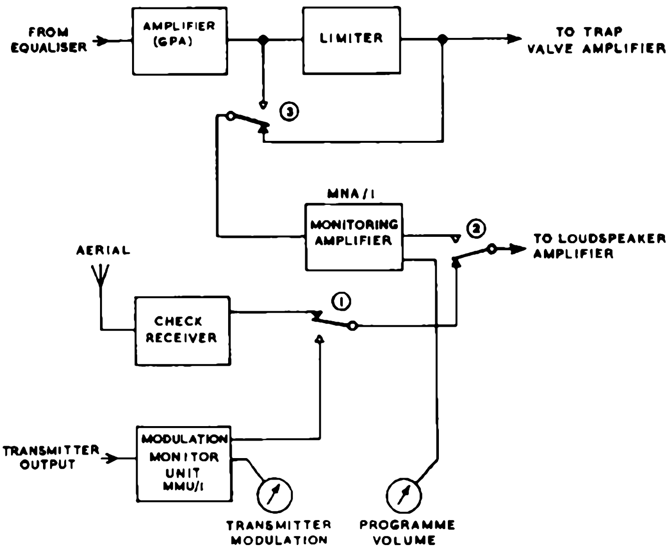


Fig. 5.8. Schematic diagram of monitoring arrangements

5.2.5 *Transmitter R.F. Amplifier Stages*

The initial carrier frequency produced by the drive unit has to be amplified very considerably before modulation is undertaken. Since a comparatively narrow band of radio frequencies has to be amplified resonant circuits may be used as indicated in the simple circuit of Fig. 5.9.

The r.f. input is applied to the negatively-biased grid of a valve whose anode circuit consists of a variable tuning capacitor C and an inductor L. When C is varied, the reading of the ammeter A varies and has a minimum value when the circuit is correctly tuned to the incoming frequency. The reason for this is that the impedance of the anode tuned circuit is at a maximum at the resonance frequency. The magnitude of the maximum value is dependent on any load which may be introduced from the coupled secondary coil, and it is reduced as the loading increases. The advantages of using a tuned circuit are that the peak a.c. anode voltage nearly equals the h.t. voltage and currents at harmonic frequencies are by-passed through the comparatively low reactance of C and produce very little voltage across L. The valve is generally biased beyond cut-off and operates in what is called the Class C condition, thereby achieving an anode conversion efficiency (r.f. output to d.c. input

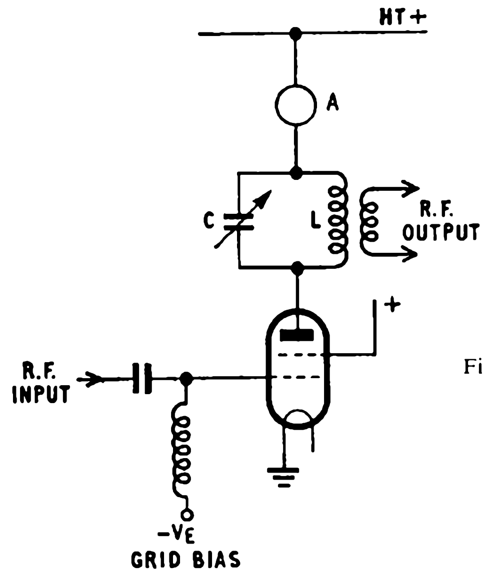


Fig. 5.9. A simple r.f. amplifier circuit

power) of between 65 and 70%. Thus a r.f. power output of 100 kW needs about 150 kW of d.c. power to be supplied to the anode circuit of the final r.f. stage. To handle these high powers an amplifier may have two output valves connected in push-pull or in parallel. The output stage may be series-fed with the LC circuit connected directly in the anode or it may be shunt fed with a r.f. choke in the anode and capacitance coupling from anode to LC circuit. By biasing the valves beyond cut-off, anode current only flows for about one third of the time and takes the form of pulses of current, which can be resolved into

(i) a d.c. component, the value of which is indicated on the ammeter A and which is derived from the e.h.t. supply,

(ii) a fundamental r.f. component which produces the output power at the carrier frequency and

(iii) many harmonic components which are by-passed to earth by the tuning capacitor C.

A tetrode valve is shown in Fig. 5.9 but r.f. power amplifiers normally use triodes. A disadvantage of the triode is that it is possible to feed a voltage from the anode into the grid circuit

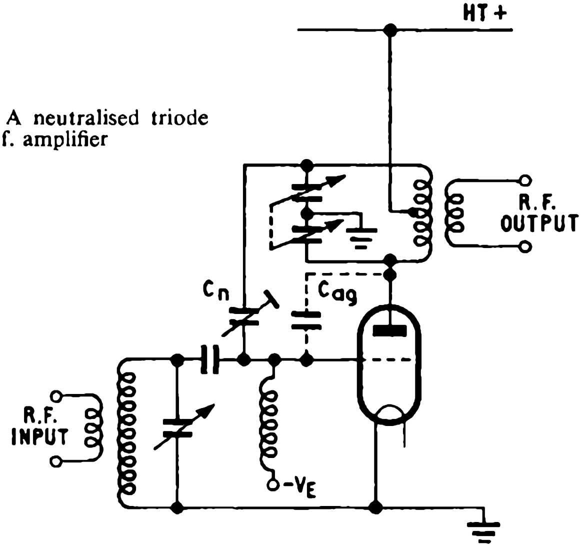
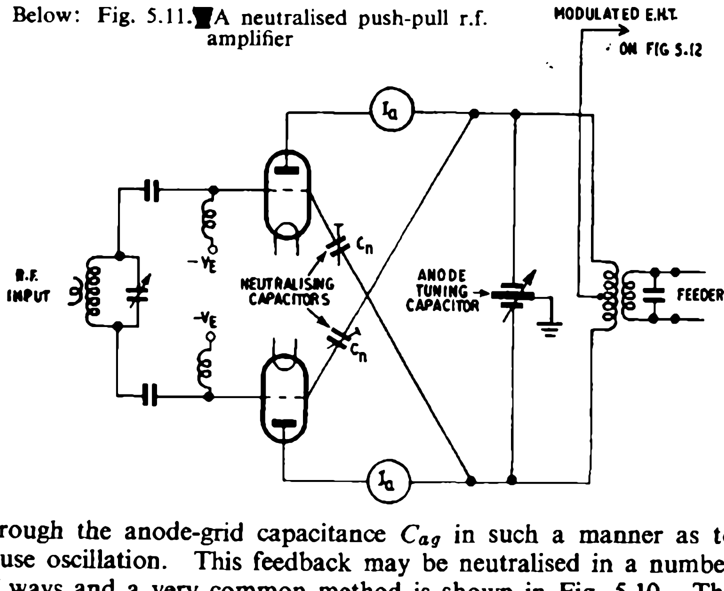


Fig. 5.10. A neutralised triode r.f. amplifier

Below: Fig. 5.11. A neutralised push-pull r.f. amplifier



through the anode-grid capacitance C_{ag} in such a manner as to cause oscillation. This feedback may be neutralised in a number of ways and a very common method is shown in Fig. 5.10. The anode circuit is centre-tapped by applying h.t. to the mid-point of the inductor and by splitting the capacitor. The end of the centre-tapped circuit opposite to that joined to the anode is connected to the grid circuit via a neutralising capacitor C_n. If C_n is made equal to C_{ag} then the voltage across C_n is equal and opposite to that across C_{ag} and there is no feedback voltage between grid and earth. This type of neutralisation is easily applied to the push-pull r.f. amplifier as shown in Fig. 5.11.

In high-power transmitters used for high-frequency operation it is often necessary to change the radiated frequency, and the capacitors and inductors making up the grid and anode circuits must be capable of being changed quickly.

5.2.6 *The Audio-frequency Amplifier and Modulator Stages*

A second set of amplifiers is required in each transmitter to amplify the programme from an a.f. input power of about 1 milliwatt up to the 60- to 70-kW level necessary to modulate a 100-kW

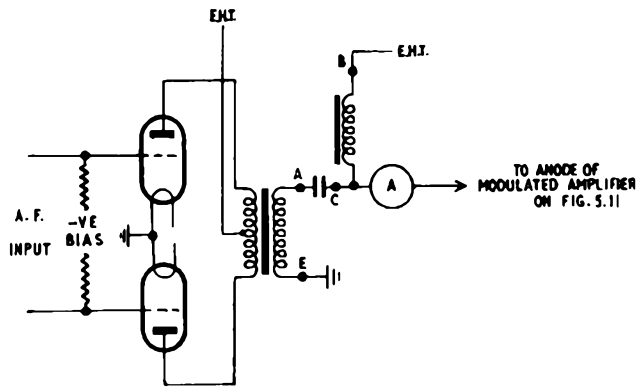


Fig. 5.12. A Class B push-pull modulator stage

r.f. amplifier. The frequencies involved are from approximately 30 c/s to 10 kc/s, and resistance-capacitance, choke-capacitance, or transformer coupling may be employed.

Since harmonic distortion must be kept to a minimum, a.f. amplifier stages generally operate in Class A, i.e., anode current flows all the time: an exception is the final modulator which, being transformer-coupled, can operate in Class B, i.e., anode current flows for approximately half the time. The anode conversion efficiency of such a stage is about 50 per cent, hence to produce about 65 kW of a.f. power requires a d.c. input power of about 130 kW.

Negative feedback is used to improve frequency response and reduce harmonic distortion and amplifier noise.

An example of the Class B push-pull modulator is given in Fig. 5.12, the secondary of its output transformer being connected to the r.f. amplifier (Fig. 5.11) whose anode-voltage it modulates. The secondary of the a.f. transformer is coupled by capacitance to the anode of the r.f. amplifier to prevent the d.c. current of the latter saturating the iron core and to reduce insulation problems. An a.f. choke (called a speech reactor) carries the r.f. amplifier d.c. current. The voltages existing in the circuit of Fig. 5.12 are as shown in Fig. 5.13 (a) to (e). Assuming that tone applied to the transmitter produces a peak a.f. voltage of 11 kV from A to E, the voltage applied to the anodes of the modulated amplifier is the sum of two voltages (d.c. and a.f.) and is shown in Fig. 5.13 (c) to be varying between the limits of 22 kV and 0. The current taken by the modulated amplifier with no modulation is shown in Fig. 5.13 (d) and with full modulation in Fig. 5.13 (e) where it varies from zero to twice the normal value. The d.c. current taken is unaffected by modulation so that there is no change in the reading of ammeter A.

5.2.7 *The Modulated R.F. Amplifier*

The conditions obtaining in the modulated amplifier are illustrated in Fig. 5.14 (a) to (f). With no modulation applied, the d.c. anode voltage on the modulated amplifier is constant (Fig. 5.14 (a)) and the anode current is a series of pulses (Fig. 5.14 (b)), the fundamental component of which produces a sinusoidal voltage (Fig. 5.14 (c)) across the r.f. output circuit (generally called the tank circuit). When the anode voltage is varied by the modulation (Fig. 5.14 (d)) the pulses of current vary in amplitude (Fig. 5.14 (e)) and the voltage across the tank circuit also varies in amplitude (Fig. 5.14 (f)). The amplitude-modulated output is transferred via the feeder to the aerial from which it is radiated.

5.2.8 *Transmitter Power Supplies*

The previous two sections have shown that the d.c. power required to operate a high-power transmitter is considerable, and the modulator and modulated r.f. amplifier stages are the main consumers. Fig. 5.15 summarises the situation in these stages when a transmitter of 100 kilowatts carrier power (unmodulated) is modulated to 100 per cent by tone.

The modulated amplifier operates in the class C condition and the anode current is in the form of r.f. pulses which may reach maximum peak values in excess of 50A. The emission from the filaments of these valves must be high enough to provide this so that appreciable

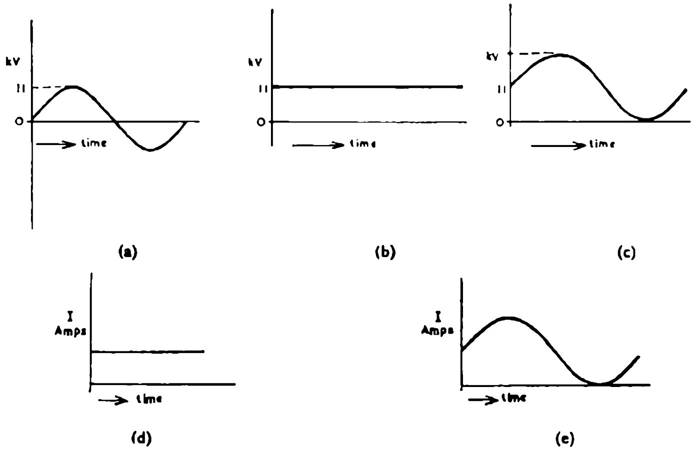


Fig. 5.13. Voltages and currents in the modulation circuit. (a) voltage across the transformer secondary A to E in Fig. 5.12; (b) e.h.t. voltage applied to modulated amplifier B to E; (c) voltage applied to the anodes of the modified amplifier C to E; (d) current shown by d.c. meter (A) with no modulation; (e) current taken by modulated amplifier when modulated as in (c) above

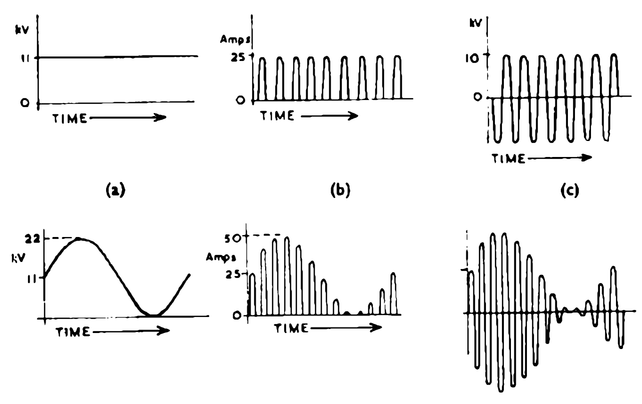


Fig. 5.14. Voltages and currents in the modulated amplifier. (a) unmodulated anode voltage; (b) unmodulated anode current pulses; (c) unmodulated voltage across the tank circuit; (d) modulated anode voltage; (e) modulated anode current pulses; (f) modulated voltage across the tank circuit

filament power is needed; each valve in Fig. 5.11 will require about 5 kW for filament heating. Modulator valves operate in Class B and are not required to give so much power, so that about 3 kW of filament heating per valve is typical. Grid-bias voltages must be provided but little power is involved. Typical voltage and current

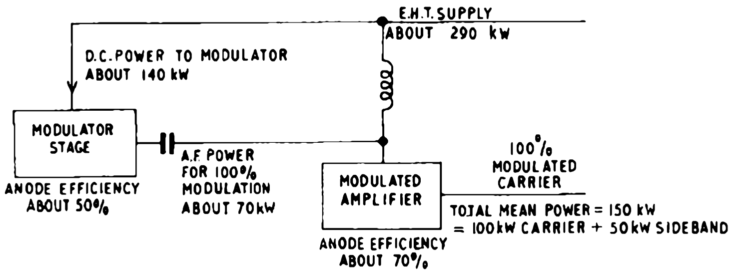


Fig. 5.15. Power requirements of the output stages of a 100-kW transmitter

values for the various stages consuming appreciable power in a 100-kW transmitter are given in Fig. 5.16. It is seen that the e.h.t. supply is required to provide about 30A at about 11 kV, i.e., 330 kW, and the filament supply about 1 200A at 17·5 V, i.e., 21 kW.

E.H.T. Supplies. The e.h.t. supplies are normally produced either by mercury-arc rectifiers or hot-cathode mercury-vapour rectifiers or excitrons. D.C. generators producing e.h.t. voltages have been used in some of the earlier medium-frequency BBC stations but they have a low efficiency compared with the mercury rectifier, and present special insulation design problems. An example of the mercury-arc rectifier is the steel-tank 6-phase rectifier shown in Fig. 5.17 (a). The e.h.t. transformer has a 6-phase secondary winding each phase being connected to an anode. Auxiliary equipment produces an arc in the tank and this initiates the main arc from the cathode to the anode. Each anode maintains the arc for about 1/6 of a cycle of the main voltage, i.e., for 1/300 sec. The cathode-to-earth voltage follows closely that of the firing anode to give the full-line waveform shown in Fig. 5.17 (b). The ripple voltage is removed by the filter, leaving only the d.c. voltage component. The firing of the main arc on each anode is altered by pulses applied to grids (not shown on Fig. 5.17) placed between the cathode and anode, so that control of d.c. output voltage can be exercised. If sufficient negative bias is applied between grid and cathode the main arc can be shut off completely, and this principle is used to provide overload protection. Excessive d.c. current

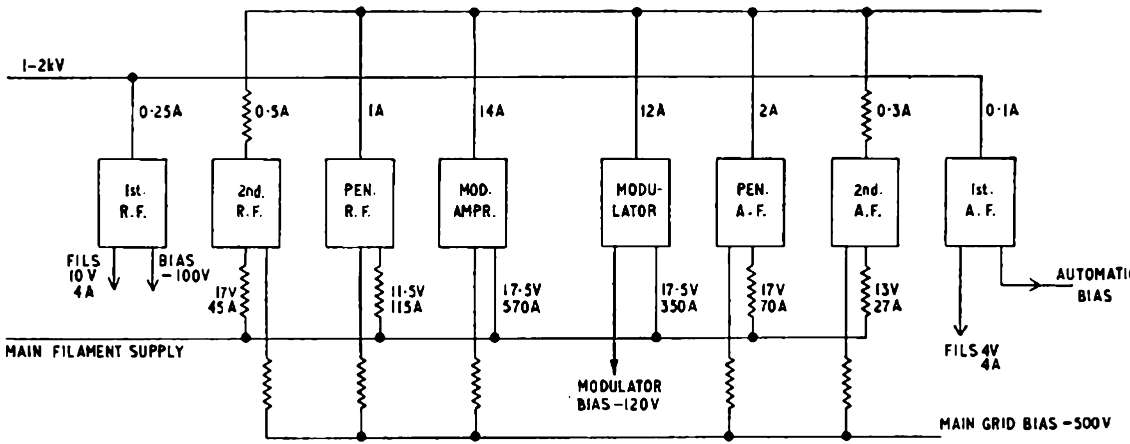


Fig. 5.16. Power consumption of the various stages in a 100-kW transmitter with an e.h.t. voltage of about 11kV

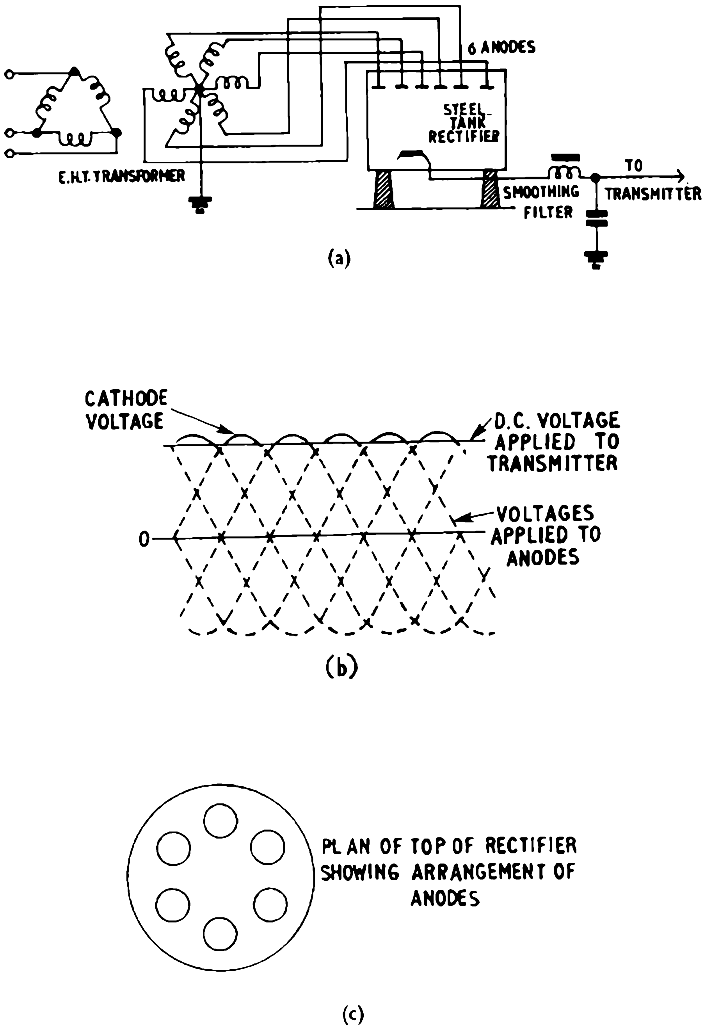


Fig. 5.17. (a) Simplified circuit of a 6-phase mercury-arc rectifier; (b) anode and cathode voltage waveforms

taken by the transmitter operates a high-speed relay which introduces a large enough bias to shut down the main arc and thereby remove the e.h.t. voltage.

Filament Supplies. The filaments of the larger valves in the medium-frequency and high-frequency transmitters are often supplied from a d.c. generator, driven by a 3-phase induction motor. After the motor has reached normal speed, the increase of generator field voltage is performed automatically according to a predetermined time schedule, so that the filament voltage is gradually applied.

Developments in the use of thoriated-tungsten filament valves have reduced the filament power required and some v.h.f. transmitters (sound and television) now employ copper oxide or selenium rectifiers to supply d.c. to the filaments of the output stages. The low-power v.h.f. transmitters often have a.c. heating for the filaments of all stages. Saturated-core transformers are used to maintain constant filament current, a necessary condition for satisfactory valve life with thoriated-tungsten filaments.

5.2.9 *Cooling of High-power Transmitting Valves*

The d.c. power supplied to any valve amplifier is always greater than its output signal power, and the difference between the two

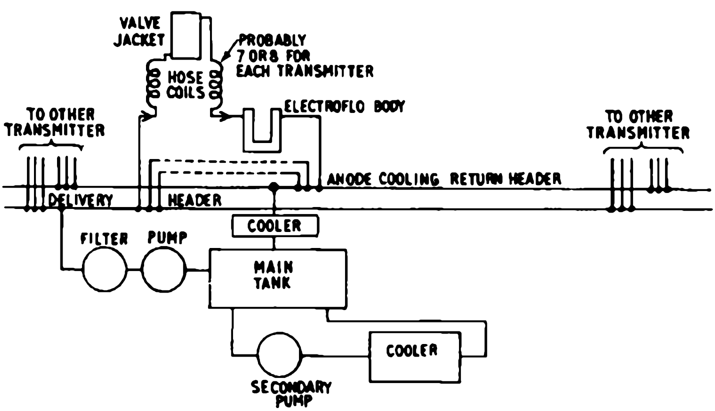


Fig. 5.18. The water cooling system

appears as heat at the anode. Heat is also generated by the filaments and this has to be dissipated as well as that from the anode. A typical output valve of a high-power transmitter may have to dissipate about 30 kW from the anode and 5 kW from its thoriated-tungsten filament, and to do this the anode is enclosed in a jacket through which water circulates at the rate of about 30 gallons per minute. Since the water is in direct contact with the anode (at 11 kV) its insulation must be high: distilled water is employed and conveyed to the anode water jacket by long hose-pipes of high insulation. The filament seals into the valve are usually cooled by an air blast.

A diagram of a typical cooling system is given in Fig. 5.18. There is a main storage tank from which the water is pumped to the valves via a filter; from the valve anodes it returns through a waterflow

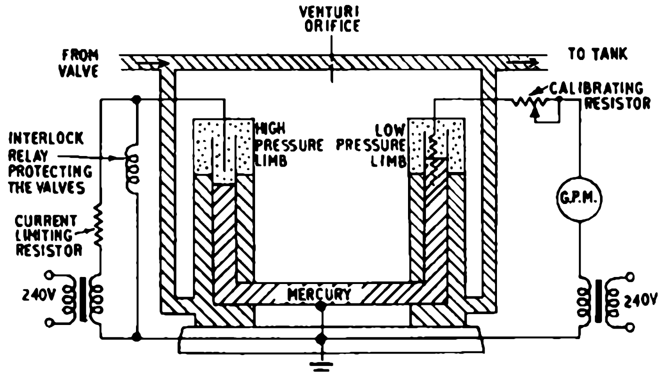


Fig. 5.19. The Electroflo body

meter called an Electroflo body to the cooler and then to the storage tank. The Electroflo body, shown in Fig. 5.19, performs two functions: it meters the waterflow and it protects the valve against failure of waterflow. A Venturi orifice in the waterflow line produces a difference in pressure, which is registered on an associated mercury manometer, the mercury being separated from the water by a liquid insulator. When the water is flowing the contact in the high-pressure limb is clear of the mercury, and the mercury in the low-pressure limb submerges and so short-circuits more of the resistance in series with the meter calibrated in gallons/minute. If the waterflow falls to about one third of normal, the mercury level rises to close the high pressure contact and short-circuits a protecting relay which cuts off the e.h.t., auxiliary h.t., grid bias and filament supplies.

The problem of cooling can be greatly simplified if the d.c./a.c. conversion efficiency of the r.f. amplifier is increased, for the heat dissipated at the anode of the valve is then reduced. This can be realised with r.f. amplifiers operating in the Class C condition if circuits tuned to harmonics of the r.f. fundamental are included between the tank (load) circuit and the anode of the valve, and if the waveshape of the driving voltage is suitably modified. The shapes of the anode voltage and current waveforms are flattened by this procedure so that minimum voltage and maximum current are maintained together over an appreciable part of the cycle. An anode d.c./a.c. conversion efficiency of about 90 per cent can be approached and the heat dissipated by the anode is appreciably reduced—to between $\frac{1}{2}$ and $\frac{1}{3}$ of that normally obtained with a Class C amplifier operating at an efficiency of about 70 per cent. A 50 kW transmitter using such an output amplifier requires only a small air-blast cooling system.

Another important development in valve cooling is to allow steam to be generated at the water jacket. The valve anode has a sheath with tooth-like projections and it operates at a temperature above the boiling point of water. The sheath is immersed in water and a continuous flow of steam is generated, a staggered arrangement of the teeth on the sheath ensuring quick removal of the steam. The water container, known as the boiler, surrounds the valve and the steam leaves from the top of the boiler and passes through an electrically-insulating section to a condenser, where the steam is converted back to water to return to the boiler via a second insulating section. The system is completely enclosed and no rotating machinery is needed. A small constant-level supply tank is included to control the level of the water, and is fitted with a visual water-level gauge and two safety contacts. One safety contact sounds an alarm and the other opens the filament interlock line if the water level falls too low.

5.2.10 *Protective Interlock Circuits*

It is obvious that with the high voltages and powers involved, every possible precaution must be taken to ensure that a transmitter is made safe to handle, but this does not absolve staff from studying and applying the rules contained in the *BBC Safety Regulations for Engineering Staff*, a booklet with which they are all supplied on entry to the Corporation. To achieve a high safety factor, transmitters contain a large number of interlock circuits which are specifically designed to protect personnel and equipment, and Fig. 5.20 indicates the essentials of a typical interlock system. The main interlock supply has three branches, one for the low-power filaments, which can be switched on immediately with the interlock supply, a second controls the main filament supply, and a third, the last to be completed, controls the grid bias, auxiliary h.t. and e.h.t. supplies.

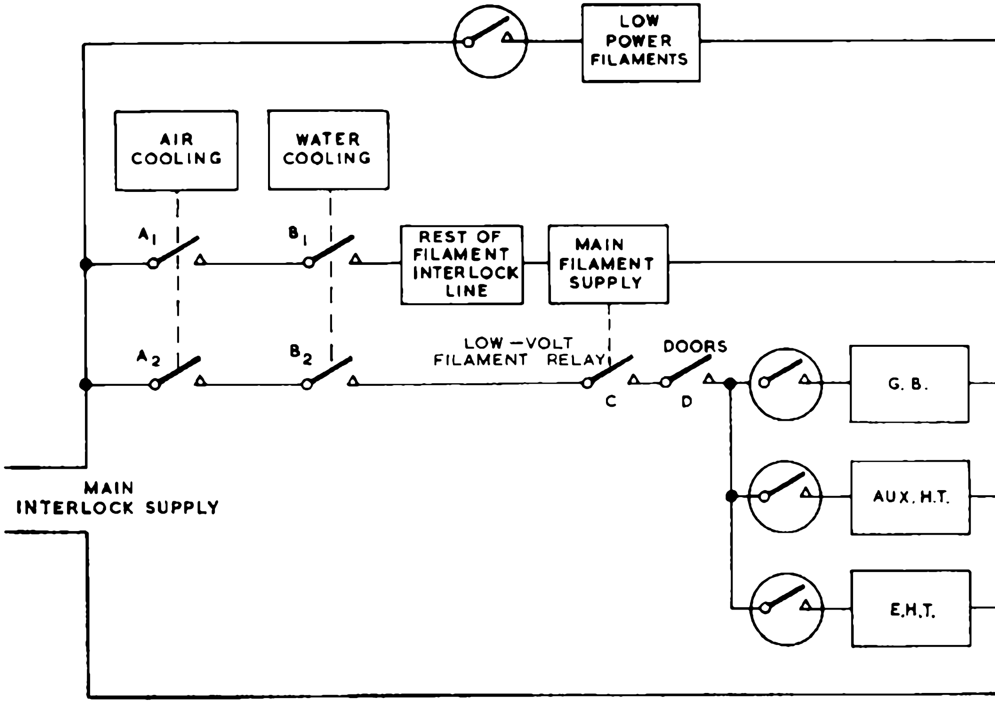


Fig. 5.20. The main circuits of an interlock system

Some valves require air as well as water cooling, and the blowers must produce sufficient air pressure to close the first switches, A_1A_2, in the main filament and e.h.t. interlock lines. Anode cooling water must be flowing satisfactorily before the electroflow bodies allow the master waterflow relay to close the second contacts B_1B_2. Closing of contacts A_1 and B_2 allows the motor of the motor-generator filament supply to be started up and the sequence of operations to be initiated for gradually bringing the filaments to full power. When the filament voltage is at about two-thirds of its normal value the filament low voltage relay closes contact C in the e.h.t. interlock line.

Up to this point, the main purpose of the interlock circuit has been to protect equipment, and now protection of personnel is introduced, for all doors must be closed and locked and aerial feeders selected before the contact D can close to enable high voltages to be switched on. The grid bias, auxiliary h.t. and e.h.t. are switched on separately but certain contactors must be closed before this can finally be done. These contactors operate from mains overloads and valve-protection relays and perhaps lightning-protection relays. Visual warning to personnel is given by the Red-Green light system. E.h.t., auxiliary h.t. and grid-bias voltages must be switched off before the transmitter doors can be opened, but even when these are removed there are still potentially dangerous voltages inside the transmitter, for example on the auxiliary contacts of filament interlock switches and on primary terminals of filament transformers. Such terminals and contacts should be known and carefully avoided. Not until all dangerous voltages have been removed is the red light extinguished and the green light switched on.

Power is supplied by the local Electricity Board from the 3-phase 50 c/s Grid system at a voltage of 11 kV or 22 kV, usually by a duplicate set of feeders terminating in a sub-station. Transformers in the sub-station step-down the voltage for distribution to 415 V, and most parts of the power distribution system can be isolated by means of oil circuit-breakers; the conditions covering manual operation of these circuit-breakers are very rigidly defined at each station.

Some stations are provided with diesel-alternator sets so that the transmitters can continue to operate even when there is a failure of the public electricity supply. When the supply is restored, the transmitter may have to be shut down and repowered or in some cases it may be permissible to bring the diesel-alternator into synchronism with the restored supply and then transfer the load without shutting down the transmitter. When this has been done the alternator is switched out of circuit and the diesel plant closed down.

5.3 V.H.F. TRANSMITTERS USING FREQUENCY MODULATION[4]

5.3.1 *General Considerations*

The range of frequencies allocated to sound broadcasting in the v.h.f. band is 87·5 to 100 Mc/s. The need for transmitting the BBC sound programmes at v.h.f. has already been explained in Section 1.7.2. The medium-frequency transmission is reasonably satisfactory during the daytime when the ground wave from the aerial is practically the only means of propagation, the rays from the aerial going skywards being absorbed in the lower part (D layer) of the ionosphere. After sunset the D layer disappears and sky waves are reflected from the E layer with little attenuation up to ranges of as much as 1 500 miles; thus transmitters working on the same frequency and spaced hundreds of miles apart may seriously interfere with each other after sunset, whereas during the day there is little or no interference. V.H.F. signals have the advantage that they have a limited range and are practically unaffected by any ionospheric changes so that v.h.f. stations spaced many miles apart do not interfere with each other even though they are operating on the same frequency. They are affected by conditions in the troposphere, that portion of the earth's atmosphere close to the earth. It sometimes happens that non-turbulent and quiet conditions with temperature inversion prevail, and then a radio 'duct' may be formed. The v.h.f. wave may be propagated for a long distance as if in a waveguide and it can interfere in the service areas of distant stations that are normally free from interference. There is a certain degree of bending of the direct waves from the aerial but nevertheless shadows are produced behind high hills and a considerable reduction in field strength can occur in hilly country to produce pockets of low field strength. No such situation arises with medium waves which are largely unaffected by hills or mountains.

It was explained in Section 1.7.2 that frequency modulation is entirely different in character from amplitude modulation, and since the effect of noise is mainly to amplitude-modulate the receiver carrier, it is possible in the f.m. receiver to discriminate in favour of the programme against the noise. This means that satisfactory signal-to-noise ratio can be achieved at the receiver even when the field strength is quite low. A service using frequency modulation can be satisfactory with a received field strength of the order of one-tenth of that necessary if amplitude modulation is used. Thus the area served by a frequency-modulated transmission is very much greater than that served by an amplitude-modulated transmission using the same power, carrier frequency and aerial. An added advantage is that the frequency-modulated transmitter is much less costly than an a.m. transmitter of the same carrier power. A price has to be paid for this improved signal-to-noise ratio and it is through increased bandwidth; a frequency-modulated transmission requires about five times the over-all bandwidth of that of a similar a.m. transmission. This can generally be tolerated in the v.h.f. range because the frequency spectrum is much wider and there is no interference from sky-wave propagation. The radiated signal is quite different from that radiated by a medium-frequency installation.

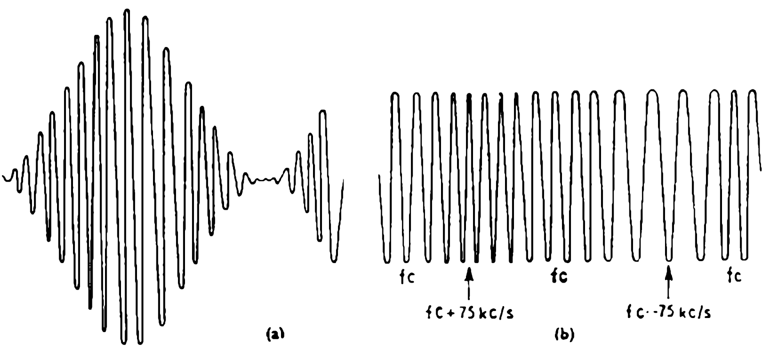


Fig. 5.21. Examples of (a) amplitude-modulated wave and (b) frequency-modulated wave

The carrier amplitude is constant and the frequency of the carrier is varied in accordance with the modulation. A pictorial representation of an amplitude-modulated and of a frequency-modulated wave is given in Fig. 5.21.

5.3.2 *Schematic Diagram of a F.M. Transmitter*

In most v.h.f. transmitting stations six transmitters are in use, two each for the Home, Light and Third Programme. The outputs from one transmitter of each pair are combined and fed into half the aerial system, and the outputs from the remaining transmitters are combined and fed to the other half of the aerial system. This means that the transmitters on each frequency are effectively operating in parallel and if one transmitter of the pair fails, the power fed to the aerial is reduced by 3 dB but the effective radiated power is reduced by a further 3 dB (total 6 dB), because of a change in the vertical directional characteristic of the aerial since only half the aerial is being powered. Fig. 5.22 gives the schematic diagram of the transmitters. If the Third Programme transmitters are operating at a frequency of f Mc/s, then the Light Programme

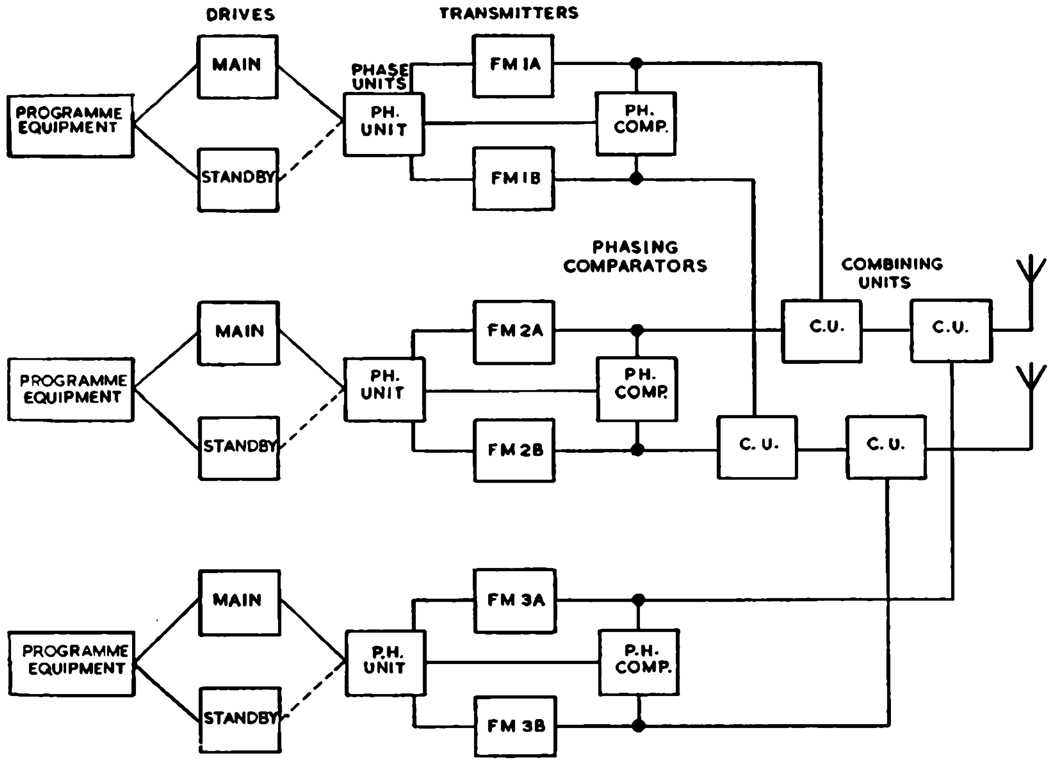


Fig .5.22. Schematic diagram of a 3-programme v.h.f. system using paralleled aerials transmitters operate at a frequency of f $-2{\cdot}2$ Mc/s and the Home Service ones at $f+2{\cdot}2$ Mc/s.

It is absolutely essential that the outputs of the transmitters radiating the same frequencies from the aerials should be in phase with each other, otherwise the field strength received at a distant point may be appreciably reduced. A check is made of phase relationship, one transmitter being used as the reference and the other having its phase adjusted in a phasing unit containing a variable reactance, feeders between sampling points and aerials which have been carefully adjusted for equal electrical length.

5.3.3 *The F.M. Carrier-frequency Drive Unit*

Since the carrier frequency has to be varied, the drive unit must be quite different from that of the amplitude-modulated transmitter and the main problem is to produce an oscillator which has a stable mean-frequency value but which can be varied instantaneously by the modulating signal. An oscillator using an *LC* circuit can easily be frequency-modulated but it generally has poor frequency stability. A crystal-controlled oscillator, on the other hand, has good stability but is more difficult to modulate. Both types of drive are in use by the BBC, and before giving a brief description of these two circuits it is important to consider the method of producing the variable reactance causing the frequency of the carrier to be modulated.

As mentioned in Section 1.7.2, a valve is used for this purpose and the fundamental circuit is shown in Fig. 5.23 (a). The reactance valve itself and its associated circuit are placed in parallel with the tuned circuit of the oscillator. Z_1 and Z_2 are two impedances between which there is an approximate 90° relationship. For example Z_1 may be a capacitive reactance $(-jX)$ and Z_2 a resistor, R. The method of operation of the variable reactance valve is best shown by reference to the vector diagram of Fig. 5.23 (b). The reactance X has a much higher value than the resistance R so that the current flowing through X and R is practically 90° ahead of the r.f. tuned circuit voltage E. This current I_1 produces a voltage across R which is in phase with it and this acts as a grid voltage drive to the valve.

The anode current change in the valve is in phase with the grid voltage and is therefore nearly 90° leading on the radio-frequency voltage. This means that the valve circuit looks like a capacitance. If the gain of the valve is varied by an audio-frequency voltage the magnitude of the anode current change will also be varied, and the valve appears as a variable capacitance directly proportional to the audio-frequency voltage change—the condition

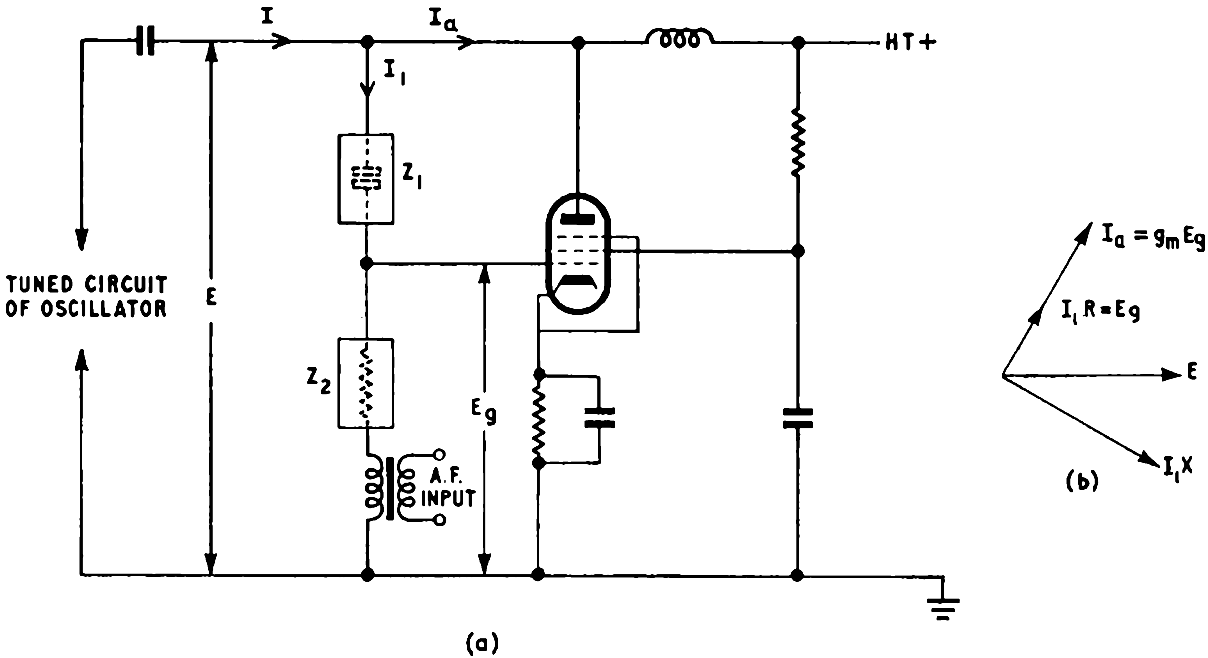


Fig. 5.23. A reactance valve circuit

for correct frequency modulation of the oscillator. Owing to the fact that the current through Z_1 and Z_2 is not exactly 90° ahead of the voltage across Z_1Z_2, a resistance component is introduced into the impedance presented by the valve, and this may cause amplitude modulation of the oscillator. Various circuits are available for reducing or neutralising this effect and the use of two reactance modulators in push-pull is helpful.

Turning now to the drive circuits themselves and dealing first with the crystal-controlled drive oscillator there is the Marconi FMQ. This uses a crystal which oscillates at 1/24 of the final carrier frequency and it is specially cut to avoid any spurious resonances occurring over the frequency band covered by modulation. Multiplication of the oscillator frequency by 24 to bring it to the correct carrier frequency also multiplies the frequency deviation, so that if the final deviation is to be ± 75 kc/s, then the deviation required at the original oscillator circuit must be 75/24 = $\pm$ 3·125 kc/s.

The advantage of this method is that the carrier mean frequency has a stability equal to that of the crystal, which is quite high and certainly within the limits normally specified.

The other type of drive unit employed in the S.T. and C. transmitter is a simple *LC* oscillator frequency-modulated by a push-pull reactance modulator. The centre frequency of the oscillator is compared against a crystal-controlled oscillator, and any error between the two operates a motor to which is connected a variable capacitor across the oscillator tuning circuit. Drift of oscillator frequency causes the motor to rotate and alters the capacitor to restore the oscillator to its original frequency. A schematic diagram of the system is shown in Fig. 5.24. The reference oscillator operates at a frequency of 15 kc/s and an output from the main oscillator drive is applied to a frequency changer which gives an output at a frequency of 7·5 Mc/s whatever may be the main oscillator nominal frequency. The oscillator associated with the frequency changer is crystal-controlled. The 7·5-Mc/s output is divided down to 15 kc/s and is then compared against the crystal oscillator. Any difference in frequency causes power to be supplied to the motor operating the main oscillator tuning capacitor.

The final carrier-frequency output is fed to phasing units and from there to the two transmitters feeding each half of the aerial. Outputs from each of the transmitters are applied to a phase comparator which produces a d.c. voltage when they are out of phase, the polarity of which changes when one voltage leads or lags on the other. This polarised d.c. output is used to control a motor driving capacitors in the phasing network in such a direction as to bring the

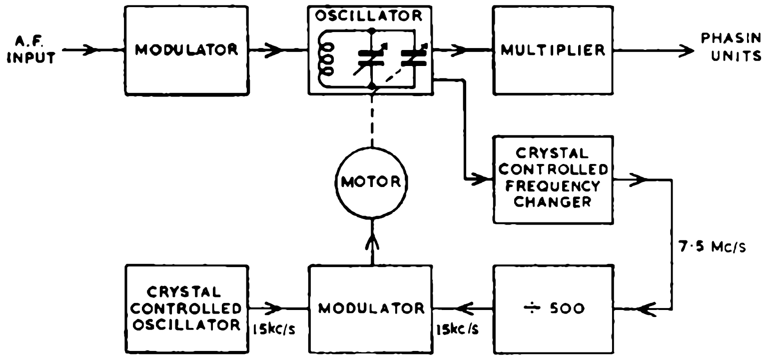


Fig. 5.24. Schematic diagram of the mean frequency control circuit for an LC oscillator f.m. drive

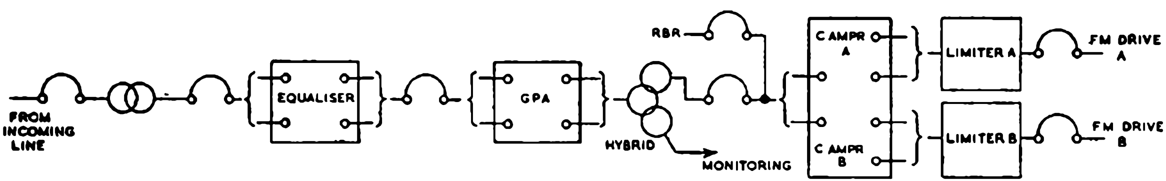


Fig. 5.25. Schematic diagram of the programme input equipment for an f.m. transmitter

voltage of one transmitter into phase with the other, which acts as a reference.

5.3.4 *Programme Input Equipment*

The programme input equipment between the incoming programme line and the transmitter audio-frequency input is made as simple as possible; a schematic diagram is given in Fig. 5.25. A standby C amplifier and limiter are provided and to prevent complete loss of programme if the incoming programme line fails, rebroadcast receivers (RBR) are kept in readiness at the f.m. stations. The Light Programme is made available from the Droitwich 200-kc/s long-wave transmission, and m.f. or v.h.f. receivers (depending on local conditions) are used to obtain Home Service and Third Programme spare feeds. The output from the rebroadcast receiver serves as the input to the C amplifier, when RBR is providing the programme.

5.3.5 *The R.F. Amplifier Stages and Power Supplies*

Multiplication of the carrier frequency from the drive unit is achieved in over-biased valve stages acting as non-linear amplifiers. Their anode tuned circuits select the particular harmonic frequency that is required. The power output of the final multiplier stage is about 10 watts and amplifiers are required to raise this to the final output which for the high-power transmitters is 4·5 or 10 kW. The Marconi transmitters employ two low-power push-pull stages with tetrode valves after the multipliers. Next are two single-ended earthed-grid amplifiers in cascade using coaxial-line type tuned circuits. The final stage is also earthed-grid with two of the same type valves in parallel. Special precautions are taken to ensure that the paralleled valves share the load equally. The main e.h.t. is obtained from a 3-phase full-wave rectifier circuit using xenon valves, reduced voltage for the auxiliary h.t. supply being obtained from the star point of the secondary of the e.h.t. transformer.

The S.T. and C. transmitters employ three cascade stages of single-ended circuits with a.c. heated thoriated-tungsten-filament valves having air-blast cooling. The first stage is a tetrode which is neutralised, but the last two are earthed-grid triode stages. The tuned circuits are made up of coxial lines tuned by rotating loops. The first two stages require 2·5 kV for their anode voltages and the final stage 6 kV, derived respectively from 3-phase full-wave selenium and Xenon rectifiers. The filaments of the Xenon rectifiers are maintained at 80% of their normal voltage when the transmitter is switched on but not powered. The remaining supplies to the transmitter are obtained from an a.c. regulator and when the transmitter is switched to OPERATE, the regulator gradually increases the voltage from zero to the full value. The regulator returns the voltage to zero when fault conditions develop.

5.3.6 *Protective Interlock Circuits*

The interlock systems of the two types of high-power transmitter are fundamentally different. The Marconi transmitter uses sequential switching and it is not possible to obtain a given supply unless all previous supplies are functioning correctly. The switch sequence can be made manually (local control) or automatically (remote control), and the operational procedure is as follows: the 50-volt interlock control voltage is switched on and this actuates the blowers for air-blast cooling; the air-pressure closes the 'air' switch in the filament lines. The latter incorporates a time-delay circuit which prevents the e.h.t. circuits being switched on immediately. Another time-delay circuit is included to prevent the application of the full e.h.t. voltage. The 3-phase e.h.t. rectifier transformer is initially powered on two phases only and the time delay connects the third phase to give full power.

The S.T. and C. transmitter uses a voltage regulator to control the filament voltages for the main amplifier valves and also the e.h.t. and auxiliary h.t. voltages. The voltage regulator is operated automatically to raise the supply voltage from 0 to 415 volts in 30 seconds. It is brought into action either manually or by time switch and has protective overload circuits which reduce the voltage to zero if a fault develops. The drive and low-power stages derive their supplies direct from the mains and are not controlled by the voltage regulator. The filaments of the xenon e.h.t. rectifiers receive 80% of the voltage direct from the mains, the additional 20% being derived from the voltage regulator. The drive and low-power stages and the xenon rectifier filaments are normally powered continuously so that the only operation required is to close the voltage regulator switch.

5.3.7 *The Aerial Combining Unit*

The outputs of the three transmitters carrying the three programmes are combined in bridge-type circuits similar to those (Section 5.4.12) used for adding the sound carrier to the vision carrier in a television transmitter. Two transmitter outputs at f_1 and f_2 (or f_3 and f_2) are first combined in one bridge circuit and the combined output together with the output at f_3 (or f_1) is applied to a second bridge circuit. The output of the latter containing f_1, f_2 and f_3 is then connected to the feeder.

5.4 TELEVISION TRANSMITTERS

5.4.1 *The Radiated Signal*

The television waveform has already been discussed in 1.5.3 and has been shown to consist of synchronising pulses and the picture signal. The modulated waveform of all BBC television transmissions has maximum carrier amplitude for peak-white signals and minimum carrier amplitude during the synchronising pulses; this is known as positive modulation. The method used in America and in some European countries involves negative modulation with maximum carrier amplitude during synchronising signals and minimum carrier amplitude at peak white.

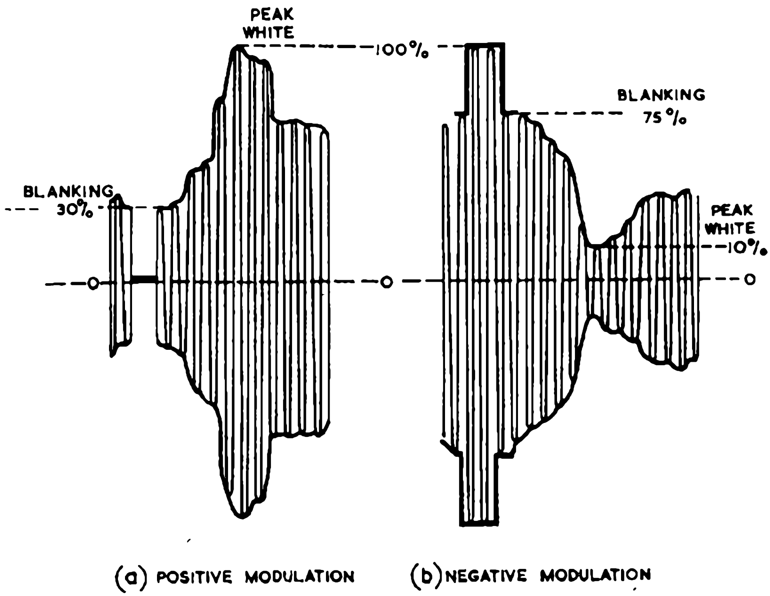


Fig. 5.26. Waveform (a) for positive modulation; (b) for negative modulation

With the positive modulation system used by the BBC the transmitters are modulated from about 2 per cent during the synchronising pulses up to 100 per cent at peak white with 30 per cent corresponding to blanking level as shown in Fig. 5.26 (a). With the negative modulation system used in America, the transmitters are modulated from 100 per cent during the synchronising pulses down to about 12 per cent at peak white as indicated in Fig. 5.26 (b).

Since the modulating waveform can contain frequency components up to 3 Mc/s, double sideband transmission would require a bandwidth of 6 Mc/s, plus spacing for the sound channel. It has been found that quite successful television transmission is possible when the carrier, one set of sidebands and only a small part of the lower frequency components of the other are transmitted. This vestigial-sideband method reduces the required bandwidth to about 4 Mc/s and it is used on all BBC television transmitters. Fig. 5.27 illustrates the frequency ranges covered by Channels 2 and 3.

5.4.2 *Schematic Diagram of a Vision Transmitter*

In section 1.7.2 it is stated that amplitude modulation could be obtained by varying the h.t. or the grid voltage of a carrier-frequency

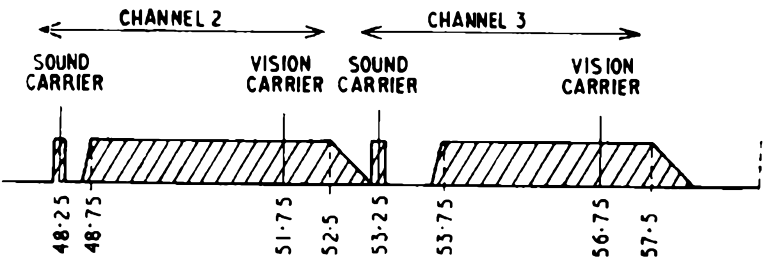


Fig. 5.27. The frequency ranges in Mc/s for the television and sound transmitters in channels 2 and 3

amplifier stage. In modern sound transmitters e.h.t. variation to the final stage is employed because it gives low distortion and a slightly higher overall efficiency. Grid-voltage variation is unsatisfactory for sound transmitters because it is not possible to secure a high modulation percentage without appreciable harmonic distortion of the modulation envelope. Harmonic distortion of a video waveform has relatively much less effect on the reproduced image, and that caused by grid modulation can be largely corrected by predistortion of the video signal in the opposite direction before using it to modulate the r.f. carrier. Grid modulation of television transmitters is therefore normal practice, and it has considerable advantages in that the power required to modulate the grid of a high-power output valve is very much less than the power required to modulate the anode. Furthermore it would be very difficult to obtain a very high power output together with a frequency response up to 3 Mc/s. Modulation of the grid of the output stage (known as high-level modulation) leads to high efficiency in the r.f. output amplifier, but requires a fairly high power output from the modulator stages. A satisfactory alternative is to modulate the grid of an r.f.

amplifier prior to the output stage; this method known as low-level modulation simplifies the design of the video amplifier without appreciably changing the overall efficiency.

High-level and low-level modulation methods are both in use, but the majority of transmitters use low-level modulation. Fig. 5.28 shows a simplified schematic diagram of a typical medium-power television transmitter employing low-level modulation. Two stages of r.f. amplification follow the grid-modulated amplifier, which is coupled to a modulator stage with cathode-follower output. The features of various stages shown in Fig. 5.28 will now be discussed.

5.4.3 *The Vision Carrier-frequency Drive Unit*

Television transmitters operate at fixed frequencies and a crystal-controlled drive is usually employed. It is broadly similar to that used for the medium-frequency sound transmitters but has to be followed by a series of multipliers to bring the oscillator frequency of about 5 Mc/s up to the final carrier frequency of about 50 Mc/s. In Band I there are five channels allocated to the BBC for vision and sound, and these have to be shared by over 20 transmitters. Interference between transmitters on the same channel is reduced by slightly off-setting the carrier frequencies; for example, in Channel 2 the high-power vision transmitter on 51·75 Mc/s, shares with medium- and low-power vision transmitters operating at 51·75 Mc/s $\pm$ 6·75 kc/s. The carriers of the associated sound transmitters are offset 20 kc/s in frequency.

5.4.4 *Vision Input Equipment*

The television programme is distributed to the transmitting stations by P.O. coaxial cable or radio link, or by BBC radio link or direct pick-up, and a peak-to-peak (p-p) signal of about 1 volt is available at the input of the Vision Input Equipment. This is connected to a BBC standard distribution amplifier[5], which provides four outputs at 75 Ω and a p-p voltage of about 1 volt. One of these outputs supplies the transmitter multi-stage video amplifier. The first stage is a linear amplifier but in the second and third stages modifications are made to the video waveform, i.e., it is predistorted to correct for the distortion produced in the modulated amplifier so that the modulation envelope of the radiated carrier may follow as closely as possible the input video waveform. The last stage contains a cathode follower, black-level clamp, an amplifier and an output cathode follower, which has a very low output impedance. The latter helps to preserve a level frequency response; in addition, it reduces non-linear distortion due to the grid current taken by the modulated amplifier.

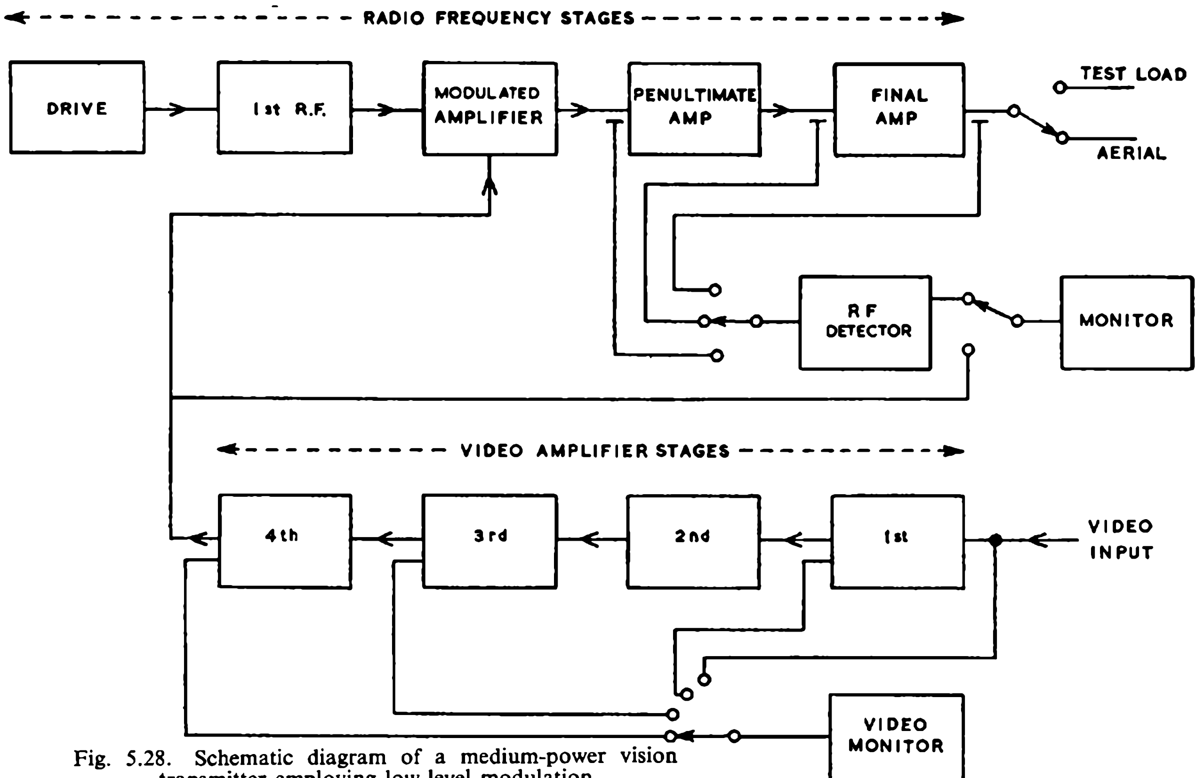


Fig. 5.28. Schematic diagram of a medium-power vision transmitter employing low-level modulation

The signal can be monitored at a number of points as shown in Fig. 5.28. A video detector is employed to extract the envelope from the modulated signal when monitoring at the modulated amplifier and beyond.

5.4.5 *R.F. Amplifier Stages*

In the radio-frequency amplifier stages following the drive the carrier voltage is amplified in narrow-band circuits which are similar to those used at medium frequency. After the modulated amplifier the radio-frequency stages must have wide-band characteristics in order to amplify properly the video-modulated carrier. In these modulated-carrier amplifier stages the gain, which is dependent on the reciprocal of the product of the capacitance and bandwidth, is made a maximum by having the capacitance as small as possible. Generally the earthed-grid form of connection is employed because this redistributes valve capacitances and reduces their effect across the tuned circuit. In such an amplifier the input voltage is applied to the cathode circuit, and the grid is connected by capacitance to earth and also directly to the grid-bias supply.

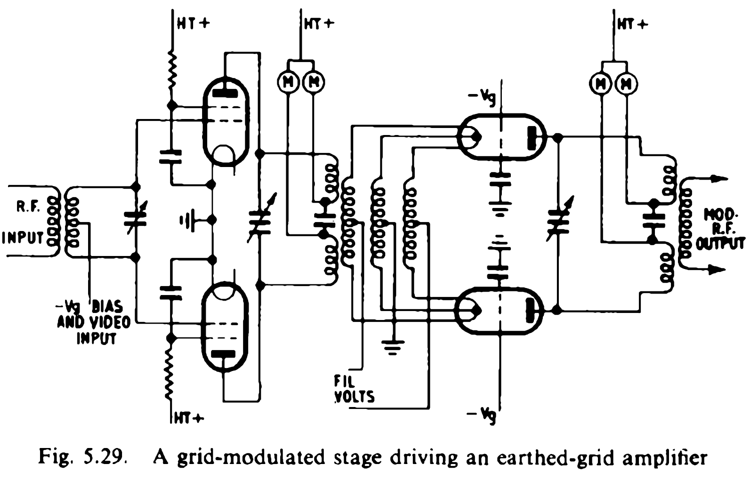


Fig. 5.29. A grid-modulated stage driving an earthed-grid amplifier

The use of the earthed-grid stage has the further advantage that the feedback of energy from output to input takes place through the anode-cathode capacitance which is very much less than the anode-grid capacitance so that neutralising is rarely necessary. An example of such a modulated-carrier amplifier is shown in Fig. 5.29. For the sake of simplicity the inductors in the tuned circuits are shown by the conventional symbol but at the carrier frequencies involved (50 Mc/s) the inductors normally consist of parallel lines with movable short-circuiting bars for adjustment of inductance value. Three windings are required at the input to the stage because the

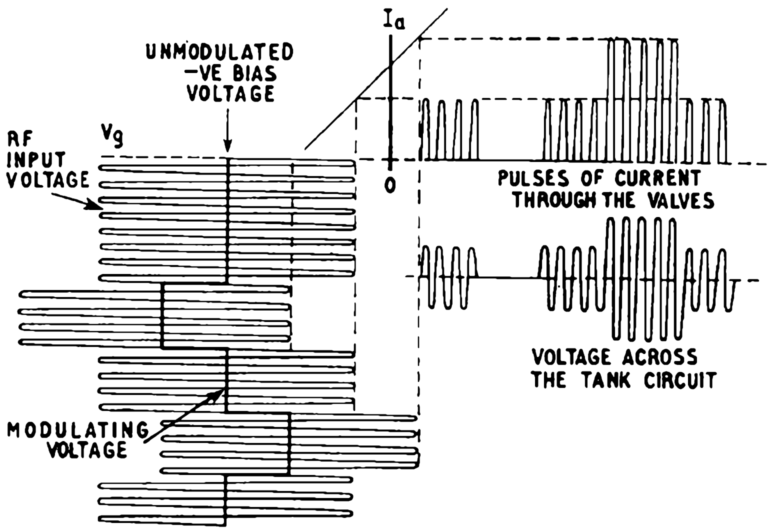


Fig. 5.30. Waveforms produced by grid modulation

two outer ones have to carry the filament currents. The inner provides the d.c. path to earth for anode current.

5.4.6 *The Modulated-amplifier Stage*

A schematic diagram of a low-level grid-modulated amplifier is shown in Fig. 5.29 using tetrodes as the amplifying valves. The video signal and the grid bias for the stage is inserted between the centre tap of the tuning coil and earth, and the action of the modulation is shown in Fig. 5.30 for a linear $I_a V_g$ characteristic. Normally this characteristic is curved and this could lead to an appreciable amount of harmonic distortion, but it is in fact compensated by predistorting the video signal in the opposite sense. To illustrate how this may be accomplished Fig. 5.31 shows a video signal with 30 per cent synchronising pulse and a 70 per cent saw-tooth voltage from black (30 per cent) to peak white (100 per cent). If this is applied to a grid-modulated amplifier there will be a tendency for the synchronising envelope amplitude to be reduced, because of bottom-bending in the $I_a V_g$ characteristic, and for peak white to be crushed

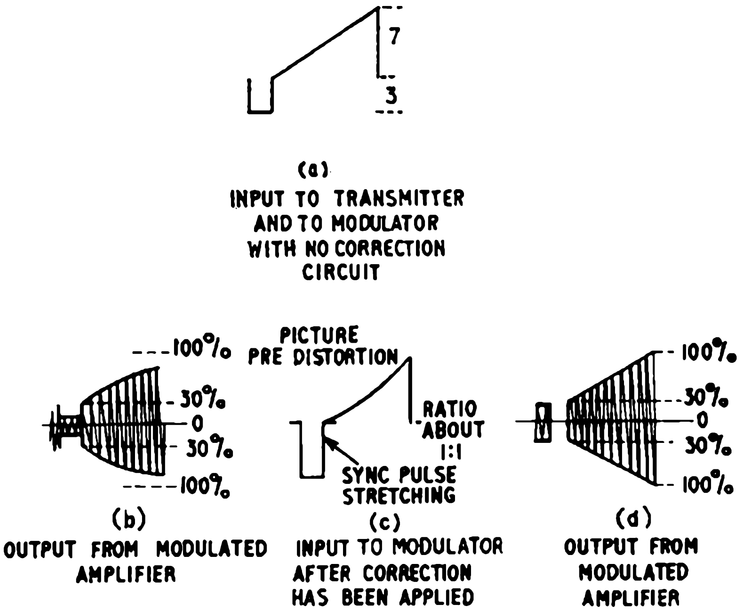


Fig. 5.31. Distortion produced by grid modulation and its correction by pre-distortion

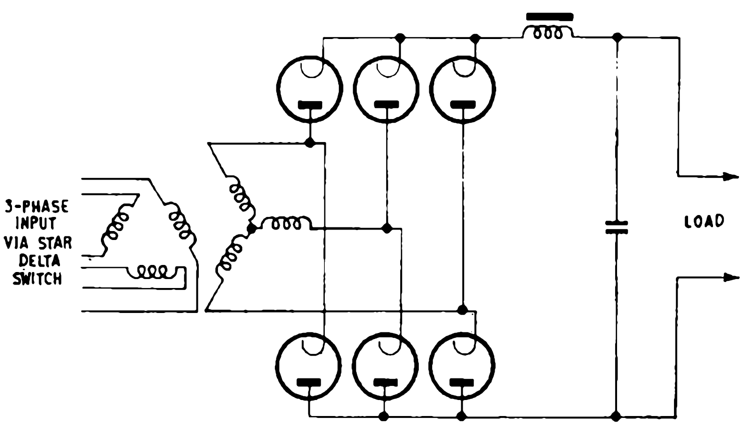


Fig. 5.32. 3-phase full-wave rectifier for a vision transmitter

by top-bending (Fig. 5.31 (b)). The signal must therefore be predistorted in such a way as to increase the input synchronising amplitude, making it almost equal to that of the picture amplitude, and the picture saw-tooth must be bent upwards as shown in Fig. 5.31 (c). When this is applied to the modulator the output envelope is as shown in Fig. 5.31 (d) which is a correct reproduction of the original input to the video amplifier. The picture blanking level must remain a point of reference, and to ensure that this is always at the correct value the voltage during the post line synchronising suppression period (known as the back porch) is separately controlled by what is termed a black-level clamp circuit. This consists of a diode switch which operates during the back porch, and applies the correct bias to the grids of the valves which have been clamped. Thus once during each line period the blanking level of the vision waveform is clamped to its correct value corresponding to 30 per cent modulation of the carrier.

5.4.7 *Power Supplies*

There are generally many more separate power supplies for a television transmitter than for a sound transmitter and all must have their voltages stabilised so as to make them almost independent of their output current. This is because the vision signal always contains the equivalent of a d.c. voltage dependent on the mean light level of the picture signal; the mean current as well as the alternating current therefore varies, and every attempt must be made to ensure that the h.t. supply voltage is independent of d.c. current variation. The e.h.t. rectifier circuits are conventional and generally consist of three-phase full-wave mercury-vapour rectifiers as shown in Fig. 5.32. Such circuits cannot contain stabiliser control and the main problem is to ensure that their internal resistance is as low as possible. An inductance input filter is employed because for a certain current change it gives a voltage change much less than does the reservoir capacitance filter. Although the circuit in Fig. 5.32 requires 6 valves and four filament transformers it has the advantage that:

(i) output voltage is similar to that of a six-phase rectifier with a low ripple component and a high d.c. voltage component;

(ii) a simple three-phase transformer only is required;

(iii) the circuit operates with high efficiency and has a good power factor;

(iv) the primary of the transformer can be changed from delta connection, which gives the maximum voltage, to star connection, which gives a lower voltage ($1/\sqrt{3}$ of the maximum) for starting or when fault location is in progress. The valves are protected against excessive current by overload current relays which break the e.h.t. interlock line.

Some idea of the mean power supply requirements of a medium-power and a high-power television transmitter is given in Table 5.1. The medium-power transmitter had low-level modulation and the

TABLE 5.1

Typical Mean Power Values for Medium- and High-power T.V. Transmitters

	Peak White	*Black*	*Test Card C*
Medium-power			
R.F. output (approx.)	4·2 kW	0·5 kW	2·8 kW
D.C. power from main 3 kV rectifier supplying the 2 final stages following the modulated amplifier	10·9 kW	5·2 kW	8 kW
High-power			
R.F. output (approx.)	40 kW	6 kW	29 kW
D.C. power from main 7 kV rectifier supplying the modulated amplifier	70 kW	22 kW	43 kW
D.C. power for the modulator amplifier and cathode-follower	11·5 kW	9·7 kW	10 kW

high-power high-level modulation, the modulating waveform contained the normal synchronising pulses and the test picture signals consisted successively of

(a) peak white,
(b) black,
(c) test card C.

5.4.8 *Cooling*

In the high-power vision transmitters supplying a power of 50 kW or more to the feeder the output valves are water-cooled, but for almost all the other stages the power dissipated in the valve is sufficiently small to permit airblast cooling. An air-pressure switch opens contacts in the e.h.t. interlock supply if the air pressure fails.

5.4.9 *Protective Interlock Circuits*

Basically the interlock circuit for any transmitter is the same, and that shown in Fig. 5.20 could equally well apply to a television transmitter. There are the usual air-pressure switches, time delay switches in filament and e.h.t. supplies, and overload switches.

The state of the interlock circuits is given on a main indicator panel which, by means of lighted lamps, shows which parts of the circuits are operating. This panel is of considerable help in identifying apparatus which has developed a fault because the interlock circuits will disconnect all supplies to the faulty circuit and those that follow it.

5.4.10 *Vestigial Sideband Filter*

Figure 5.27 shows that the television system uses vestigial sideband transmission, the high-frequency components of the upper sideband not being transmitted by the aerial. In the medium-power transmitters this is accomplished by off-tuning the transmitter circuits so that the upper sideband is automatically attenuated in the r.f. amplifier circuits. In the high-power transmitters the upper sideband power is removed from the radiated signal by a vestigial sideband filter which is terminated in a resistance load.

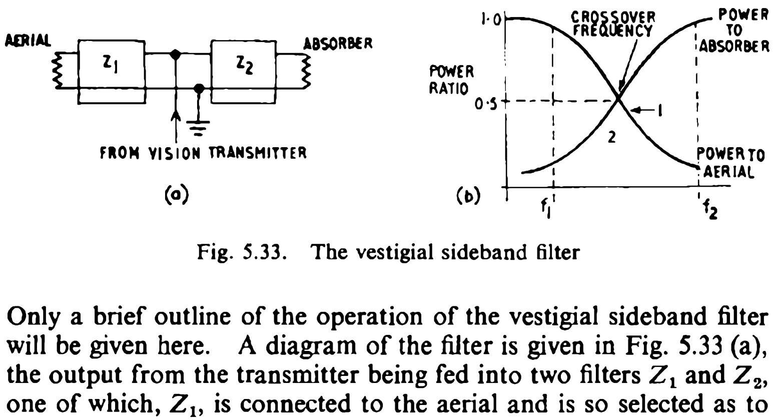


Fig. 5.33. The vestigial sideband filter

Only a brief outline of the operation of the vestigial sideband filter will be given here. A diagram of the filter is given in Fig. 5.33 (a), the output from the transmitter being fed into two filters Z_1 and Z_2, one of which, Z_1, is connected to the aerial and is so selected as to give the characteristic curve 1 shown in Fig. 5.33 (b). The other Z_2, gives an opposite characteristic (curve 2) and is terminated by an absorber load. Z_1 only allows the required proportion of the upper sideband to pass to the aerial and Z_2 enables the power in these sidebands to be dissipated harmlessly. The actual impedances are generally coaxial lines whose lengths have been adjusted to give the required electrical characteristics. Before the output from Z_1 is coupled to the aerial, the output from the associated sound transmitter is combined with it and the two signals are then applied to a common aerial system.

5.4.11 *Television Sound Transmitters*

The power outputs from the sound transmitters for the medium-power television transmissions are 1·25 kW and for the high-power transmissions 12.5 kW. Apart from the final stage there is little difference between the two types of transmitters. The drive units are crystal-controlled and are followed by multipliers to give the final sound-carrier frequencies. The radio-frequency circuits of a transmitter generally consist of two or three push-pull amplifiers driving single-ended earthed-grid output amplifiers. Anode modulation is employed but the previous r.f. amplifier stage must also be partially modulated. This is necessary because some of the power supplied from this stage passes through the earthed-grid stage to the output circuit and unless the input signal is modulated it will not be possible to modulate fully the last stage.

Programme is received via Post Office lines or by direct pick-up, and the programme input facilities and monitoring arrangements are similar to those already shown in Figs. 5.7 and 5.8. Negative feedback is employed in the modulation chain from the primary of the modulation transformer to the input. If the filaments are a.c. heated, hum modulation may occur; it may be reduced by combin-

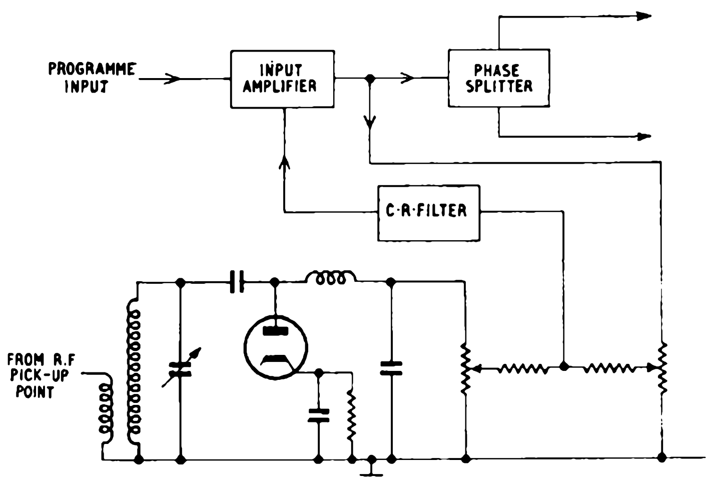


Fig. 5.34. The reduction of hum and noise in the sound transmitter by using negative feedback

ing the modulation output of a rectified r.f. voltage from the output feeder with hum-free programme from the a.f. chain. The hum-free programme amplitude is adjusted so that it cancels that in the rectified output and this leaves the hum and ripple negative feedback, which is passed through a low-pass CR filter (50 to 400 c/s pass range) to the a.f. input amplifier as shown in Fig. 5.34. The power supplies and interlock circuits are similar to those of the vision transmitters.

5.4.12 *Sound and Vision Combining Circuits*

The combining of the outputs from the sound and vision transmitters is usually done in the main transmitter building. It is not possible to go into great detail here concerning the combining circuits but an indication of their method of operation is as follows. One method is illustrated in Fig. 5.35, which shows a number of coaxial line stubs spaced along the sound transmitter feeder-line; these present to the vision carrier and its associated sidebands a very high impedance at A whilst themselves acting as short-circuits to these frequencies at points 1, 2 and 3. They appear

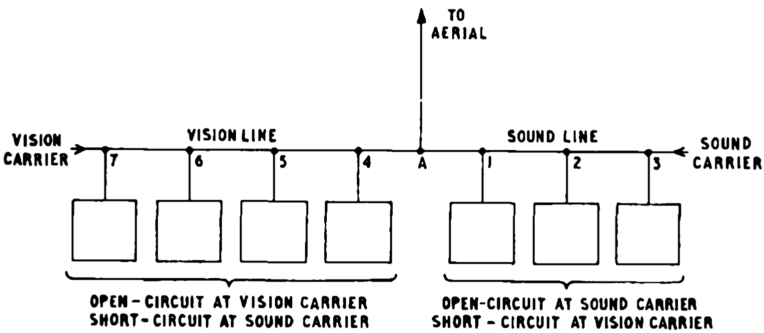


Fig. 5.35. A method of combining sound and vision transmitter output

as open circuits at the sound signal frequency. Similarly on the vision side the coaxial line stubs present a high impedance to the sound-carrier frequency and its sidebands at A but act as short-circuits at 4, 5, 6 and 7. They appear at these same points as open-circuits to the vision signal. Thus the modulated sound carrier delivers power to the aerial and none enters the vision transmitter, and vice versa for the vision carrier.

Another form of combining circuit is that of the bridge illustrated in Fig. 5.36. Impedances Z_1 and Z_2, which are lengths of coaxial feeder, are opposite arms of the bridge, the other two arms being formed by the aerial and a balance resistor. Z_1 acts as a pass-circuit to the vision signal and a stop-circuit to the sound signal, and Z_2 functions in the opposite manner. The sound signal is applied across the corners of the bridge 1, 3 and the vision signal

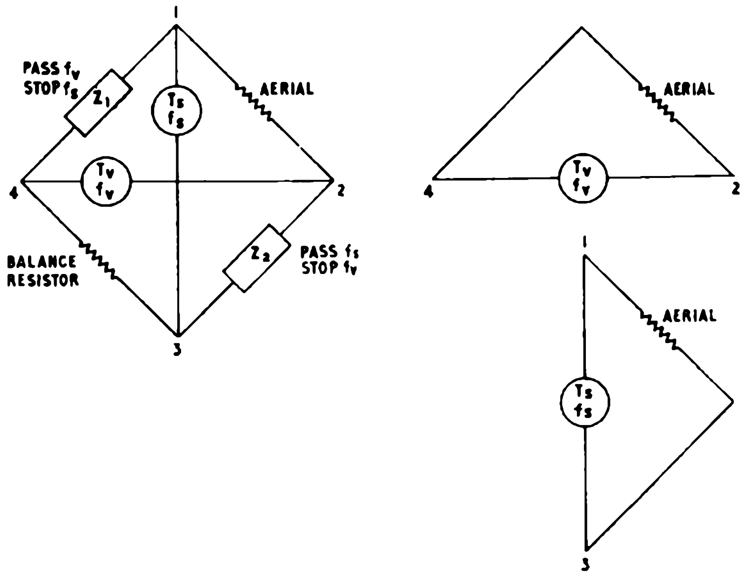


Fig. 5.36. A bridge method of combining sound and vision transmitter outputs

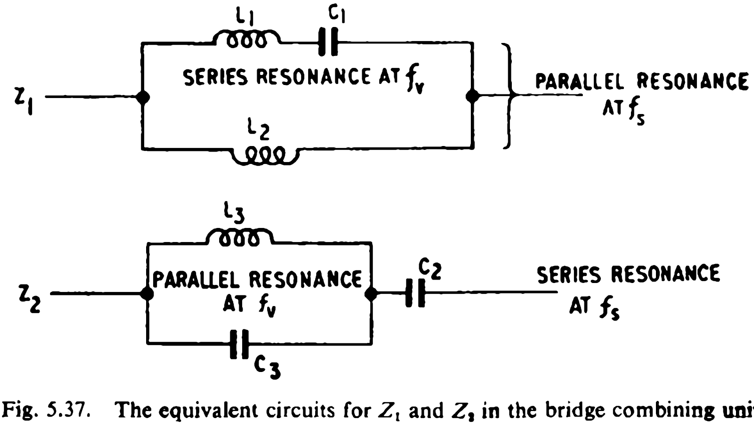


Fig. 5.37. The equivalent circuits for Z_1 and Z_2 in the bridge combining unit

across corners 2, 4. The sound signal is therefore fed to the aerial via Z_2 which acts as a pass-circuit at the sound frequency, and the vision signal to the aerial via Z_1 which is a pass-circuit at the vision frequency. The bridge is held in balance by the balance resistor between 4 and 3 so that no sound signal is fed into the vision transmitter and vice versa. Though the impedances Z_1 and Z_2 are made up of sections of coaxial line they are equivalent to the LC circuit shown in Fig. 5.37. Z_1 has a series resonant shunt arm at the vision frequency which is higher than the sound frequency. At the sound frequency the L_1 and C_1 circuit appears as a capacitance and tunes with L_2 to form a parallel-resonant high-impedance circuit at the sound-carrier frequency. Z_2 has a parallel circuit L_3C_3 which is a high impedance to the vision component. At the lower frequency of the sound signal this circuit appears as an inductance which tunes with C_2 to form a series resonant circuit at the sound-carrier frequency.

5.5 TRANSMITTING AERIALS AND FEEDERS

5.5.1 *Low- and Medium-frequency Aerials and Feeders*

The function of low- and medium-frequency aerials is generally to produce a vertically-polarised omnidirectional ground wave, and they take the form of a vertical radiator with one end at ground level. The radiator may be a single insulated mast or a wire in the form of a 'T' supported between two masts. As a rule the height of the aerial is dependent on the power of the transmitter; thus a low-power transmitter would use a comparatively cheap aerial of 90–100 feet in height whereas 100-kW transmitters would justify the use of an aerial of 500 feet or more in height. A high aerial has definite advantages for it is more effective as a radiator of ground waves. For example, an aerial of height equal to half the transmitted wavelength produces a ground-wave signal greater than one equal in height to a quarter of the wavelength. There is however an optimum value of aerial height which produces maximum ground wave radiation and this is at about 0·6 λ. An aerial $\frac{3}{4}$ λ in height tends to project a good deal of its energy skywards and to reduce the ground wave. It is possible to increase the effective height of the aerial by connecting it to a horizontal section. Thus a comparatively cheap aerial for a low-power transmitter would probably consist of a 'T' aerial supported between two masts. The effective height of such an aerial is increased because the current distribution is modified by the top of the 'T' so that the current in the vertical part of the aerial is increased.

The masts supporting a 'T' aerial would distort the horizontal radiation pattern and an omnidirectional pattern is easier to achieve with a single mast radiator. There are a few examples of directional aerials in use. In some a mast is situated behind the aerial and acts as a reflector whilst in others the aerial consists of two vertical wires spaced approximately $\lambda/2$ apart and driven in antiphase, thereby producing a figure-of-eight horizontal radiation pattern.

The reduction in service area of a transmitter due to the reflection of the sky waves after nightfall has already been mentioned and it is

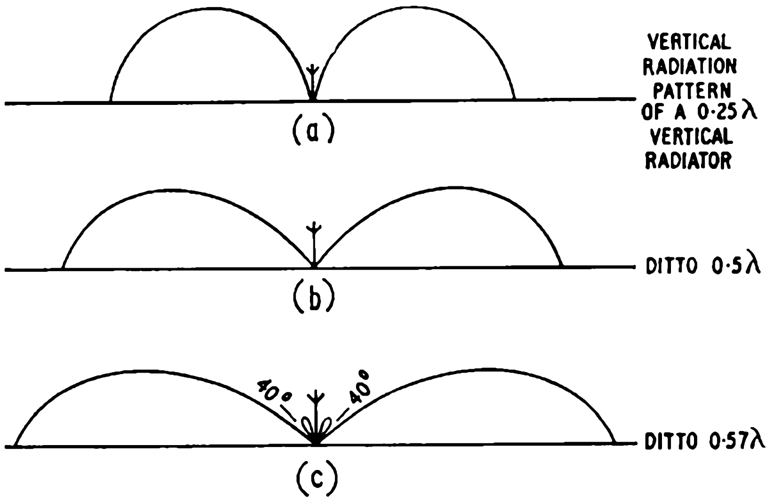


Fig. 5.38. Vertical directional diagram for medium-frequency aerials of different heights

important to ensure that this effect is kept to the minimum. This can be achieved if the effective height of the aerial is correctly chosen. The vertical directional diagrams of aerials of differing heights are indicated in Fig. 5.38, and it will be seen that for a height of approximately 5/8 λ there is a good ground wave but also two lobes projecting skywards at a high angle with a minimum between them and the main lobe. This minimum corresponds to the angle at which a sky wave projected from the transmitter would return to earth at the edges of the service area thereby causing interference. This type of aerial is known as the anti-fading aerial, the sky wave (the cause of the fading) being a minimum.

Adjustment of the effective length of mast radiators can be achieved without the complication of changes of physical length either by using a 'capacity top' or by an insulated break part way up the mast, the break being bridged by an inductor. The 'capacity top' is provided by an umbrella of wires from the top of the aerial.

This modifies the current distribution to increase the effective height. Such a method does not lend itself to easy adjustment, but the insulated break does because the number of turns on the bridging inductor can be changed to give fine adjustment of effective length or to accommodate a change in transmitted frequency.

The aerial has normally to be erected away from the transmitter building, and the power developed in the transmitter has to be conveyed to its base by means of a feeder. Nearly all such feeders are unbalanced with an inner conductor live and an outer conductor or series of conductors earthed, as indicated in Fig. 5.39. Each

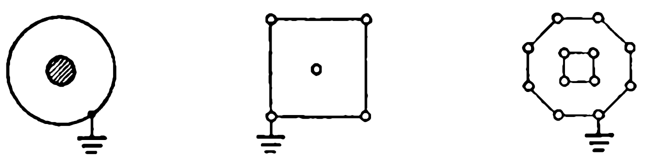


Fig. 5.39. Examples of medium-frequency feeder construction

feeder has its own characteristic impedance which is the impedance measured at the input of an infinitely long feeder. This impedance depends entirely on the physical dimensions of the feeder, and in order that the feeder may transmit power with the minimum of loss and without reflection of power it should be terminated by a load of the same impedance value. Medium-frequency aerials have base impedances from 10 Ω up to about 1 000 Ω consisting of resistive and reactive components, so that matching to the feeder impedance must be made by inductance-capacitance networks. The outer of the feeder wires is connected to the main earth system around the aerial, and in order to reduce losses in the earth due to the return currents from the aerial a network of copper wires is buried just under the surface in the form of a number of radials out from the base of the mast.

5.5.2 *High-frequency Aerials and Feeders*[6]

High-frequency broadcasting is essentially for long-distance transmission, with transmitter and receivers hundreds or thousands of miles apart. The programme is normally intended for a particular area and this means that radiation from the aerial must not be omnidirectional, but 'beamed' in the desired direction. The beaming must be such as to give the correct vertical angle as well as the correct horizontal direction since it must meet the reflecting layer at the correct angle for reflection. Comparatively narrow beams are required, otherwise there is a waste of power by covering too large an area; it is interesting to note that a beam diverging horizontally and vertically by 5° can cover an area greater than 15 000 square miles at a range of 1 000 miles. Narrow beams are produced by using aerial arrays consisting of many radiating

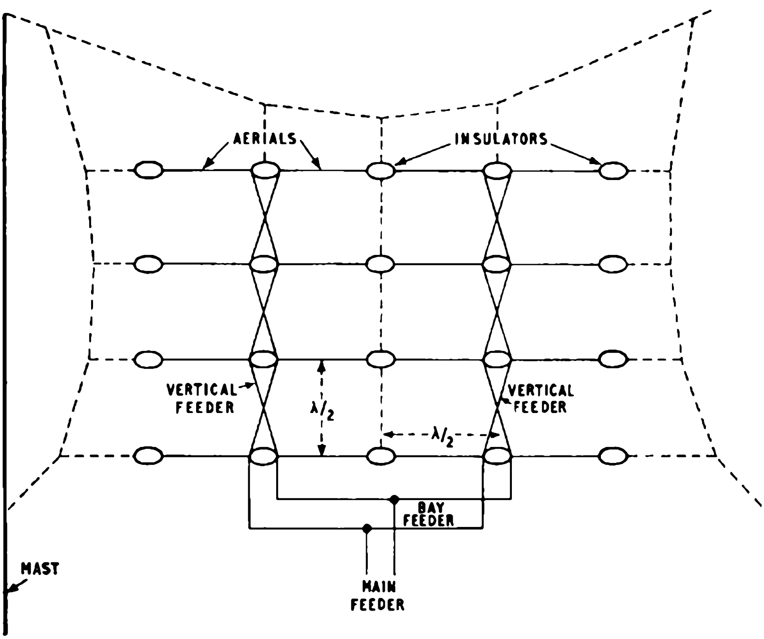


Fig. 5.40. A typical short-wave aerial array

elements; the greater the number of vertical stacks, the narrower is the beam in the vertical plane, and similarly the greater the number of radiators in a given horizontal tier the narrower is the beam in the horizontal direction. The length of each radiator is approximately half of the transmitted wavelength ($\lambda/2$) and the vertical spacing between the stacks is $\lambda/2$. The aerial array shown in Fig. 5.40 has two directions of propagation, into and out of the paper, and it would send out its main beams perpendicular to the plane of the array. Thus if a perpendicular to the plane of the array is at an angle of $\theta°$ from North, propagation will be at θ and $\theta+180°$. Suppression of radiation in one of these directions is achieved by placing at $\lambda/4$ distance behind the aerial a similar array, which acts as a reflector to suppress the beam on that side and push the suppressed energy out in the forward direction.

It will be clear that one aerial system plus reflector of this kind can be made to give a beam in one of two opposite directions because if a transmission is required in the opposite direction, the reflector can be connected to the transmitter and the original aerial used as a reflector. The aerial array of Fig. 5.40 consists of two halves, each supplied from a vertical feeder which is connected by what is known as a 'bay feeder'. If the main feeder is connected to the centre point of the bay feeder each part of the array receives r.f. power at exactly the same time. If, however, the connection from the main feeder is moved to the left of the centre point the left-hand aerials receive power slightly ahead in time of the right-hand ones, which gives much the same effect as would be produced had the main feeder connection remained at the centre point and the aerial system been slewed, causing the beam to be moved to the right. This method of electrical slewing of the beam is used to change the direction of propagation, but the maximum slewing angle is limited to about 12° on either side of the normal beam position. If too much electrical slewing is attempted the beam splits into two.

The vertical angle of the beam is important if satisfactory reflection is to occur from the ionospheric layer, and generally the angle needs to be about 8° for long-distance operation and for shorter range work up to about 20°. This angle is governed by the height of the bottom aerials above ground and the greater this is, the smaller is the angle. Thus for a low-angle radiation the height at the bottom of the stack requires to be about one wavelength whereas for high-angle it needs to be about 0·3 of a wavelength.

A h.f. transmitting station sending out a large number of programmes to various parts of the world requires a large number of arrays, and a special coding is employed. Thus an array might have the following code number: HRRS 4/2/·8/25 – 97°, **109°**, 121°, **289°**. This indicates that the aerials are horizontal (H), there is a reversible reflector (RR), the array can be slewed (S), there are four aerials in each horizontal row (4) and two vertical rows (2) with the lower row at a height of 0·8 λ above ground, the array operates in the 25-metre band, and the main bearings are 109° and 289° (both slewable by $\pm$12°). The height of 0·8 λ for the lowest stack fixes the centre of the main lobe at an angle of about 14° above the horizontal.

The arrays are usually supported on masts about 325 feet high and the siting is important since they must not only be on the right bearing but they must not 'fire' through one another. This involves spreading a high-frequency aerial system over a large area.

There must also be facilities for connecting each transmitter to any one of a number of different arrays and this is achieved by a special feeder-switching tower, or in the earlier stations by means of a hook-switching arrangement.

5.5.3 *V.H.F. Aerials*[7]

The design of v.h.f. aerials is more difficult because large bandwidths are involved. In Band I each BBC vision and associated sound transmission requires a bandwidth of about 4·5 Mc/s and

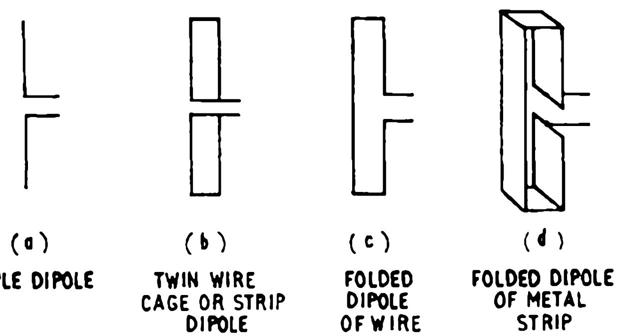


Fig. 5.41. Types of dipole aerial construction for v.h.f. broadcasting

nearly the same bandwidth is needed by BBC f.m. transmissions in Band II, since one set of aerials is used to radiate the three (or four) programmes. Many types of aerial are in use, e.g., the dipole, folded dipole, slot, vee, batwing, and turnstile. It is not possible to consider all here, and attention will be concentrated on those used at the high-power stations, viz., the folded dipole (Band I) and the slot (Band II) aerials.

An example of a simple dipole is shown in Fig. 5.41 (a). It consists of two wires which are fed with a balanced voltage at their centre. The over-all length of the two wires is very nearly half the wavelength of the r.f. carrier being transmitted, and the two wires then present an impedance of 72 Ω. At frequencies other than that corresponding to $\frac{1}{2}\lambda$, the impedance presented by the two wires is reactive as well as resistive. At higher frequencies it appears as an inductive reactance in series with a resistance (greater than 72 Ω) and at lower frequencies the impedance is represented by a capacitance in series with a resistance (less than 72 Ω). An aerial having such a variation of impedance cannot easily be matched to a feeder. If an attempt at matching is made, attenuation distortion of the sidebands generally results and energy is reflected back along the feeder to distort further the radiated signal.

If the impedance characteristic of a dipole aerial is examined over a frequency range on either side of its $\frac{1}{2}\lambda$ frequency, it is found to approximate quite closely to a series LCR circuit and the problem becomes one of trying to modify the circuit so that the impedance variation over the bandwidth required to be transmitted is as small as possible. This can be achieved either by increasing the value of the resistance (this is not possible with the dipole) or, better still, by reducing the value of the inductance and increasing the value of the capacitance, because the impedance of a series circuit is equal to $\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]^{\frac{1}{2}}$. It can be proved by considering two series circuits having the following component values:

$$L_1 = 1\,\mu\text{H}, C_1 = 10\,\text{pF}, R = 72\,\Omega, L_2 = 0{\cdot}5\,\mu\text{H}, C_2 = 20\,\text{pF}, R = 72\,\Omega$$

The product LC is the same for both circuits so that they resonate at the same frequency, i.e., at about 50 Mc/s and at this frequency the impedance is 72 Ω (resistive) in value. If the frequency is increased by 5 per cent to 52·5 Mc/s circuit 1 has an impedance equivalent to 72 Ω resistance in series with 25 Ω inductive reactance whereas circuit 2 has an impedance of 27 Ω resistance in series with 12 Ω inductive reactance. Thus for a given change in frequency the impedance of the second circuit changes less than that of the first circuit, and it will produce less distortion of the signal covering a bandwidth of 5 Mc/s. Alternatively it can be said that a lower LC ratio circuit will have a wider effective bandwidth. It is possible to vary the LC ratio of a dipole by changing its form from that of two thin wires to two cages of wires or metal strip and this type of aerial is illustrated in Fig. 5.41 (b).

Folding a dipole as shown in Fig. 5.41 (c) increases its impedance 4 times and slightly increases its bandwidth. Such an aerial radiates in a manner similar to the two-wire dipole but the impedance at the input terminals has two reactive components of opposite sign which can be made very nearly to cancel each other over the pass range. The two cancelling reactive components appear because the folding process produces at the aerial input terminals the equivalent of a short-circuited $\lambda/4$ transmission line and the radiating effect the equivalent of an open-circuited $\lambda/4$ transmission line, as if the fold had not been made. This means that an increase in frequency produces an inductive reactance from the dipole viewed as unfolded and a capacitive reactance from the fold, and it is possible to arrange for these two reactances very nearly to cancel each other over a reasonably wide frequency range. The bandwidth can be further increased by using metal strip instead of wire for the folded dipole as shown in Fig. 5.41 (d). Folding changes the resistance of the dipole from 72 Ω to about 280 Ω and this is an advantage when a number are to be connected in parallel.

An illustration of the folded dipoles used for Band I aerials on most high-power television transmitters is shown in Fig. 5.42. The aerial consists of eight folded dipoles arranged in two tiers of four.

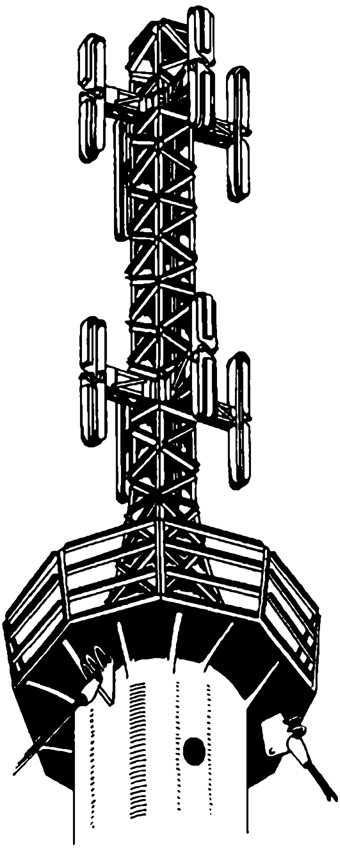


Fig. 5.42. The folded dipole for v.h.f. transmission of vision signals

The advantage of using two tiers one above the other is that the directional pattern in the vertical plane is made narrower and this effectively increases the gain (of the direct signal) in the required horizontal direction. The gain is of the order of 3 dB so that if the power applied to the aerials is 50 kW, the effective radiated power (E.R.P)—the power which would have to be applied to a simple $\lambda \times 2$ dipole to produce the same field strength at the same distance —would be 100 kW. The connections of these aerials to the feeder are complicated, since the aerial system is a balanced one and the

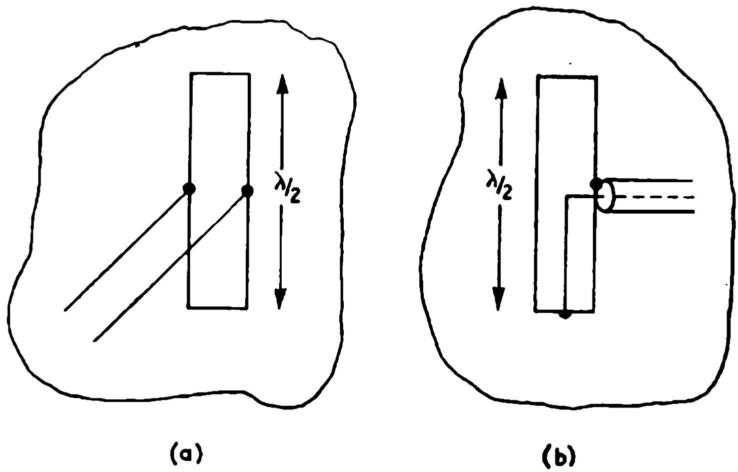


Fig. 5.43. A slot aerial for (a) balanced connection and (b) unbalanced connection

aerial feeder is a coaxial unbalanced circuit. There must therefore be some conversion system from unbalance to balance as well as the normal impedance matching; arrangements must also be made to feed both tiers in phase.

The Band II f.m. transmissions use a slot-aerial system for the high-power transmissions, and an example of a simple slot aerial cut in a metal sheet is shown in Fig. 5.43 (a). The feed points are at the centre of the opposite long sides of the slot and the electric field is horizontal across the slot so that a horizontally-polarised wave is produced. A receiving dipole should therefore be horizontal in order to pick up the signal. The bandwidth of the slot is similar to that of a dipole of the same dimensions as the slot itself. If the horizontal dimensions of the sheet metal in which the slot is cut are very large, radiation is almost omnidirectional, but if the metal sheet is small the directional pattern in a horizontal direction is similar to a figure-of-eight. A single slot cut in a cylinder tends to produce omnidirectional radiation.

The f.m. transmitting aerials consist of slots in groups of four cut in a cylindrical mast and these slots produce an omnidirectional horizontal pattern. An increase in the bandwidth can be achieved if the slot is given a centre conductor from the centre of the lower or the upper narrow side (Fig. 5.43 (b)) and the r.f. input is connected to the conductor and the centre of one of the long sides. An unbalanced input is obtained between the mast itself and the central conductor, which can be connected directly to the inner conductor of a coaxial feeder and this is the method used for the high-power transmitters. The horizontal gain of the slot aerial can be increased by using tiers of such slots one above the other as illustrated in Fig. 5.44. Although of different polarisation, one tier of four slots produces the same field strength as a vertical dipole, two tiers of four slots double the field strength, four double that again so that eight tiers, the number used in the Band II high-power aerials, will produce a gain of 9 dB. In practice, feeder losses, etc., reduce this gain to about 8 dB, giving an equivalent power gain of 6 over the dipole. Thus if 20 kW is supplied to the aerial an effective radiated power of 120 kW is achieved. The aerial is normally divided into two, the top four stacks being fed from a feeder connected to the combined outputs of the Home, Light and Third programmes from one of each pair of transmitters mentioned in Section 5.3.2, and the lower stacks being fed from the others of the pairs of transmitters.

5.6 PROPAGATION

The magnitude of the signal which reaches the receiver aerial is determined as much by the characteristics of propagation as by the r.f. power available from the transmitter and the aerial characteristics, and no discussion on transmitters could be regarded as complete without some description of propagation characteristics for the different frequency ranges used in broadcasting.

5.6.1 *Low- and Medium-frequency propagation*[8]

Aerials operating at low and medium frequencies take the form of vertical wire or mast aerials with one end at ground level, the output of the transmitter usually being applied between the base of the aerial and earth. Most m.f. aerials are omnidirectional in a horizontal plane, i.e., the signal is radiated equally in all directions, reducing in value as it travels further from the aerial. The strength of the signal at any given point is termed the field strength, and it is generally the field strength of the wave travelling parallel to the ground, and generally called the ground wave, that determines the useful transmission range. Two factors, the carrier frequency and the nature of the ground over which the wave is travelling, govern this; the higher the carrier frequency, the greater is the attenuation

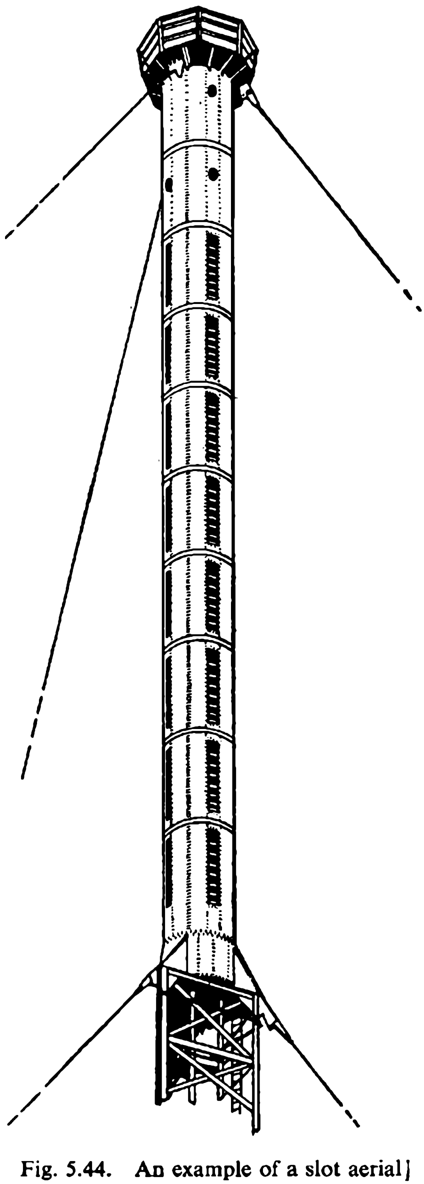


Fig. 5.44. An example of a slot aerial

of the ground wave, so that a frequency of 600 kc/s is much more valuable for broadcasting than one of 1 500 kc/s. Table 5.2 shows the effect on propagation of material on or near the ground surface and Fig. 5.45 illustrates this with reference to the United Kingdom.

Charts are available to allow the field strength at a given distance from a particular transmitter to be predicted when the nature of the surface over which the ground wave travels is known. The charts

TABLE 5.2

Effect of Ground Material on Propagation

Surface Material	*Propagation Quality*
Sea Water	excellent
Fresh Water Clay (over most of the Midlands) New Limestone (over the Cotswolds)	good
Chalk (over the Chilterns and N. and S. Downs) Old Limestone (over the Pennines)	fair
Granite (over Dartmoor, and the Grampians)	poor

only provide information concerning daylight propagation, and to appreciate what happens after night fall it is necessary to discuss the effect of the ionosphere on propagation.

The ionosphere consists of a number of ionised regions or layers of gas surrounding the earth, the ionisation being caused by ultra-violet radiation and corpuscular bombardment from the sun. The important regions and their approximate average heights are:

Region	*Height*
D	85 km
E	110 km
F	250–400 km

The D and E regions play an important part in m.f. broadcasting by absorbing and reflecting respectively. During the day ionisation is most intense and m.f. signals leaving the aerial at an angle above the horizontal are completely absorbed in the D region as shown in Fig. 5.46 (a). Ionisation rapidly decreases after sunset and the D region virtually disappears to expose the E region, which then reflects the m.f. signal back to earth (see Fig. 5.46 (b)). With the aid of the E region m.f. signals can be transmitted over considerable

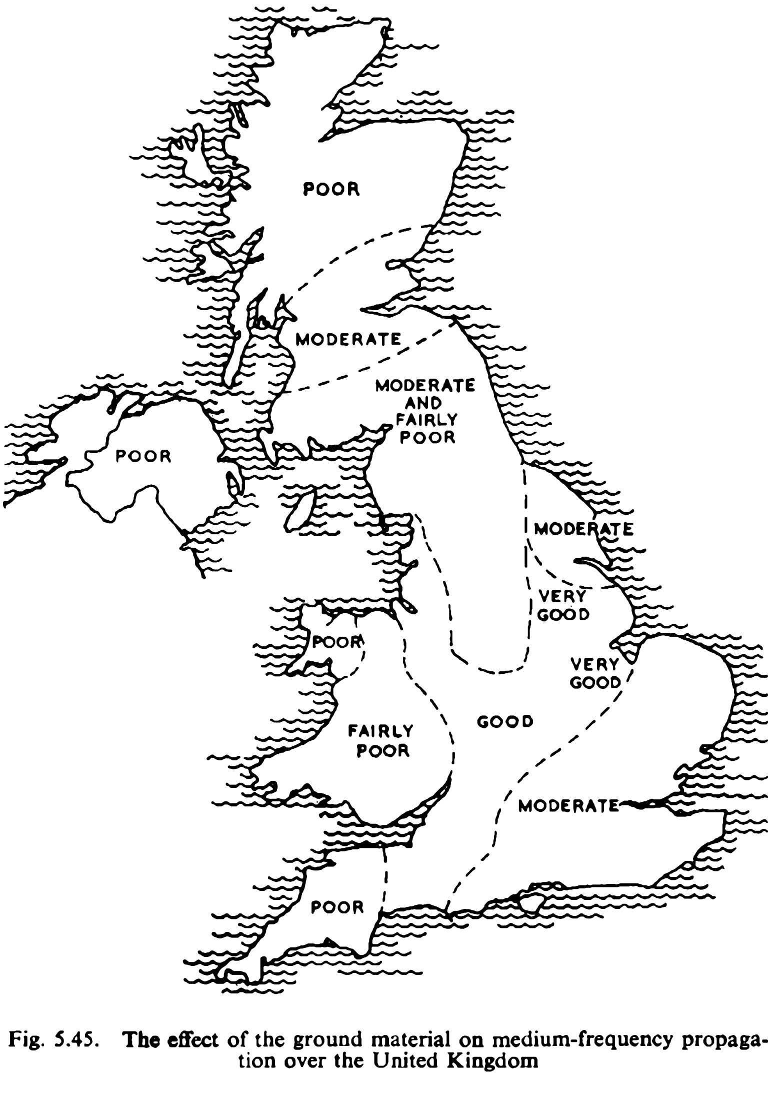


Fig. 5.45. The effect of the ground material on medium-frequency propagation over the United Kingdom

distances with very much less attenuation than occurs for the ground wave. Thus transmitter T_2 can operate during the day on the same carrier frequency as T_1 without causing serious interference, but after sunset both severely restrict the service area of the other. If transmitter T_1 is assumed to have an interference-free channel, there will still be a night-effect because its own sky wave may be returned to earth and seriously affect the service area by adding to or subtracting from the ground wave. This self-interference would be much less serious if the ionosphere were not constantly changing and had no selective transmission effect on the carrier and side-bands. The final result is distortion of the a.f. content of the signal as well as a variation in signal strength.

5.6.2 *High-frequency Propagation*[9]

In section 5.6.1 it was stated that the attenuation of the ground wave increases with increasing frequency so that at frequencies exceeding about 2 Mc/s the service area for the ground wave is restricted almost to the immediate vicinity of the transmitter. However as frequency is increased the effect of the ionosphere changes, and carrier frequencies from about 6 to 22 Mc/s pass through the D region quite readily to be reflected back to earth by either the E or the F regions. The higher frequencies tend to pass through the E region and are reflected back to earth by the F region. Not only the frequency of the carrier but also the angle at which it is projected upwards determine whether it passes through or is reflected by the E or F region. The greater the angle to the horizontal the more likely is the region to be entered. This is illustrated in Fig. 5.47, where high-angle 6-Mc/s radiation is shown as being reflected whereas radiation at 10 Mc/s passes through the layer. The 10-Mc/s transmission is reflected if it is sent at a lower angle to the horizontal. Propagation of high-frequency signals is therefore achieved in a series of hops by using the ionospheric regions and the earth as the reflecting surfaces.

Since the ionisation of the layers is caused by the action of the sun three types of effect are observed, namely; daily (diurnal), seasonal (summer, winter) and an eleven-year cycle corresponding to sunspot activity. Successful operation of the BBC Overseas Services depends on being able to predict with reasonable accuracy the ionospheric conditions at any given time and over any given path. This is achieved through information gained by a close study of the ionosphere over many years and by constant monitoring of the height and condition of the ionospheric layers. The critical frequency, f_0, of the various layers is extremely important and this is obtained by transmitting pulses at vertical incidence at increasing

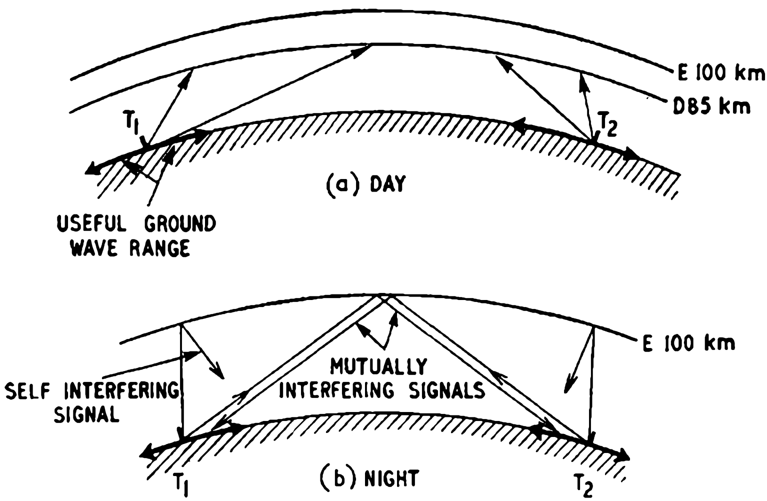


Fig. 5.46. Day and night effect on propagation

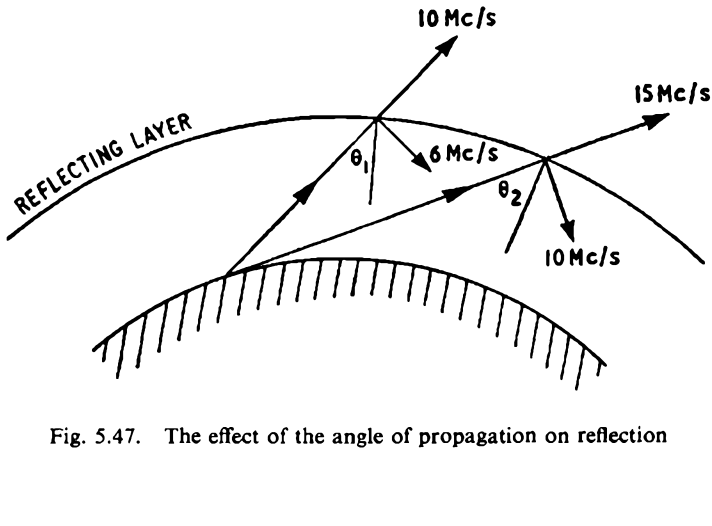


Fig. 5.47. The effect of the angle of propagation on reflection

carrier frequency until no return signal is obtained. The layer designation is usually included, thus f_0E means the critical frequency at vertical incidence for the E layer. The highest carrier frequency to give a return signal is the critical frequency. Fig. 5.48 shows the daily variation of this critical frequency for midsummer and midwinter at sunspot minimum and maximum. The F layer tends to split into two, known as F_1 and F_2 during the day as shown in Fig. 5.48. The greatest daily changes occur during midwinter at sunspot maximum, a change of about 8 Mc/s being recorded over a few hours.

To illustrate the prediction procedure, consider the transmission path TBR of Fig. 5.49. Knowing the time, month, year and route of the intended broadcast, the critical frequency f_0 and the layer height can be predicted. The angle of incidence θ and the angle of propagation α, is fixed by the height AB, the distance TR and the earth's radius (6 360 km).

The highest frequency that can be transmitted from T and reflected from A is called the maximum usable frequency (M.U.F.) and is approximately given by

$$\text{M.U.F.} = \frac{f_0}{\cos \theta}$$

In operating a high-frequency service it is not satisfactory to transmit at the M.U.F. because variations in ionospheric conditions will change its value, and it is usual to operate at a lower frequency called the optimum working frequency (O.W.F.), which is defined as the highest frequency at which propagation between two specified points may be expected to be maintained regularly in undisturbed conditions at a certain time on each day. It is generally of the order of 0·85 M.U.F.

If a broadcast is to continue for several hours, e.g., the General Overseas Service, a number of frequencies may be required, each one being selected in the frequency bands available to broadcasting. Fig. 5.50 shows O.W.F. plotted over a 24-hour period with the actual transmission frequencies marked by horizontal lines.

The prediction of the O.W.F. for a long distance path may be complicated by the transition from day to night conditions in an east-west path or from summer to winter conditions in a north-south path. When this occurs, the O.W.F. for each end of the path is estimated and the lower one is used as the O.W.F. for the transmission path.

From the above discussion it will be clear that high-frequency propagation via the ionosphere can provide communication over distances from about 500 miles to a maximum of 2 500 miles in a single hop, and if multiple hops are used world-wide communication is achieved. For very long distance operation, e.g., England to Australia, a frequency of the order of 20 Mc/s is required because the hops must be a maximum and the attenuation minimum. For comparatively short (about 500 miles) single-hop transmission a low frequency (about 6 Mc/s) is needed because higher frequencies pass through the layers instead of being reflected as shown by Fig. 5.46 (a). This method of propagation by reflection between the ionosphere

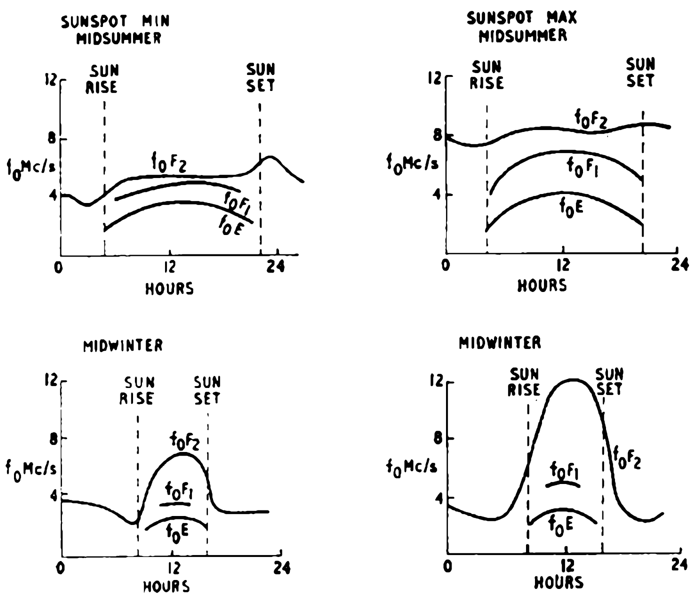


Fig. 5.48. Daily and seasonal variations of critical frequency for minimum and maximum sunspot activities

and earth means that over an area in between the reflections, signals will be very difficult if not impossible, to receive. The length of the 'no signal' area in the direction of propagation is known as the skip distance.

Since high-frequency propagation is completely dependent on the ionospheric conditions, which are always changing, it follows that the received signal will also be varying. Automatic gain control in the receiver can reduce the severity of these variations, and diversity reception can also help by selecting the strongest signal from two or three aerials spaced well apart. The ionosphere can produce a more serious effect, that of selective fading, whereby its

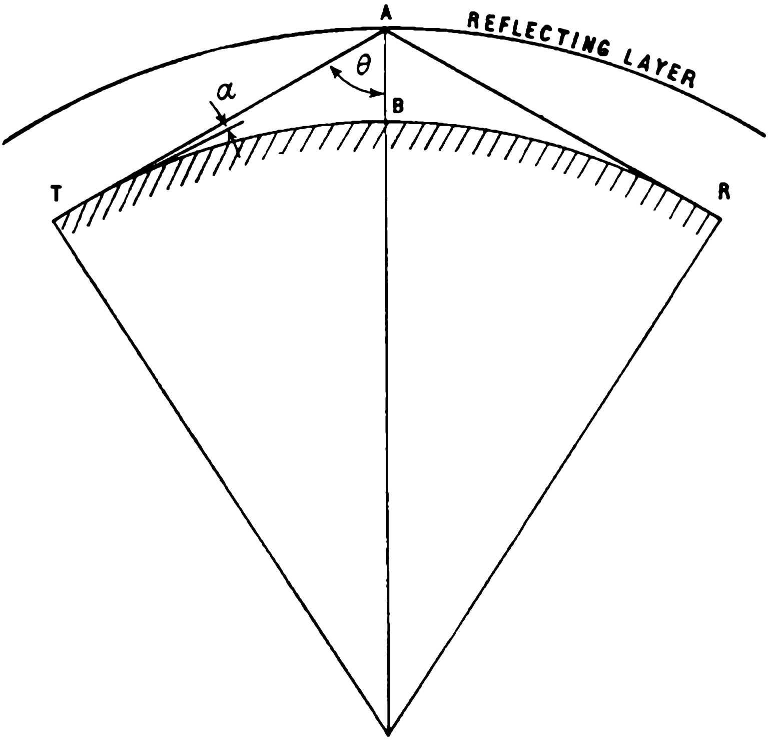


Fig 5.49. A typical example of a high-frequency transmission path

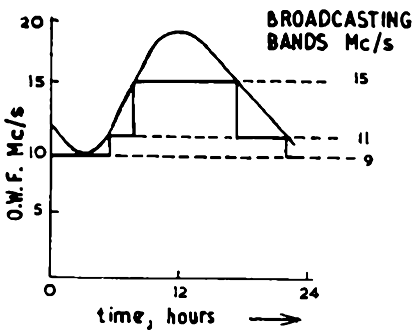


Fig. 5.50. Typical daily variation of optimum working frequency

propagation characteristics vary over the frequency band occupied by the carrier and its sidebands. The amplitude and phase relationships of the component frequencies are disturbed and the reproduced signal suffers serious distortion.

There are other sporadic conditions that have a considerable effect upon h.f. broadcasting. Radiation from eruptive disturbances on the sun known as solar flares sets up at about the height of the D layer, a layer of intense ionisation which completely absorbs h.f. signals, to produce what is often called a 'Dellinger' fade-out. Disturbances on the sun's surface can also produce ionospheric storms, the effects of which are not so severe as a Dellinger fade-out but generally last much longer. The effect is felt mainly in the F layer which has a very low critical frequency and which rises to great heights. The highest frequencies which the F layer will reflect may be as much as 50 per cent below normal. Whilst a Dellinger fade-out is generally unpredictable, a warning of an ionospheric storm can fairly often be given because it frequently follows about 30 hours after a Dellinger fade.

5.6.3. *V.H.F. Propagation*

The v.h.f. range is specified internationally from 30 to 300 Mc/s but only certain bands within this range are fully available for broadcasting in the United Kingdom and they are as follows:

Band I	41–68 Mc/s used for 5 television channels
Band II	88–95 Mc/s used for frequency-modulated sound services
Band III	174–216 Mc/s used for 8 television channels

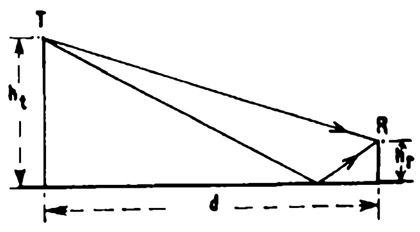


Fig. 5.51. V.h.f. propagation over a perfectly-conducting path

It should be noted that only part of Band III is at present available for television. There are some significant differences between the propagation characteristics of signals at 50 Mc/s and at 200 Mc/s, but there are also many similarities. The v.h.f. transmitting aerial at a height h_t above ground, which is perfectly flat for a distance d to the receiving aerial at a height h_r (Fig. 5.51), provides two main transmission paths from T to R, one by direct free-space signal and one via a reflection from the ground. At the point of reflection the signal suffers a phase change of 180° but very little attenuation. The two signals therefore arrive at the receiving aerial almost equal in amplitude but very nearly in anti-phase so that the resultant signal is quite small, being equal to the vectorial sum of the direct and reflected signals. They would be in anti-phase were the direct and reflected paths equal in length and there would then be no resultant at R. Clearly anything which can be done to increase the path-length difference between the two signals increases their vectorial sum by bringing the two signals nearer to the in-phase condition, which occurs when there is a path-length difference of $0{\cdot}5\,\lambda$. For values greater than $0{\cdot}5\,\lambda$ field strength decreases. An increase in the path-length difference is achieved by increasing the height of

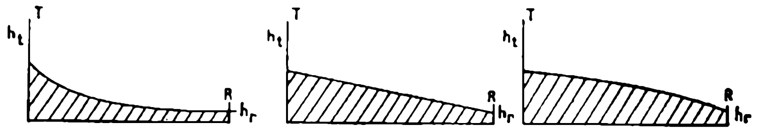


Fig. 5.52. Examples of concave, inclined plane and convex ground profiles

transmitting and receiving aerials. The expression for the resultant field strength at R assuming ideal conditions is given by

field strength at R

$$= (\textit{free space field strength at } 1 \textit{ km from } T)\frac{4\pi h_t h_r}{\lambda d^2}$$

In practice the surface of the ground will be uneven and this will affect the final field-strength value obtained. When the ground is not flat the relationship given above will be modified depending on the shape of the ground profile. Fig. 5.52 shows three different types of profile illustrating concave, inclined plane, and convex ground profiles. For the inclined plane the voltage received at R will not differ very appreciably from that calculated by the expression given above, but with the concave profile the received signal will be rather higher because the path followed by the reflected ray has been increased, and conversely the convex profile will give a lower value of received signal. Very-high-frequency transmissions tend to travel in straight lines and there is little atmospheric refraction; also behind any large obstruction between the transmitter and receiver there is a region of weak diffracted field. These effects combine to give a very much reduced field strength.

Some indication of the variation of field strength over a profile containing a valley and a hill is shown in Fig. 5.53. The average field strength shown by the dotted line will conform fairly closely to that predicted from the expression given above. When estimating the field strength over any given path, allowance must be made for the curvature of the earth and also for the slight refraction that occurs as the wave travels outwards from the transmitter. The service area is therefore not limited to the optical horizon.

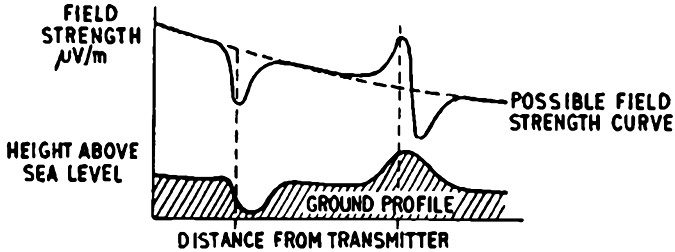


Fig. 5.53. Effect of a valley and hill on v.h.f. field strength

It has been found that the radio horizon may be determined on the assumption that the earth's radius is about 4/3 times its physical radius. An example of a good v.h.f. transmission path profile, that in a west-east direction on either side of the Holme Moss transmitter, is shown in Fig. 5.54.

Refraction of the v.h.f. wave towards earth is helped by the normal atmospheric conditions producing a decrease in temperature,

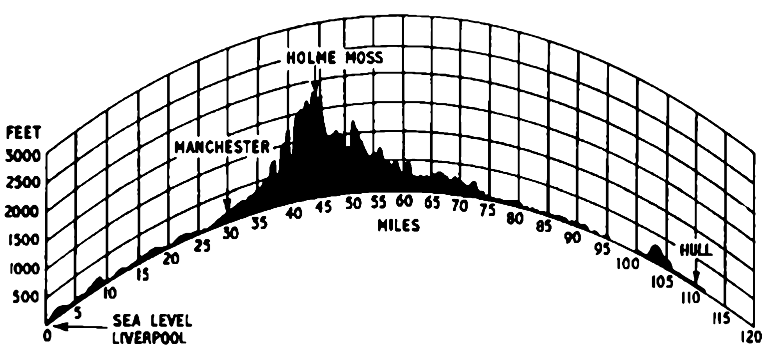


Fig. 5.54. East-west transmission path profile for the Holme Moss transmitter. Height of aerial 2435 ft. above sea level

pressure and humidity with increasing height. These conditions, however, may be changed, particularly during anti-cyclonic weather when the atmosphere is very still, and inversion layers may be set up at heights varying between 100 and 3 000 metres. The chief effect of these inversion layers is to provide partial reflections downwards which may tend to reduce the service area by fading and also to lead to interference effects at long distances between transmitters sharing the same frequency channel. It is also possible that a reversal will occur and the waves will be reflected back to earth at very much increased distances and long-distance propagation may be achieved. Interference can then result between stations operating on or near the same frequency and spaced geographically far apart, but fortunately the percentage of programme time during which this interference is serious is not large.

5.7 PARALLEL OPERATION OF TRANSMITTERS

One of the most important aims in broadcasting is to maintain an uninterrupted service. The use of transmitters operating in parallel from the same drive unit and modulated with the same programme can increase the reliability of the service, because a failure in one transmitter merely reduces the effective power radiated by the aerial but does not shut down the service. The transmitters may be connected in parallel to a single feeder and aerial, or they may be connected separately to two halves of an aerial system. The first method is used at the low-frequency and at some of the medium-frequency stations, whereas the second is used on the Band II f.m. transmissions. A schematic diagram of the paralleling system used at Droitwich for the low-frequency transmission at 200 kc/s is shown in Fig. 5.55. Either or both transmitters can be connected to the feeder but the dummy load which is used for testing the transmitter can only accept the output of one. The matching networks between the transmitters and the feeder ensure that when only one transmitter is used the load impedance is 300 Ω, whereas with two transmitters in parallel the impedance is reduced to 150 Ω. Two important conditions must be fulfilled to make parallel operation successful. The r.f. outputs from the transmitters must be in phase and the modulating voltages must also be in phase. No special precautions are necessary in the modulator stages apart from using a.f. amplifiers whose characteristics are as nearly as possible the same. The r.f. outputs must, however, be adjustable in phase, and phasing units containing variable reactances are included between the drive and the input to the transmitter r.f. stages. When a phase comparison is to be made the output from each transmitter is switched in turn to the dummy load and is compared against a reference voltage: each is brought into phase with the reference voltage by varying the reactance in the phasing unit.

A drive-suppression amplifier is included between the drive and the transmitters, and if a fault develops in one transmitter to cause

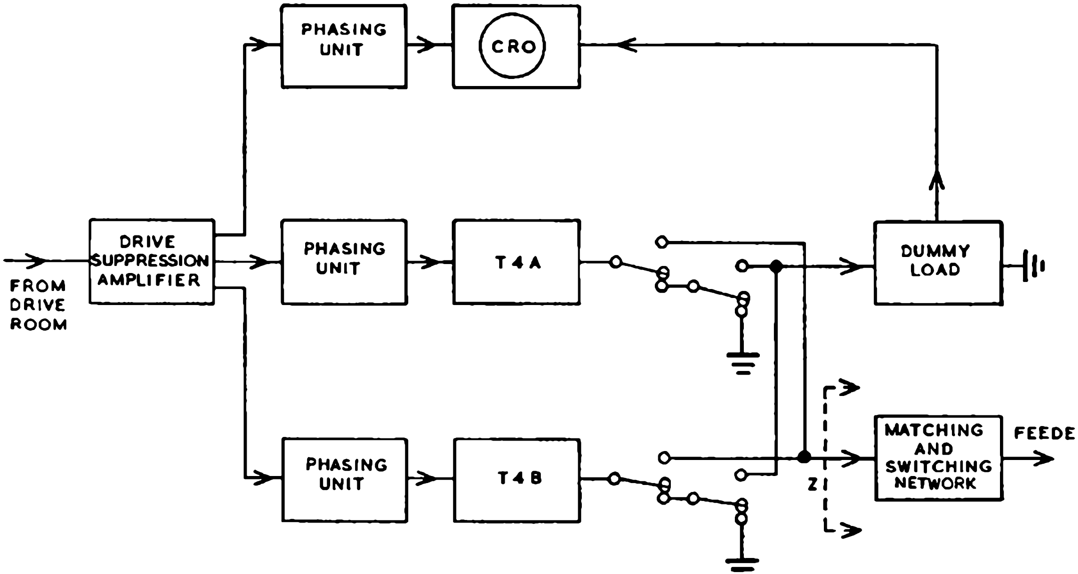


Fig. 5.55. Method of paralleling low-frequency transmitters as used at Droitwich

the e.h.t. to be switched off, the drive-suppression amplifier cuts off the drive to both transmitters and closes down the other transmitter. The faulty transmitter is switched to the dummy load, the drive is restored and radiation is resumed on one transmitter. There is therefore a brief break in the programme whilst the switching is carried out. The Third Programme installation at Daventry is an example of a more modern system of parallel operation and the schematic diagram is given in Fig. 5.56 (a). The special bridged-T combining unit presents a load of 110 Ω to the transmitters, i.e., each transmitter is given a load of 220 Ω.

The equivalent circuit of the combining unit is that of Fig. 5.56 (b) when the two transmitters are correctly phased and sharing the load. The voltage outputs are in phase and equal in amplitude and the bridging arm carries no current. A meter coupled to this arm is used as an indication of correct operating conditions, which are adjusted to give zero reading. If one transmitter develops a fault and closes down, the equivalent circuit is that of Fig. 5.56 (c) and the load presented to the operating transmitter is 220 Ω, with an equal sharing of the power between the bridging arm and the feeder. The power output with the single transmitter is therefore reduced to $\frac{1}{4}$ but there is no break in the programme. If attempts to restart the shut-down transmitter fail, the feeder connections are rearranged so that the other transmitter supplies all its power to the feeder. The improvement in reliability obtained by parallel operation means that the system lends itself to remote or automatic control.

The 150 kW Third Programme transmitter at Daventry is controlled from the Daventry main control room. Many low-power Home Service transmitters and the v.h.f. frequency-modulated transmitters are switched on and off automatically by time switches set to operate at the appropriate times. More than two transmitters may be paralleled, and some of the low power m.f. installations use three 660 W transmitters operating in parallel to give a power of approximately 2 kW. The three transmitters are combined in a somewhat similar manner to the two at Daventry. The combining unit is common to the three units so that every precaution has to be taken to ensure that the chances of a fault developing in this unit are remote.

5.8. AUTOMATIC MONITORS[10]

In the earlier days of broadcasting, monitoring of sound transmissions was performed aurally but it was not entirely satisfactory because it imposed a strain on the conscientious listener and could not be undertaken for any length of time without loss of efficiency.

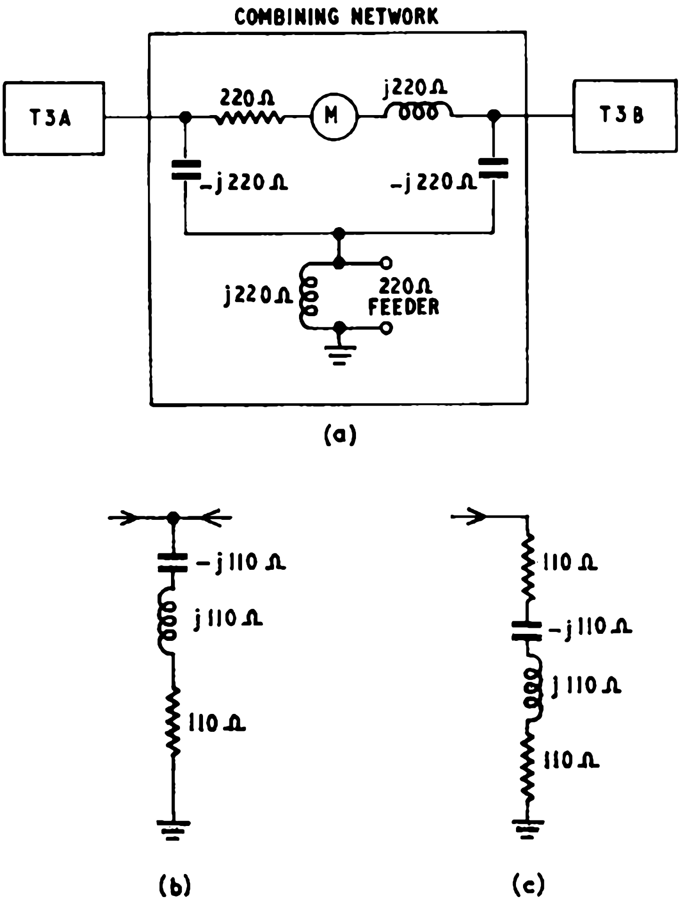


Fig. 5.56. The combining unit for the Third Programme paralleled transmitters at Daventry

In recent years, automatic monitors have been developed by the BBC Designs Department and these are now installed at strategic points in the broadcasting chain. Their widespread use represents considerable economic advantages.

The principle of operation is that a comparison is made between the amplitudes of two signals. One is a reference signal, a processed version of the original good-quality programme, and the other is a similarly processed version of the signal whose quality is to be checked. If the amplitude difference between the processed signals exceeds 3 dB, an alarm gives warning to staff or if no staff are available the monitor may switch parts of the equipment out of circuit.

The most commonly used apparatus is the Automatic Monitor Minor and two examples of its application are shown in Fig. 5.57. The studio centre sends programme by line to the transmitter and receives via a spare line or directly by radio pick-up a signal back from the transmitter. This is processed in the automatic monitor which then compares it with the originating signal from the studio. If the distance between studio and transmitter is considerable, direct pick-up of sufficiently satisfactory quality may not be feasible and a high-quality line may not be available. Use is made of a carrier system to take a processed version of the programme to the transmitter where an Automatic Monitor Major is installed. In essential principles it does not differ from the Minor and only the latter will be considered. Faults which produce differences between the compared and reference signals include the following:

(a) Breakdown of lines, amplifiers, transmitters.

(b) Excessive noise level. Signal-to-noise ratio at 100 per cent modulation should be at least 40 dB.

(c) Variation of frequency response. A satisfactory response is considered to be obtained when the level variation from 50 c/s to 7 kc/s is not greater than 1·5 dB.

(d) Non-linearity.

(e) Variation in transmission equivalent of the line.

Referring to the schematic diagram of Fig. 5.58 it will be noted that the signal to be checked and the reference signal are connected to two volume-folding and limiting amplifiers (VFLA) and in these the signals are processed and applied to a differential amplifier which energises an alarm system when the difference between the two outputs reaches a value of 3 dB. The volume-folding and limiting amplifiers have circuits possessing particular frequency responses and specified amplification characteristics.

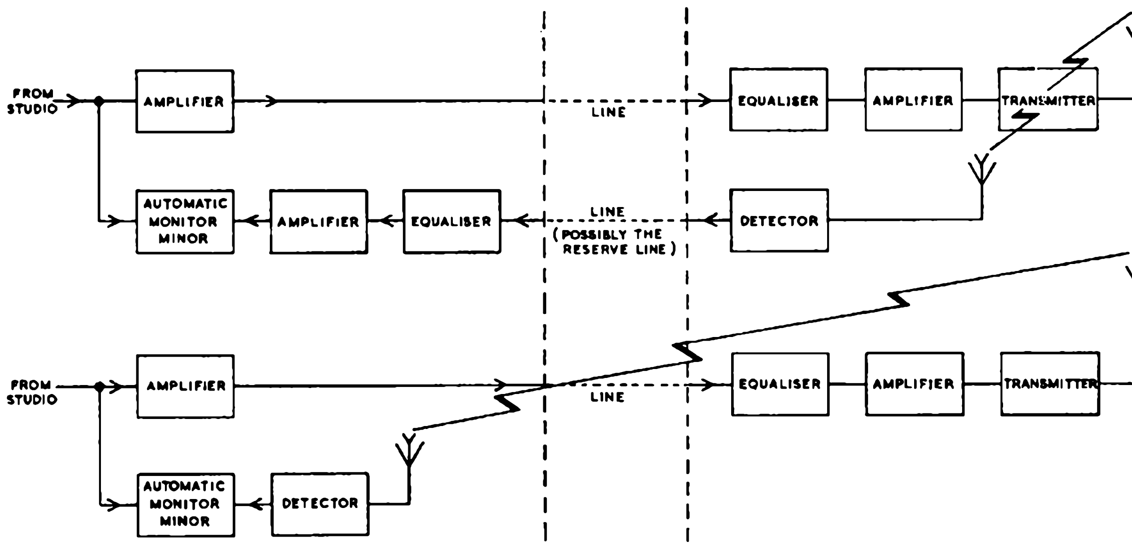


Fig. 5.57. Two methods of using the automatic monitor

The reference signal is also applied to the alarm suppressor over-modulation (A.S.O.) which prevents warning being given until the over-modulation peaks have continued for at least two minutes. Normal over-modulation lights a green lamp, whereas excessive over-modulation lights a red lamp.

If a radio link is used to return the signal from a distant station, noise or interference may be picked up with the signal and could

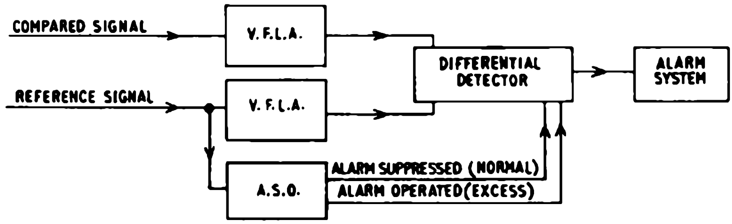


Fig. 5.58. Schematic diagram of the automatic monitor

operate the alarm. An alarm suppressor static (A.S.S.) is employed to prevent this; noise and interference picked up in a narrow-band receiver tuned to a frequency near that of the transmitter being monitored is used to operate a relay which suppresses the alarm. Equipment known as a 'transmitter executive monitor' may be installed at a station to keep a watch on distortion due to overload and noise such as hum. If either of these fault conditions is appreciable, the transmitters are closed down. When this happens a signal is sent via a phantom circuit to the controlling station where it gives an alarm.

The state of the equipment at the remote station can be checked either by a telephone call to the local technical staff, or if the station is unattended, by a series of code signals the sequence of which gives the required information.

5.9 TEST EQUIPMENT AND PERFORMANCE TESTS

Detailed procedure for checking the performance of all types of transmitters is laid down, and the performance tests and apparatus will be briefly described in this section.

5.9.1 *Apparatus and Performance Tests for A.M. Sound Transmitters*

The equipment required to test an a.m. sound transmitter consists of a low-distortion tone source variable over a frequency range from 30 c/s to 15 kc/s, a means of extracting the modulation, and equipment for measuring distortion and other undesired effects. The performance of a sound transmitter is checked by taking measurements of:

(i) harmonic distortion,
(ii) noise, and
(iii) frequency response.

Harmonic distortion is mainly a valve effect though certain components such as an a.f. transformer can contribute, and a schematic diagram of the equipment required is shown in Fig. 5.59. The output from a tone source such as TS/7 or TS/9 is applied to the programme input equipment and the modulation is set for 40 per cent (indicated on the modulation monitor unit MMU/1). A r.f. voltage is taken from the output of the transmitter or from the aerial and applied to a detector followed by a filter, which removes the fundamental frequency of the tone source and leaves only the harmonic distortion. The output of the filter is connected to an amplifier followed by a meter.

The apparatus may be a complete equipment of commercial manufacture or may be made up from the modulation meter unit, a filter (FHP/3) and the amplifier detector AD/5. The output meter may be calibrated directly in percentage distortion or in dB. The relationship between the decibel reading and the percentage harmonic distortion is dB $= 20 \log 100/H$ where H is the percentage distortion. Measurements are taken at 20 per cent, 70 per cent,

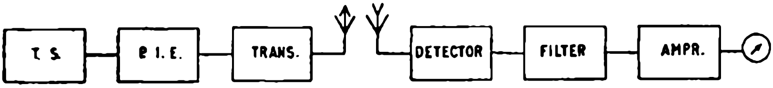


Fig. 5.59. Schematic diagram of connections for performance tests on transmitters

80 per cent and 90 per cent modulation as well as 40 per cent, but the tone modulation must not be maintained for a period longer than a minute at the higher percentage modulations.

The equipment for noise measurement is similar to that for distortion except that the filter is replaced by an attenuator. The transmitter is modulated by 1 000-c/s tone to 40 per cent and the attenuator adjusted to give full-scale reading on the meter; the 1 000-c/s tone source is removed and replaced by a 600-ohm resistance across the input to the programme input equipment. The 600-ohm resistance is required to keep the input circuit to the equipment unchanged. The attenuator is then readjusted to give full-scale reading and the attenuation removed is a measure of the noise level with reference to 40 per cent modulation. Since the noise is generally referred to 100 per cent modulation, the reading obtained must be increased by 8 dB, thus a 34-dB signal-to-noise measurement obtained with 40 per cent modulation is equivalent to 42 dB at 100 per cent modulation.

The frequency-response measurement is taken by noting the percentage modulation radiated by the transmitter when a constant voltage of variable frequency is applied at the input.

5.9.2. *Performance Tests on F.M. Sound Transmitters*

The Marconi f.m. station monitor is normally used for checking the performance of the v.h.f. sound transmitters, and many of the tests, e.g., harmonic distortion, noise and frequency response are similar to those used on a.m. transmitters. The station monitor contains a frequency-to-amplitude converter, a filter and an amplifier. Total harmonic distortion is measured at full modulation (± 75 kc/s deviation at different modulating frequencies), and since the power taken by the transmitter is independent of the modulation, there is no time limit on this test. Noise measurement is made in a similar way to that for amplitude modulation. The same applies to frequency response but it must be remembered that there is a pre-emphasis circuit included in the f.m. transmitter and either this should be disconnected from the circuit or allowance made for the increase in response at the higher audio frequencies.

The station monitor usually undertakes two further tests, a measurement of the amplitude modulation caused during normal frequency modulation, and a measurement of the shift of the centre frequency during modulation. The former can be obtained quite simply by detecting the frequency-modulated carrier by means of the normal diode detector, any output being a measure of the amplitude modulation. Measurement of centre-frequency shift is performed by applying the frequency-modulated signal to a correctly tuned frequency-to-amplitude converter giving zero d.c. output when the centre frequency is at its correct value.

5.9.3 *Performance Tests on Vision Transmitters*

Much more apparatus is required for tests on vision transmitters and a schematic diagram of the testing and monitoring equipment is shown in Fig. 5.60. The waveform generator produces a complete television synchronised waveform to which can be added as required the following test signals: (a) line saw-tooth for checking linearity, (b) cruciform giving a black cross on a white background for checking low-frequency performance, and (c) line spike, a pulse of 1 to 2 microseconds duration occurring at the middle of each

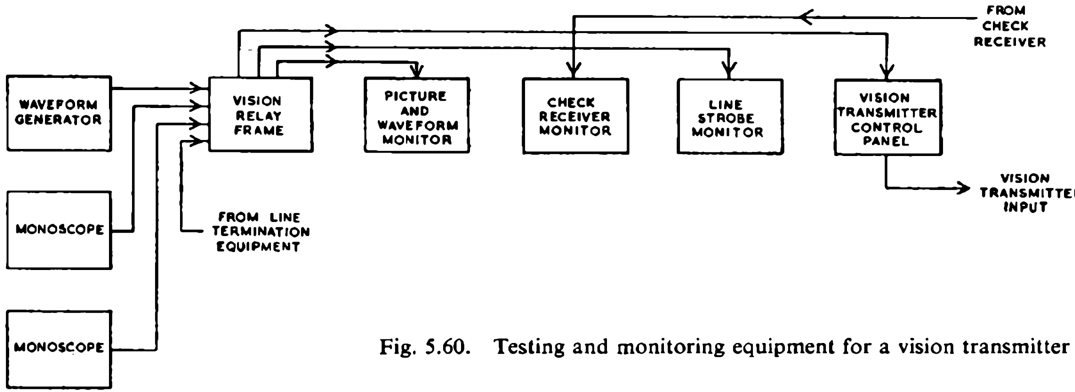


Fig. 5.60. Testing and monitoring equipment for a vision transmitter

line and producing a vertical white line to test high-frequency performance. The vision relay frame shown in Fig. 5.60 can select an input from the waveform generator, from the line termination equipment, which carries the vision programme, from a monoscope displaying a test card, or from an apology caption. From the vision relay frame the vision signal is applied to the vision transmitter control panel and the various monitors. The picture monitor gives a reproduction of the scene that is being transmitted and the waveform monitor displays the frame and line waveforms. The line strobe monitor allows the waveform of any particular line in the vision signal to be selected and viewed. Facilities are available for monitoring at any of the inputs to the transmitter and at important points in the transmitter with the aid of a check receiver. Assessment of performance is largely carried out by inspection of waveform, and both the saw-tooth and the vertical line are used as test waveforms.

Vertical line has a high fundamental frequency and harmonic components which extend to the highest video frequency in the passband. Attenuation of the high-frequency components produces a rounding of the corners of the wave and increases the rise time of the pulse. If the high-frequency components are accentuated or the cut-off outside the pass range is too rapid, overshoot will tend to occur. Frequency-response and noise-level tests are similar to those made on sound transmitters except that the frequency response has to be taken to 3 Mc/s.

5.10 FREQUENCY CHECKING[11]

5.10.1 *General Considerations*

The carrier frequencies of all broadcasting transmitters must be maintained within prescribed limits, and a regular check must be undertaken. Accurate measurements of frequencies are regularly made at Tatsfield, but supplementary measurements are also carried out locally. The low-frequency transmitter (200 kc/s) at Droitwich has a very high carrier-frequency stability and its checking is carried out by Tatsfield only. The medium-frequency transmitters are supplied with frequency-checking apparatus which enables them to compare their own carrier frequency against a reference frequency of high stability sent by line from a central point or obtained from the low-frequency Droitwich transmission. The high-frequency (short-wave) transmissions are compared against a locally-generated standard, and the v.h.f. transmissions for sound and vision are checked locally on station frequency monitors as well as at Tatsfield when possible.

5.10.2 *Checking of Medium-frequency Transmissions*

The reference frequency for checking the medium-frequency transmissions is 1 kc/s, and in one type of apparatus (FRC/2B) a marker pulse derived from this frequency is used to give vertical deflection of a cathode-ray tube beam, which is deflected horizontally by a stepped waveform time base which is derived from the r.f. carrier, each step corresponding to one cycle of the r.f. carrier.

The horizontal trace will appear as a series of spots, corresponding to the 'horizontal' portion of the step, joined by faint lines, corresponding to the 'vertical' portion of the step. The number of spots selected for display must be a submultiple of the carrier frequency (expressed in kc/s) if the marker pulse derived from the 1 kc/s reference frequency has a repetition rate of 1 000 times per second.

If the number of spots selected is not a submultiple, a single vertical marker pulse will not be obtained and this may create difficulties in interpretation.

Suppose it is desired to measure the carrier frequency of the Midland Home Service transmitter, nominally 1 088 kc/s, possible numbers of spots are 2, 4, 8, 16, 17, 32 or 64, all of which are submultiples of 1 088. If 8 spots were selected 7 would probably be clearly seen on the screen and the eighth or a part of it might be 'lost' in the flyback. The marker pulse derived from the 1 kc/s reference is of short duration and is used to give vertical deflection as well as a brightening pulse on the cathode-ray tube grid. It therefore produces a bright vertical line which remains stationary if the carrier frequency is an exact multiple of the 1-kc/s reference. If the carrier is not at its exact value the vertical line will move to left or right: if it moves from one bright spot on the horizontal trace to the next on its right in 1 second, it is in error by $+$ 1 c/s in 1 088 000 cycles, i.e., its frequency is greater than it should be: if it moves to the next on the left in 1 second, the error is -1 part in 1 088 000. If n cycles are covered in 1 second the error is $\pm$ n parts in 1 088 000.

This method of operation cannot be used if the carrier frequency in kc/s is a prime number, e.g., 1 151 kc/s because it is then not possible to find a submultiple. This difficulty can be overcome by deriving from the 1-kc/s reference a marker pulse which has a repetition of rate of 250 times per second. As long as the carrier frequency in kc/s is a whole number it will always be divisible by 250 to produce a submultiple of 4. Since the apparatus must be capable of functioning to measure carrier frequencies which may nominally be prime numbers (in kc/s), the marker pulse is always repeated 250 times per second and normally 4 spots are displayed on the screen.

In the alternative form of frequency-checking equipment known as the Type FCE/1, the Droitwich 200-kc/s carrier frequency is divided down to 1 kc/s and used as a reference signal. The 1 kc/s reference is converted to two special pulse-shaped waveforms which are applied to the X and Y plates of a cathode-ray tube to produce a triangular figure on the screen. The r.f. carrier which requires checking is applied to the grid of the cathode-ray tube to modulate the beam current and produces a series of spots in the triangular waveform, each spot corresponding to a half-cycle of the r.f. wave. If the r.f. carrier is not an exact multiple of the 1-kc/s reference frequency, the spots will travel round the triangle. The 1-kc/s modified waveform produces a brightening at the ends of the triangle and this can be used as a marker for the travelling r.f. spots. The reciprocal of the time between the disappearance of one spot and the next spot into the corner of the triangle is the number of cycles error. The latter is positive if the spots are moving clockwise and vice versa. Thus if the time taken is 0·5 seconds in an anticlockwise direction, the error on a 1 088-kc/s carrier is 2 parts in 1 088 000. Many of the medium-frequency transmitters work in synchronised groups and the carrier frequencies must be within about 0·05 of a cycle. As a rule they are all set to have a slight positive error.

5.10.3 *Checking of High-frequency Transmissions*

At the short-wave stations the permissible frequency tolerance is greater, and a simpler method of checking dependent on a local sub-standard of frequency is employed. The standard is a 100-kc/s crystal-controlled oscillator, associated with a divider producing a 5-kc/s output. The outputs at 100 kc/s and 5 kc/s are applied to a mixer which produces sum and difference terms, giving a continuous spectrum of frequencies spaced 5 kc/s apart. The variable frequency oscillator drive units for the short-wave transmitters are set near to their nominal frequency and are then steered into the correct value by beating against their appropriate 5-kc/s multiple frequency from the frequency standard. The standard and carrier frequencies are applied to a detector whose output is connected to headphones and the carrier frequency is 'steered' to give zero beat.

REFERENCES

1. 'Crystal Oscillator Units (COU4, 4A and 4B)', *BBC Technical Instruction T3.*
2. 'BBC Variable-frequency Drive Equipment', *BBC Technical Instruction T4.*
3. 'Audio-frequency Amplifiers', *BBC Technical Instruction S3.*

4. 'Frequency Modulation', *BBC Engineering Training Supplement No. 9.*
5. 'Television Amplifiers', *BBC Technical Instruction V2.*
6. 'Short-wave Transmission Lines and Aerial Arrays', *BBC Technical Instruction T6.*
7. 'An Introduction to Slot Aerials', *BBC Engineering Training Supplement No. 5.*
8. 'Long-wave and Medium-wave Propagation', *BBC Engineering Training Supplement No. 10.*
9. Bennington, T.W., 'Short-wave Radio and the Ionosphere', Iliffe Books Ltd., 2nd Edition (1950).
10. 'Automatic Monitor Minor', *BBC Technical Instruction S6.*
11. 'BBC Frequency Checking Equipment', *BBC Technical Instruction T5.*

CHAPTER 6

THE LINE INTERCONNECTION SYSTEM

THE need for a satisfactory interconnecting system by line, in order that the sound and vision programmes of the BBC can be distributed and collected, will have been made obvious in the preceding chapters. Equally important is the provision of a comprehensive internal communication network, which is so necessary for programme planning, news distribution, general administration and engineering purposes such as control and monitoring. Telephone links need to be supplemented by telegraph circuits for quickly and accurately conveying messages, and by facsimile when exact copies are required.

With very few exceptions all circuits used by the BBC for programme and communications are owned by and rented from the Post Office. The exceptions occur on links where P.O. lines are not available and would be uneconomic, and a solution is generally found through the use of comparatively short-range radio links provided by the BBC itself. Communication circuits will first be considered.

The problem of providing an adequate communication system is complicated by the large number of premises operated by the BBC in London and the other six regions. In the very early days of broadcasting communication was achieved by using the public trunk and local call system, but this was soon replaced by manual and later automatic switchboards with exclusive private wires for interconnection giving 'bothway' speech circuits.

The BBC permanent programme (music) network requires a proportion of reserves, and circuits for the Third Programme and Network Three are generally unused during office hours. These can therefore provide a number of wide-band (approximately 10 kc/s) one-way channels which may be used for communication purposes. A considerable system has been built up of carrier multiplex channels, consisting of a number of narrow-band speech and/or telegraph signals contained within the music band. The speech and telegraph channels are handled through the Private Branch Exchange (PBX), Private Automatic Branch Exchange (PABX) and Teleprinter

Switching units, with suitable arrangements for restoring the lines to programme use and supervision when needed.

The necessarily complex terminal equipment required to do this, much of it made by the BBC, is maintained by engineers of the BBC Lines Department and the purpose of this chapter is to indicate briefly their work and to describe in more detail the general principles of the methods of communication used by the BBC as well as the technical problems involved in the S.B. distribution system used for sound and vision programmes.

6.1 THE WORK OF STAFF CONCERNED WITH THE LINE INTERCONNECTION SYSTEM

The BBC Lines Department has staff in each Region to handle day-to-day activities associated with programme and communication lines, and at its headquarters in London it has six sections referred to as Communications, S.B. and London Lines, Sound O.B.s, Television, Finance and Special Duties.

The Communication section is concerned with providing, maintaining and testing the communication apparatus such as carrier equipment, facsimile machines and teleprinters in London and at the Regional centres.

The S.B. and London Lines Section is responsible for the technical planning, ordering and acceptance of the permanent Sound and Television-Sound network from the Post Office and for the equalisation of the lines before they are put into regular service. It organises routine tests, the interpreting of cable temperature records, the issue of instructions for temperature correction compensating for seasonal variations in line circuit constants, and the reporting and clearing of faults. The section issues daily charts covering the use of circuits for programme and other purposes, and orders and equalises temporary inter-regional circuits when requirements cannot be met by the permanent channels. It also undertakes the general liaison with the P.O. and lays down the technical standards for the lines used by the BBC.

The Sound O.B.s Section centralises the ordering of Sound O.B. lines, including some of the sound lines for Television O.B.s, handles the testing of O.B. lines in the London area and arranges for the installation of split-band equipment whereby two lines whose individual frequency responses are inadequate for carrying programme may each be used to convey half the programme frequency range.

A very important aspect of its work is the planning and implementation of the temporary (sound) network for both Sound and Television when complex national or Eurovision transmissions are undertaken. This entails the construction, installation and manning of special apparatus.

Many of the long-distance temporary circuits (known as Occasional Programme Circuits) are now equalised and repeatered by the P.O., but it is sometimes still necessary to install temporary repeaters in P.O. exchanges, and this is undertaken by the Sound O.B. Section. This Section arranges with suppliers inside or outside the BBC for the design and supply of O.B. lines apparatus, and takes responsibility for the standardisation of requirements.

The Television Section operates the London Television Switching Centre and the Television Lines Booking Office, which handles all line requests for television purposes. The section also supervises the performance of, and organises the routine test schedules for, the television distribution and contribution systems, and orders and accepts vision lines and other links needed for television O.B.s. A considerable amount of planning for all television O.B.s, and particularly the complex ones, is undertaken. The section maintains and operates the Continental Control Point which is the United Kingdom intake and transmission centre for all Eurovision transmissions.

Of the two remaining sections, the Finance section prepares estimates, acts as a channel for all Post Office contracts and circuit orders and provides PABX and PBX facilities. It works closely with the Post Office and contractors in planning telephone facilities, arranges for the payment of accounts and prepares statistical summaries. The Special Services section looks after stores as well as general constructional work.

Before discussing the problems involved in providing a communication and programme line system for sound and television broadcasting it is important to discuss the characteristics of a typical line.

6.2 CHARACTERISTICS OF A LINE

Any line, whether it is used for communication, sound or television programme purposes has four parameters, resistance, R, inductance L, conductance G and capacitance C. These occur in distributed form throughout its length and if a short enough length of balanced line is taken its parameters may be represented in H form as though they were lumped components (Fig. 6.1). The series arms are made up of $\Delta R/4$ and $\Delta L/4$ with a shunt arm of conductance ΔG and capacitance ΔC, where R is the series resistance of the line per unit length, L is the inductance per unit length and Δ is one of the *short* lengths into which the line is considered to be divided. G and C are the conductance and capacitance per unit length. Many other forms of equivalent circuit for a line can be used.

The impedance which a very long line presents to its input terminals is known as its characteristic impedance Z_0, and it may be determined for any length x of line by measuring the input impedance (Z_{sc}) with the output terminals short-circuited, and the input impedance (Z_{oc}) with the output terminals open-circuited. The square root of the product of these two values of input impedance gives the characteristic impedance of the line, i.e., $Z_0 = \sqrt{(Z_{sc}.Z_{oc})}$. If it is assumed that $R + j\omega L$ is much less than $\frac{1}{G + j\omega C}$ then $Z_{sc} = (R + j\omega L)x$ and $Z_{oc} = \frac{1}{(G + j\omega C)x}$ giving $Z_0 = \sqrt{\left(\frac{R + j\omega L}{G + j\omega C}\right)}$. An interesting situation arises with $R/G = L/C$ because the characteristic impedance is then equal to a constant value $\sqrt{(L/C)}$ or $\sqrt{(R/G)}$, and has no reactive component. When such a line is terminated in a resistance equal to $\sqrt{(L/C)}$ it shows no discrimination against signals of different frequencies but attenuates all equally, and is known as a distortionless line. This

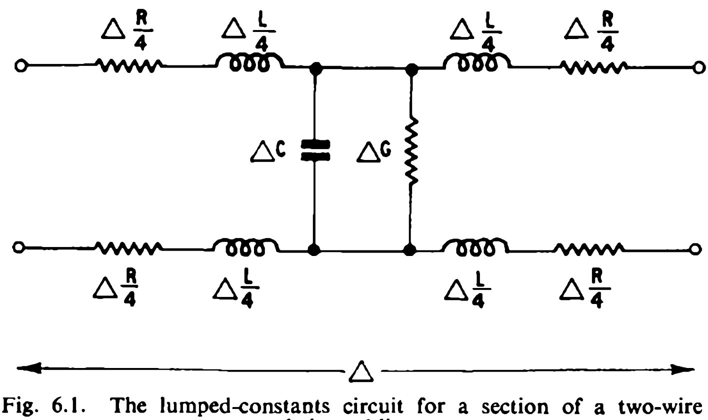


Fig. 6.1. The lumped-constants circuit for a section of a two-wire balanced line

ideal distortionless condition cannot be realised with an underground cable, for $R/G > L/C$ because C is large. When the frequency is low $Z_0 \simeq \sqrt{(R/G)}$ because $R \gg \omega L$ and $G \gg \omega C$, but at high frequencies $Z_0 \simeq \sqrt{L/C}$ because $\omega L \gg R$ and $\omega C \gg G$. Fig. 6.2 gives an indication of the variation of characteristic impedance Z_0 with frequency for a typical line in an underground cable intended for communication purposes.

The other important line parameter is its propagation coefficient $P = \sqrt{[(R + j\omega L)(G + j\omega C)]}$ and from this the attenuation of the line and the time retardation of the frequency components being transmitted down the line can be determined. The derivation of attenuation constant (α) and phase constant (β) is given elsewhere[1], and this shows that attenuation in general increases with increase of resistance, capacitance and frequency. Since the line attenuates

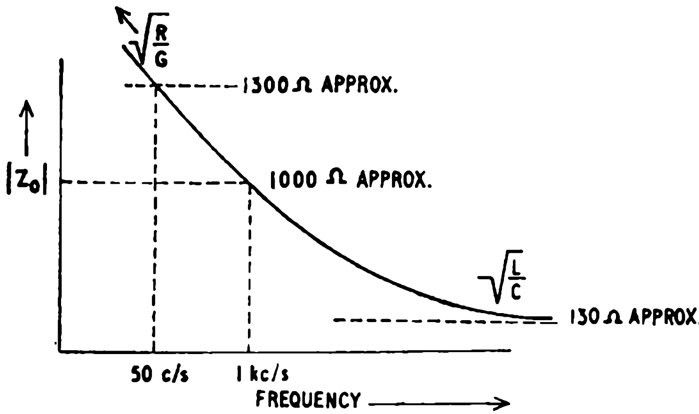


Fig. 6.2. The impedance-frequency characteristic of a typical line

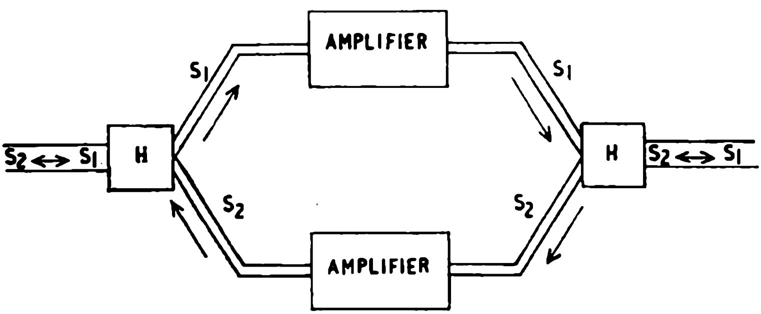


Fig. 6.3. The essential components of a long distance two-way communication system

the higher frequencies much more severely than the lower, an equaliser with an inverse frequency response characteristic is required to correct and restore the frequency response as outlined in Section 2.7.1. The equaliser can only level up the response by reducing the output at all frequencies to a value slightly less than the output of the line at the highest desired frequency, and an amplifier is needed after the equaliser to bring the signal level up to the desired level at the receiving end.

The characteristics required from a line depend on the service it has to perform, and a list of the usual services together with their required bandwidths is given below:

Service	*Bandwidth*
Teleprinter	0–100 c/s
Speech	300–3 300 c/s (CCITT Standard) 300–2 300 c/s (for BBC internal communication)
Facsimile	1 300 c/s (carrier $\pm$ 1 000 c/s (sidebands)
Music and sound broadcasting generally	40 c/s to 8 kc/s (minimum)
Television	50 c/s to 3 Mc/s

The BBC internal speech communication system uses a lower maximum frequency limit than the CCITT* standard because the more complete control possible allows a lower over-all loss; the reproduced signal is at a level comparable to that of the signal at the sending end and also has a good signal-to-noise ratio. Under these circumstances satisfactory intelligibility can still be achieved with the narrower band.

6.3 CHARACTERISTICS OF A LINE COMMUNICATION SYSTEM[2]

The simplest form of line communication system would be a pair of wires, a microphone, a source of power, and a telephone, but in cables this would probably only be useful for covering between 10 and 20 miles. For longer distances amplifiers would be required and Fig. 6.3 gives an indication of the essential components of a long-distance communication system. Amplifiers will be needed at regular intervals along the line to prevent the signal falling to so low a value that noise and interference, which inevitably occur on any communication system, become troublesome. Since amplifiers can accept signals only in one direction, two amplifiers are required at each amplification point, one for the forward and the other for the return communication. The distances between the amplification points are determined by signal-to-noise ratio and also by geographical considerations. For long-distance transmission it is essential to separate the transmit and receive paths, GO and RETURN, otherwise a closed loop is formed with the

* CCITT = Comité Consultatif International Télégraphique et Téléphonique.

amplifiers and 'howl-back' will result. The separation is effected by a hybrid circuit, usually consisting of a single multi-winding transformer. The characteristics of the line are such that it does not pass equally all frequencies, and equalisers must be inserted at suitable points to produce an over-all flat frequency response. The ultimate limit of equalisation is fixed by the inherent noise of the receiving amplifier. Equalisation of lines used for speech only is not always necessary but lines for music must always be equalised to the limits required by music transmission.

Hybrid Coil.[3] An important element in a two-way communication system is the hybrid coil (or 3-winding transformer) which allows a two-way conversation to be satisfactorily amplified without howl-back.

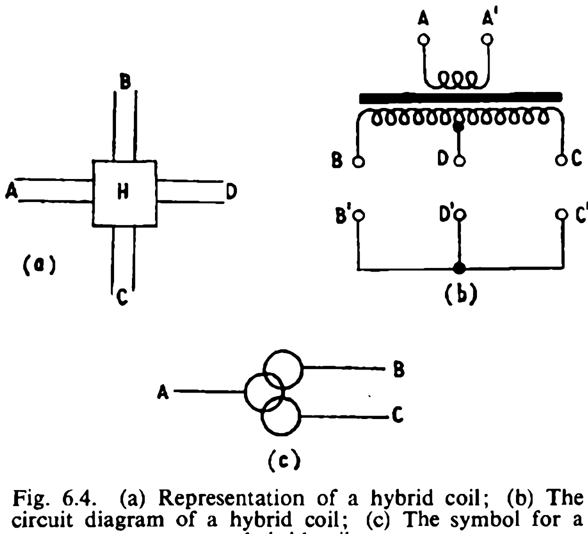


Fig. 6.4. (a) Representation of a hybrid coil; (b) The circuit diagram of a hybrid coil; (c) The symbol for a hybrid coil

The hybrid coil may be a special type of transformer with four pairs of connections, *A*, *B*, *C* and *D*, as indicated diagrammatically in Fig. 6.4 (a), or it may consist of two repeating coils; a hybrid circuit can also be made up with the aid of a balanced-bridge circuit. One important property is that an input at *A* produces no output at *D* and equal output powers at *B* and *C* when the latter are terminated in equal loads. This is also true of an input to *B* or *C* which produces no output at *C* or *B* but equal outputs on the adjacent pairs *A* and *D* when the latter are correctly terminated. In its simplest form the circuit of the hybrid coil is that shown in

Fig. 6.4 (b) which is assumed to be connected to 600 Ω lines at its *A*, *B* and *C* terminals. To obtain an input impedance of 600 Ω at *A* the turns-ratio of winding *BC* to *AA'* must be $1:\sqrt{2}$ because *BC* carries a 1 200 Ω load when *BB'* and *CC'* are connected to 600 Ω impedances. *D* is the centre tap between *B* and *C* and since the loads at *BB'* and *CC'* are equal, a balanced bridge is formed with no voltage between *DD'*.

In order that an input at *A* shall produce no output at *C* the terminals *DD'* must be terminated in 300 Ω. This can be most easily shown by assuming that *CC'* is open-circuited. The winding *BD* sees 300 Ω from the load at *A* so that the voltage input at *BB'* is divided equally between *BD* and *DD'*, i.e., $V_{BD} = V_{DD'} = \frac{1}{2}V_{in}$ and in a voltage equal to that across *DB* is induced in *DC*., i.e., $V_{DC} = \frac{1}{2}V_{in}$. The net voltage between *CD'* or *CC'* is zero and therefore no power is transferred to *CC'* from *BB'*. The hybrid coil is generally used in this way with *DD'* terminated in a balance resistor of 300 Ω, and the conventional symbol is that shown in Fig. 6.4 (c); other symbols are also in use. The input from the 'subscriber' at one of the two ends is at *A*, the output to the GO line at *B* and the input from the RETURN line at *C*. If the hybrid is exactly balanced over the range of communication frequencies, the

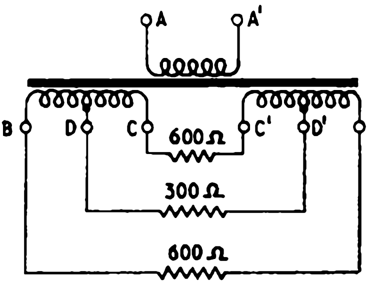


Fig. 6.5. A hybrid coil for balanced-line operation

input from *C* divides between *A* and the balance resistor at *D*, and similarly the input at *A* divides between *B* and *C* but can only progress along line *B* because it cannot pass the first amplifier in *C*. In practice, perfect balance will not be achieved but there will be very considerable attenuation between *B* and *C* so that howl-back can be prevented.

When the hybrid coil is to be used with balanced lines, two *BDC* windings are required as shown in Fig. 6.5. The 600 Ω lines are connected between *B* and *B'* and *C* and *C'*, and *D* and *D'* are joined by a 300 Ω resistance. The hybrid coil can be used to provide a clean feed for programme purposes or for echo as described in Section 2.5.

6.4 ECONOMIC EXPLOITATION OF A LINE[1,4]

Since lines are costly to construct and lay, it follows that the maximum possible use must be made of each one. The simplest method is probably the shared line shown in Fig. 6.6. The line

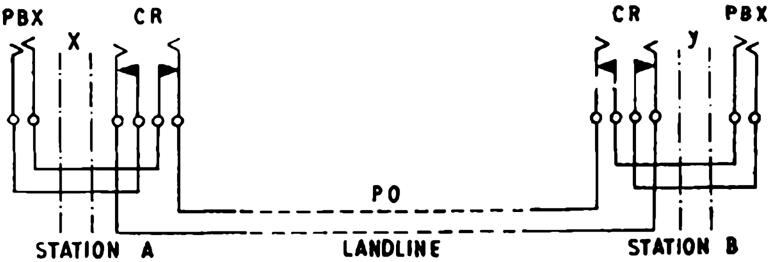


Fig. 6.6. The shared-line system

is available for PBX general use but the engineers in the Control Room (CR) have over-riding control and are able to withdraw the line from PBX in order to call their engineering opposite number. Selective ringing tone at 17 c/s or 600 or 700 c/s is used to achieve this. The scheme only applies to ordinary speech lines and only one conversation can be carried at a time. The shared line is unsatisfactory on circuits which have to carry a good

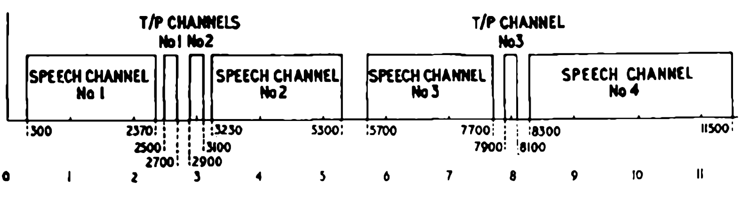


Fig. 6.7. The 1 + 3 channel carrier system

deal of traffic, and the method normally adopted by the BBC on such routes is to use wide-band one-way music lines. Thus a 10-kc/s music line can carry one speech and three carrier speech channels (each 300–2 300 c/s) with spaces in the frequency spectrum into which less demanding services such as teleprinters and signalling can be inserted.

A diagram showing the disposition of the various channels over the frequency spectrum is given in Fig. 6.7, and a simplified schematic diagram of the normal method of securing this (1 + 3) channel carrier system is shown in Fig. 6.8. The design allows 2 070 c/s for the speech channel bandwidth, slightly more than the minimum BBC requirement and this is indicated on Fig. 6.7. The telegraph signal, whose important frequency components cover a range from 0 to 100 c/s, is used to amplitude-modulate a 2 600 c/s carrier giving a double sideband signal. The amplitude-modulated telegraph carrier is passed through a filter cutting off all frequencies below about 2 450 c/s so that all telegraph-frequency components which might interfere with the speech frequencies are removed. This telegraph-modulated signal is added to the 0–2 370 c/s speech signal of channel 1, which has had its components above 2 370 c/s removed. The composite signal is passed through a low-pass filter cutting off at 2 730 c/s and it is then ready for transmission. A second telegraph signal is used to amplitude-modulate a 2 600 c/s carrier and is added to the speech channel which will form channel 2 in the manner already described (see Fig. 6.8). This composite speech and modulated-telegraph signal is used to modulate a 5 600 c/s carrier and the resultant is passed through filters which eliminate all frequencies outside a range 2 870–5 300 c/s. This means that the lower inverted sideband of the speech signal plus the double sideband telegraph modulation is selected, 5 300 c/s corresponding to 300 c/s and 3 230 c/s to 2 370 c/s of the speech components. The modulated telegraph signal originally at 2 600 c/s now appears at a carrier of 5 600 − 2 600 c/s = 3 000 c/s. A similar process is used for channel 3 but the carrier frequency is 5 400 c/s and the upper erect sideband of the speech signal from 5 700 to 7 770 c/s together with the double sideband telegraph (carrier frequency 8 000 c/s) are selected. Channel 4 uses a speech carrier of 8 000 c/s and the upper erect sideband of the speech signal is again selected; no telegraph signal is associated with this channel.

Channels 1, 2 and 3 with their associated telegraph signals and channel 4 are fed to the line, at the far end of which the process must be reversed, and the composite 4-channel signal converted back to 4 telephone and 3 telegraph signals. Channel 1 with its telegraph signal is first filtered from channels 2, 3 and 4 and then the speech, which needs no further processing, is separated from the telegraph signal. The latter after filtering from the speech must be detected to extract the modulation. The filtered channel 2 components (speech and telegraph) are used to modulate a 5 600 c/s carrier, the lower sideband of which is the channel 2 speech back to its normal frequency range of 300–2 370 c/s together with the modulated telegraph signal converted back to a carrier frequency of 2 600 c/s. The upper sidebands and 5 600 c/s carrier are filtered

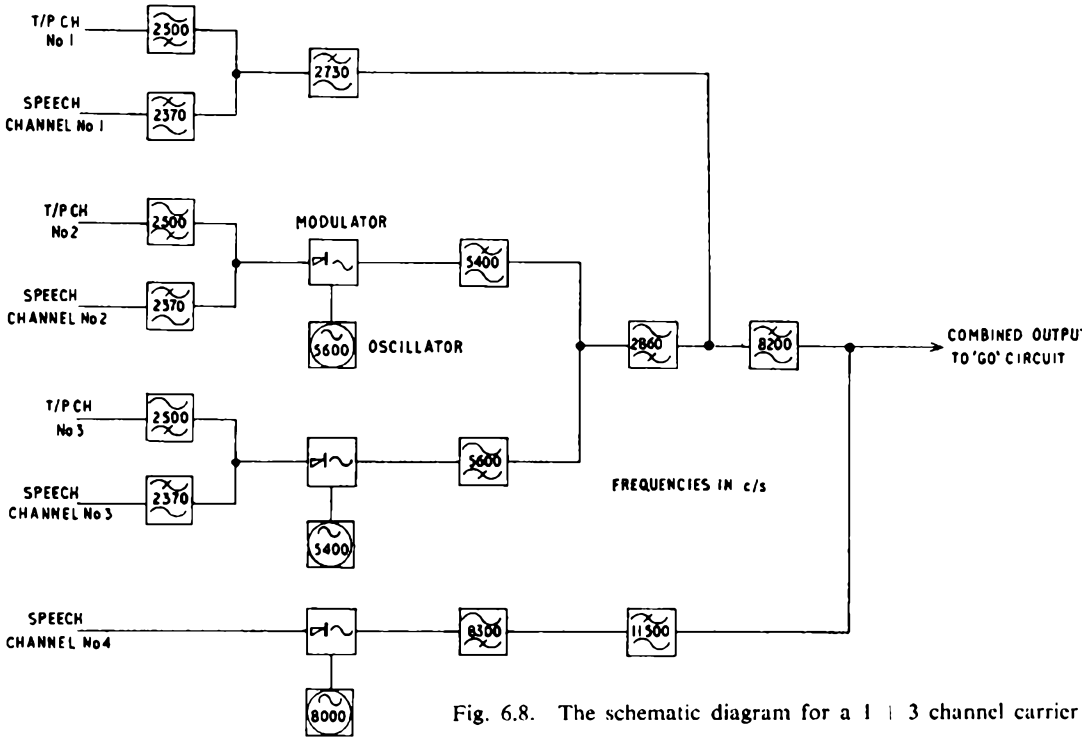


Fig. 6.8. The schematic diagram for a 1 + 3 channel carrier system

off and the lower sideband passed through a filter to separate the restored speech from the telegraph signal, which is then detected. Channels 3 and 4 are treated in a similar manner using 5 400 c/s and 8 000 c/s as the carrier frequencies. The RETURN circuit by another music line is similar to the GO circuit. The frequencies of the carrier oscillators at each end should be maintained within 1 c/s in order to keep distortion at a low level.

6.5 LINES FOR TELEPHONIC SPEECH AND SOUND BROADCASTING PROGRAMMES

The main problem with any line system is to ensure that at the receiving end signal-to-noise ratio is satisfactory and that a flat frequency response is obtained over the band of frequencies required for the service to which the line is allocated. Signal-to-noise ratio for a particular length of line is determined by the shielding of the line from external interference, its form of construction, and whether it is balanced to earth or unbalanced. Clearly an improved signal-to-noise ratio is gained by making the signal at the sending end as large as possible but there is a strict limit to what can be done in this direction because of overload in associated amplifiers. Comparatively close spacing of amplifiers will increase signal-to-noise ratio as well as ease the problem of getting adequate bandwidth. A typical communication system will therefore consist of separate GO and RETURN circuits with amplifiers spaced at intervals dictated by bandwidth and signal-to-noise ratio considerations, and such a circuit is indicated in Fig. 6.9 (a). Generally the greater the required bandwidth, the closer will be the spacing of the amplifiers. It is possible to use a two-wire system with hybrid coils at each amplifier as indicated in Fig. 6.9 (b), but the four-wire system is preferred because it gives better protection against howl-back.

Over a limited range of frequencies it is possible to improve the frequency response of a line by adding inductance at regular intervals so as to increase the effective inductance of the cable. Such a method is called loading. Fig. 6.10 shows how loading by inductance affects the frequency response of a substantial length of cable having conductors weighing 20 lb per mile length. The unloaded cable shows steadily increasing loss (curve 1) above 2 kc/s whereas loading with 88 mH every 2 000 yards turns the line into a low-pass filter having an almost flat pass-band up to 4 kc/s (curve 2). Above a certain frequency, the loss with the loaded line is greater than that for the unloaded line and rapidly increases at the cut-off frequency, at which the loading coil inductance and preceding cable capacitance resonate. This type of loaded line is very suitable

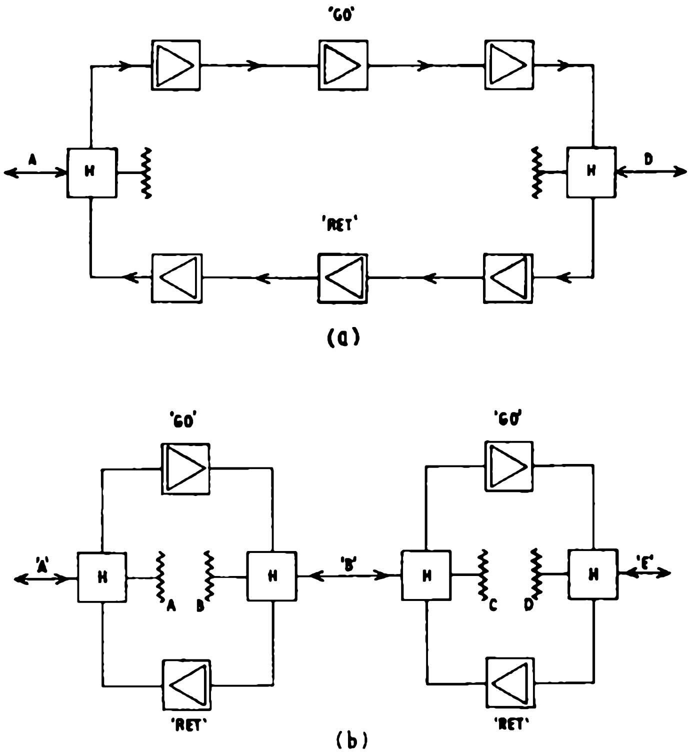


Fig. 6.9. Repeater amplifier connections for (a) a 4-wire system; (b) a 2-wire system

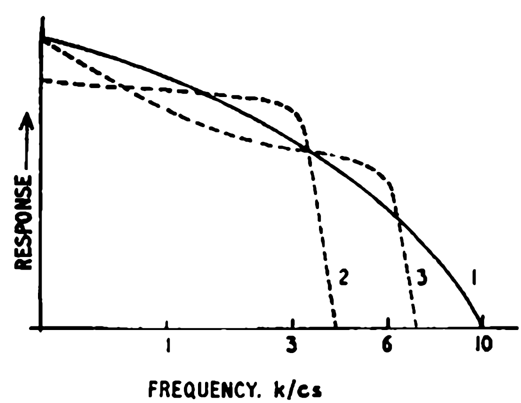


Fig. 6.10. The effect of loading on line-frequency response

for carrying a telephone conversation but it is not satisfactory for broadcast programmes since these require a frequency range from 30 c/s up to at least 8 kc/s for satisfactory reproduction. A heavier cable such as 40-lb with 16-mH loading per 2 000 yards gives the dotted loss curve 3 in Fig. 6.10. The response begins to fall off

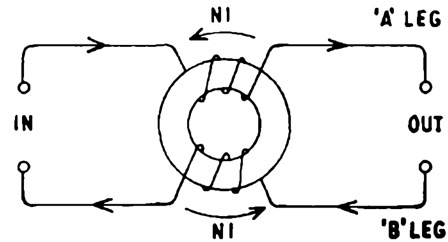


Fig. 6.11. The loading coil

sharply after 8 kc/s but the line after equalisation can be used for carrying sound programmes. The loading coils consist of two-winding toroids as shown in Fig. 6.11, the windings being wound in such a way that their magnetic fields add in the core. Pairs of

TABLE 6.1

Performance of Loaded Cables

Weight (lb/mile)	*Loading Inductance (mH)*	*Spacing of Loading (miles)*	*(yards)*	*Cut-off Frequency (kc/s)*	*Maximum Usable Frequency (kc/s)*
20	176	1·136	2 000	2·32	1·86
20	88	1·136	2 000	3·92	3·14
20	22	0·284	500	15·8	12·66
40	44	1·136	2 000	5·57	4·46
40	22	1·136	2 000	7·91	6·33
40	22	0·568	1 000	10·9	8·72
40	16	1·3	2 300	8·7	6·9
40	16	1·136	2 000	9·3	7·44
40	16	0·568	1 000	12·8	10·2
40	11	1·6	2 800	8·8	7·0
40	6	0·568	1 000	20·0	16·0

lines are almost always quadded, i.e., two pairs are twisted together in the form of a star-quad or multiple twin.

Table 6.1 indicates the performance of the different types of loaded cable in common use.

The shape of the frequency response of the loaded line makes it difficult to equalise beyond the strictly limited bandwidth (up to about 85 per cent of cut-off frequency) it is designed to accommodate, but provided equalisation and amplification can be carried out before signal-to-noise ratio has appreciably deteriorated, the unloaded line suffers no such disadvantage. Thus when a sound programme has to be conveyed and the only available lines are loaded pairs of inadequate bandwidth, a solution is found by short-circuiting one pair of a quad to form one leg and the other pair to form the other leg as indicated in Fig. 6.12. The effect of the loading coils is to increase line resistance and, owing to balance of coils within commercial tolerance, to add a residuum of inductance. Nevertheless the frequency response of this ‘ bunched ’ pair

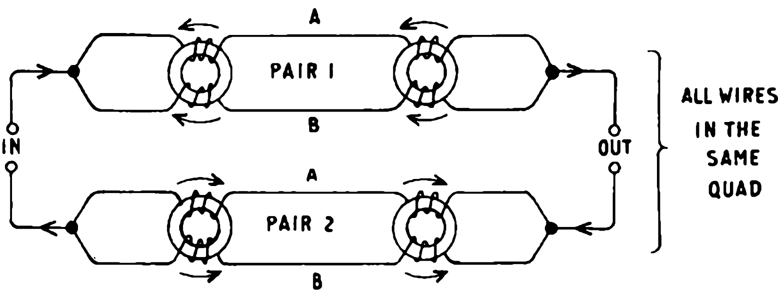


Fig. 6.12. The bunched-pair line

line closely approximates to that of an unloaded line and it can be equalised to a frequency beyond that of the loaded line (curve 2) provided signal-to-noise ratio is satisfactory. The bunched pairs must always comprise pairs of the same quad.

In some situations it is not possible to use the bunched-pair method because the distance is too great or interception points are inconveniently placed, and recourse must be had to a split-band technique. The over-all programme frequency range has to be restricted to about 6 kc/s and it is divided into two parts at approximately 3 kc/s, two separate lines being used. The lower half-programme frequencies are sent on one line; the upper half have their frequencies translated to bring them into the range 0–3 kc/s and these frequency components are transmitted on the other line. At the far end the frequencies are translated back to their original value and added to those of the lower half transmitted by the first line. As a rule the frequency range of the lower half-programme is translated upwards by about 300 c/s because the response of the line is unsatisfactory below this frequency. At the receiving end the frequencies are returned to their original value before being combined with the upper half. The split-band system is not favoured for very high-quality programme material but it has three important advantages:

(a) the length of the line is virtually unlimited;

(b) no interference is caused to the lines (such as is caused by bunching) and little notice is required by the P.O.;

(c) due to the reduced energy content in the upper frequencies, considerable amplification can be applied to the upper half-programme frequencies at the sending end with correspondingly reduced gain at the receiving end. This may allow the use of a line which would otherwise be unsuitable because of noise.

With long-distance lines on heavy traffic routes the Post Office find it generally more economic to have a wide pass-band line and to accommodate a large number of channels. For example, by employing a carrier system similar to that described in Section 6.4, cables having a pass-band up to 120 kc/s can be used to accommodate 24 telephone channels using carrier frequencies spaced 4 kc/s apart from 12 kc/s to 108 kc/s. Increased bandwidth can be achieved by using cable specially designed for low capacitance per unit length, or shorter lengths of standard cable connected through equalisers and amplifiers. The frequency range below 12 kc/s is not used because it is more costly to produce a repeater covering a range from 200 c/s up to 120 kc/s than from 12 kc/s to 120 kc/s and the additional frequency range can only accommodate three telephone channels. It would be possible with the aid of filters to use the range 0–12 kc/s for carrying a sound programme but it is preferable from an economic and technical point of view to use what is known as a 'carrier phantom', in which two pairs of lines already being used to carry other signals are effectively joined together to act as a single pair for carrying the programme. The programme circuit derived from a carrier phantom is shown in Fig. 6.13. The two lines carry their own signals, which are amplified at points A, B and C. The lines are choke- or transformer-coupled to their signal sources and the programme is connected to the centre-tap of each line choke or transformer. The programme current divides and passes in opposite directions through the half-windings of the communication circuit transformers across which, therefore, no programme voltage is developed. The two half-currents pass down the lines in the same direction and add at the centre-tap of the input transformer to the amplifier. From this point they are connected via another transformer to the line pairs. The same process is continued for the second section of the line

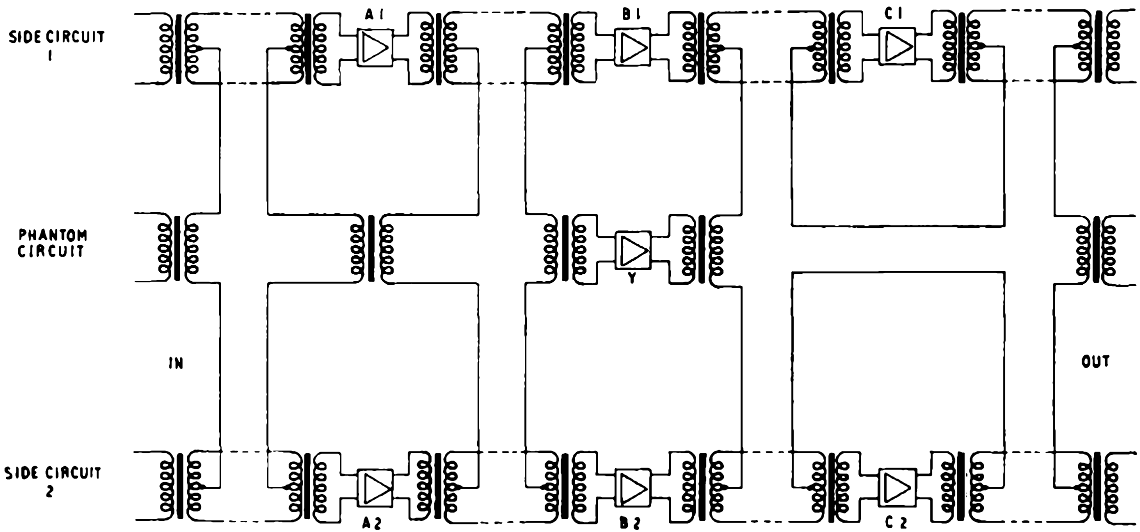


Fig. 6.13. A programme circuit derived from a carrier phantom

and if amplification is required in the phantom circuit it is included as shown at *Y*.

6.6 LINES FOR CARRYING TELEVISION SIGNALS

Video signals for the 405-line 50-field systems contain frequencies up to 3 Mc/s, so that video circuits must have a much greater pass range than sound lines.

Either balanced-pair or coaxial-line cable can be used and in both cases it is necessary to provide amplifiers and equalisers every few miles along the route, at points where the attenuation at the upper frequency required has reached from 50 to 60 dB. For a 6½-lb paper-insulated telephone cable this distance may be ¾ mile, whereas for a low-loss balanced pair or coaxial cable it may be as

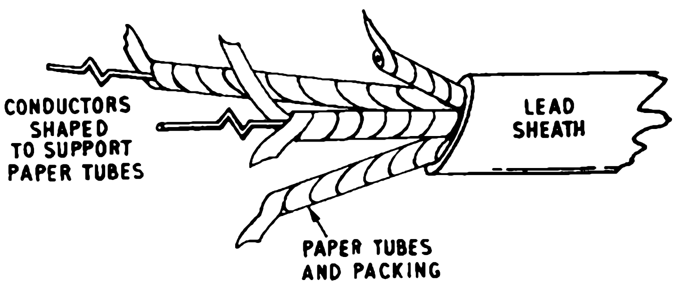


Fig. 6.14. A balanced-pair television cable

much as 7 miles. An early type of low-loss balanced pair cable, in which the conductors are carried in paper tubes and are kinked at intervals so as to centre themselves is shown in Fig. 6.14.

For links involving only a few miles the video signal itself is used, but several difficulties are encountered; for example, low-impedance power supplies must be used because very low frequencies have to be transmitted, equalisation is much more difficult because of the high ratio of the upper to the lower frequencies transmitted, and equipment must be accurately balanced to earth. Unbalance problems occur with coaxial cables and special precautions are taken to reduce longitudinal noise currents in the outer conductor. The cable is wound round a high permeability core to increase the inductance of the outer conductor to longitudinal currents and the outer conductor is insulated from earth. The reduction of longitudinal currents gives adequate signal-to-noise ratio up to 12 miles on ⅜ in., or almost twice this distance with 1 in.-coaxial cable.

Long-distance cable links for television transmissions employ coaxial cable and carrier systems, of which there are three types:

one, a BBC-designed system for short-distance operation (about 20 miles), uses a double-sideband system occupying a band from 12–18 Mc/s, the carrier being at 15 Mc/s. The practical advantage of this system is that relatively simple technique gives a very high standard of reliability, but a secondary advantage is that by providing suitable splitting filters a video channel and a carrier channel can be derived on the same coaxial tube.

Another is a P.O. system occupying a band of 3–7 Mc/s. It is a vestigial sideband system with the carrier at 6·12 Mc/s, and is used

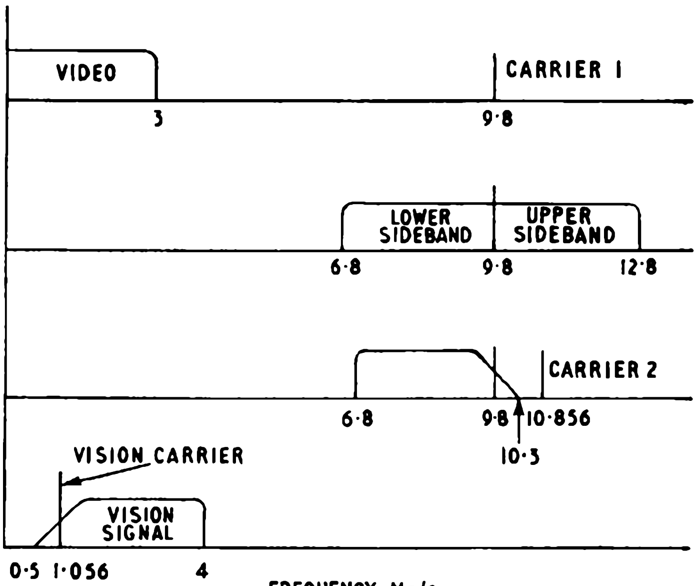


Fig. 6.15. Stages in the preparation of a television signal for transmission over lines

on $\frac{3}{8}$ in. dia. coaxial cable with repeaters spaced at 4-mile intervals or on 1 in. dia. coaxial cable with 12-mile repeater spacing. This system is also relatively simple and reliable requiring little maintenance.

The third (also a P.O. system) occupies an internationally-agreed frequency band 0·5–4 Mc/s and is used on $\frac{3}{8}$ in. coaxial cable with repeaters at 6-mile intervals. The frequency-translating process is as follows. The video signal amplitude-modulates a 9·8-Mc/s carrier, and the resultant is passed through a filter which selects the lower sideband 6·8–9·8 Mc/s and a part of the upper which extends to 10·3 Mc/s (as shown in Fig. 6.15), the carrier frequency being attenuated by about 3 dB. The output from the first modulator is passed to a second modulator supplied with a 10·856-Mc/s carrier, of which the lower sideband is selected and fed to line. The signal occupying a frequency spectrum of 0·5–4 Mc/s is a vestigial sideband version of the original video signal on a 1·056-Mc/s carrier. Positive modulation is employed, that is to say, the tips of the synchronising pulses on the modulation envelope point inwards in the direction of zero-carrier level. The standard modulation depth for a peak-white signal is 42 per cent. At the receiving end the translating process is reversed and further shaping of the frequency response is carried out so that the carrier is attenuated by 6 dB. The signal is then passed to an envelope detector which restores the video frequencies 0 c/s–3 Mc/s.

6.7 RADIO LINKS FOR TELEVISION SIGNALS

When cable laying is difficult and uneconomic, radio links may be used to carry the video signal. An example of this is provided by the P.O. link between Manchester and Kirk O'Shotts which is a two-way s.h.f. radio link operating at a carrier frequency of about 4 000 Mc/s. At some of the low-power BBC Television Transmitters, direct radio pick-up is employed from the nearest high-power BBC Transmitter. For example, the map in Fig. 3.3 shows that Les Platons, the BBC Transmitter Station in Jersey, Channel Islands, receives its signal via Torteval, Guernsey, which picks up the direct transmission from North Hessary Tor.

6.8 EQUALISATION OF LINE CIRCUITS

Line circuits suffer from attenuation distortion, and a correction circuit or equaliser is required to restore a flat frequency response. Experience in equalising lines carrying sound programmes has been built up over a long period and standard equalisers are available. The situation is more complicated with vision lines because the phase as well as the frequency characteristics are significant. Equalisation of sound programme lines, generally known as music lines, will be dealt with first.

6.9 EQUALISERS FOR SOUND PROGRAMME LINES[1,5]

With short lengths of line a satisfactory over-all frequency response can be achieved by terminating the line in a low value of resistance. This alters the value of G so that $R/G \simeq L/C$ and then Z_0 approaches $\sqrt{(R/G)}$, which is independent of frequency. The mismatching of the line due to terminating it in a resistance of much lower value than its characteristic impedance involves an appreciable loss of signal and the method cannot be used on long lines. This means that the line should be matched by being terminated in its characteristic impedance, which is normally taken to be 600 Ω. Many types of equalisers are designed to present a constant resistance of 600 Ω to the line when terminated by a load of 600 Ω. An example of a constant-resistance bridge-type equaliser is given in Fig. 6.16 and the condition of constant resistance (600 Ω) is met if $\sqrt{(Z_1Z_2)} = 600$. For the product Z_1Z_2 to be constant and resistive over the frequency range to be equalised Z_1 and Z_2 must contian reactances of opposite sign, i.e., if Z_1 is inductive Z_2 must be capacitive and vice versa. The loss due to the inclusion of the equaliser between the line and amplifier is known as the insertion loss of the equaliser whether or not the line is matched to equaliser

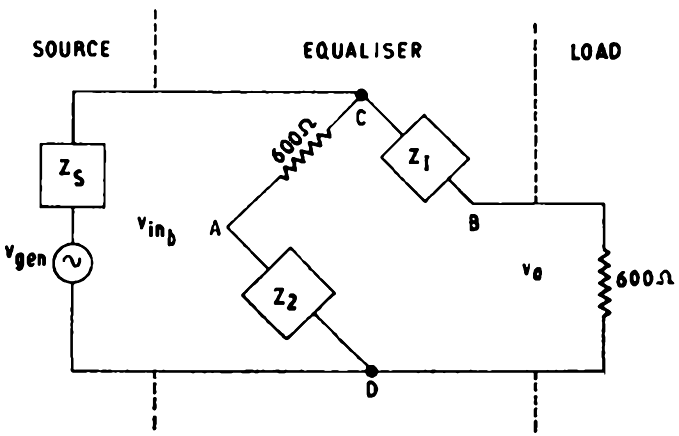


Fig. 6.16. The constant-resistance bridge-type equaliser

and equaliser to load. When both matching conditions are fulfilled minimum loss occurs. Whenever a mismatch occurs additional loss known as reflection loss is always introduced, so that insertion loss is the sum of the intrinsic loss under matched conditions and the reflection losses.

With the constant-resistance equaliser the insertion loss is given by the ratio of the output voltage to the input voltage of the equaliser. Thus the loss of the constant-resistance matched equaliser of Fig. 6.16 is $20 \log_{10}\left(\frac{R + Z_1}{R}\right)$ or $20 \log_{10}\left(\frac{R + Z_2}{Z_2}\right)$. An indication of the frequency response of the equaliser for various types of impedance Z_1 is given in Figs. 6.17 (a), (b) and (c). When Z_1 is capacitive (Z_2 inductive) the equaliser attenuates low-frequency components and equalises the high-frequency loss, whereas when Z_1 is inductive (Z_2 capacitive), it attenuates high-frequency components and equalises low-frequency loss. The maximum slope of the frequency response curve is 6 dB per octave. An

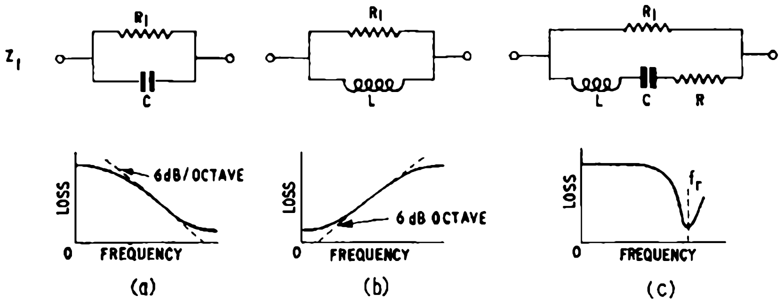


Fig. 6.17. Frequency response of equaliser when Z_1 consists of (a) C and R; (b) L and R; (c) L, C and R

increased slope can be obtained by making the impedance Z_1 contain L and C in series (Fig. 6.17 (c)) and Z_2 contain L and C in parallel.

An important consequence of the condition $Z_1Z_2 = 600^2$ is that V_{AD} and V_{BD} (Fig. 6.16) are equal in amplitude and phase so that the points A and B are at the same voltage and may be joined in any way without affecting the circuit. This provides alternative

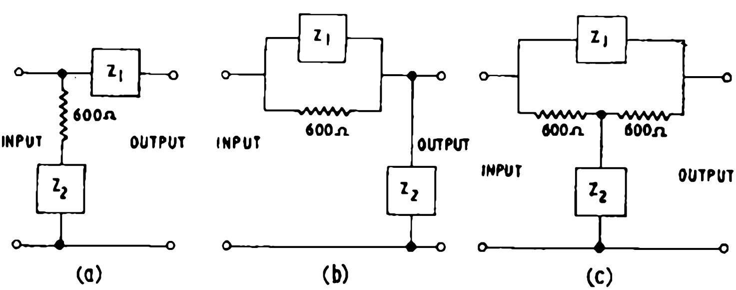


Fig. 6.18. Equivalent forms of constant-resistance equaliser: (a) Open-circuit derivative; (b) short-circuit derivative; (c) bridged-T derivative

forms of the equaliser in which AB is short-circuited to give the short-circuit derivative shown in Fig. 6.18 (b) or is connected through 600 Ω to give the bridged-T network of Fig. 6.18 (c). The original circuit (Fig. 6.18 (a)) may be considered as the open-circuit derivative. The only advantage of the alternative form is that it may be physically realisable when the original is not. Thus if Z_1 in Fig. 6.17 (a) should be a reactance with no associated resistance, this cannot be achieved if Z_1 is an inductance; either derivative can however be employed because a change may be made in the external resistance component of the shunt arm to compensate for the series resistance component of Z_1 over a given range of frequency. Similarly if Z_2 is to contain no resistance it cannot be an inductance in the two alternative forms. In the original form (Fig. 6.18 (a)) the 600 Ω resistance can be reduced to compensate for any series resistance in Z_2. Types EV3 and EV4 are examples of BBC constant-resistance equalisers and they correct for high-frequency loss in the line when Z_1 is capacitive and Z_2 inductive. Lines which have frequency response slopes greater than 6 dB per octave cannot be corrected by the use of one of these equalisers but two in cascade could be made to give up to 12 dB per octave over a limited range of frequency. Because of their constant-resistance characteristics no problem is involved in the cascade connection, and the total loss (dB) is the sum of the losses in each equaliser, but difficulty arises with signal-to-noise ratio when the over-all loss of line plus equalisers is too large. The BBC equaliser EV5 is the reverse of the EV3 and the EV4, Z_1 being inductive and Z_2 capacitive so that it compensates for loss at low frequencies. Generalised curves of the standard forms of equaliser are available on transparent sheets known as masks. They are plotted with the loss scale reversed as shown in Fig. 6.16 (a), (b) and (c), zero loss occurring at the bottom. The curve is then similar in shape to that of the frequency response of the line to be corrected. After the line frequency response has been obtained, the transparent masks for the equaliser are placed on top and the nearest fit to the line frequency response curve indicates the equaliser to be used and also gives its component values. Some BBC equalisers like the EV2 and EV12 employ resonant arms and have frequency responses with slopes greater than 6 dB per octave. The EV2 is a shunt equaliser with no series arms and its effect is only readily predictable under certain conditions. These are that it shall be preceded by at least a 10-dB attenuator terminated in 600 Ω so that its variations of shunt impedance are not appreciably reflected back into the line. When this is not done a trial-and-error method must be employed. The EV12 has a large number of components which may be varied but its performance is predictable.

Techniques for Equalising O.B. Lines. It sometimes happens on O.B. work that the line available between the O.B. point and the studio centre is long and does not pass through a P.O. repeater station. Equalisation by the normal methods at the receiving end of the line would leave the output so low that noise and interference would mar the programme. When this occurs arrangements are made for access to the cable at P.O. exchanges en route and BBC portable repeaters and equalisers are then installed to regain the initial sending level and frequency response. The BBC apparatus consists of two high-gain amplifiers and two pairs of equalisers (one of each acting as a spare), power supplies, a bridge-megger for testing purposes, and switching circuits for transferring the spare amplifier or equaliser to the line in the event of a fault developing in the connected apparatus.

Circumstances can arise whereby the required equalisation cannot be provided at the receiving end and the line is inaccessible at intermediate points. Such a difficulty may be overcome by the use of pre-emphasis, i.e., the increase of response at high audio frequencies. This is possible because the energy in the high-frequency components of the sound programme is usually much lower than that of the lower frequency components and there is little danger of overloading the line amplifiers. Pre-emphasis is achieved by including an equaliser giving high-frequency 'boost' before the amplifier to line at the sending end.

6.10 VISION PROGRAMME LINE EQUALISATION

The ear is normally very tolerant of any changes in the phase of the components in a sound wave from a single source and it is only necessary to correct for variations in amplitude, i.e., the actual waveshape is not important so long as the amplitudes of the components are unchanged. An exception occurs with long music lines (greater than 200 miles) and phase variations may then cause noticeable distortion of the received signal. In order that a vision signal should be correctly reproduced it must be transmitted without appreciable change of waveshape; this means that the phase as well as the amplitude relationship of its components must be unchanged. The effect of phase distortion on a waveshape has already been discussed in 1.6 where it is shown that all components must suffer an equal time delay in transmission if the waveshape at the receiving end is to be the same as at the sending end.

6.10.1 *Test Procedures*[6,7]

In this section only comparatively short television lines will be considered. The process of equalising such lines is guided mainly by observations of test waveforms, and originally rectangular pulses were employed as the test signal. The width of these pulses could be varied so as to give some indication of low-frequency or high-frequency response. The use of rectangular pulses for testing has two serious disadvantages: the amplitudes of the higher order harmonics fall off relatively slowly and a short-duration rectangular pulse contains useful components well beyond 3 Mc/s: thus its shape is markedly affected even when the response to a vision signal limited to 3 Mc/s might be satisfactory. The second disadvantage is that if non-linear distortion is present the output pulse may be made to look quite satisfactory by squaring due to limiting action in the amplifiers. The P.O. has developed a system using a special waveform shown in Fig. 6.19. It is known as the 'pulse and bar' test waveform and it consists of a pulse having the shape of a sine-squared function followed by a 'rectangular' waveshape. The pulse may have a duration of 0·17 microsecond (designated T pulse) or 0·33 microsecond (designated 2T pulse) and it is followed 30 microseconds later by a rectangular bar of the same amplitude and 40 microseconds duration (known as the '40 bar'), having shaped edges. The relative width of the T pulse in Fig. 6.19 has had to be grossly exaggerated for the purpose of illustration. These pulses are superimposed on synchronising pulses generated at a repetition rate of 10 kc/s, so that the waveform repeats itself at approximately line frequency.

The T pulse has an amplitude-frequency spectrum which is 6 dB down at 3 Mc/s and of negligible amplitude at 6 Mc/s; for the 2T pulse the frequencies are 1·5 and 3 Mc/s respectively. These two pulses can give information about the performance of the circuit

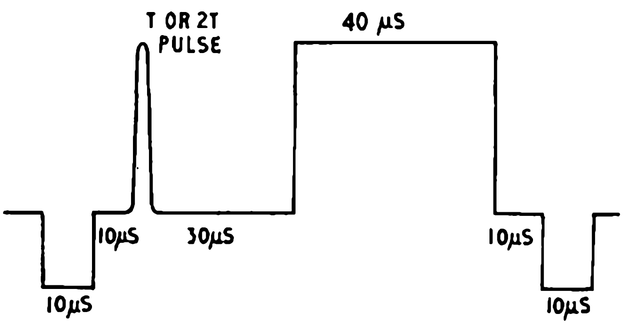


Fig. 6.19. The sine squared pulse and bar test waveform

from the upper video frequencies down to approximately 500 kc/s. At lower frequencies of the order of 20 kc/s the 40 bar provides the desired information and to cover the range between line and field frequencies a 50 c/s square-wave test signal is superimposed on the synchronising pulses.

The effect of low- or high-frequency attenuation and phase distortion on the pulse and bar signal is as follows:

(1) Loss of high-frequency response causes the amplitude of the received T pulse to be less than that of the bar and the latter will tend to have rounded corners.

(2) A rapid attenuation in high-frequency response leads to ringing excited by the T pulse. If the ringing frequency is greater

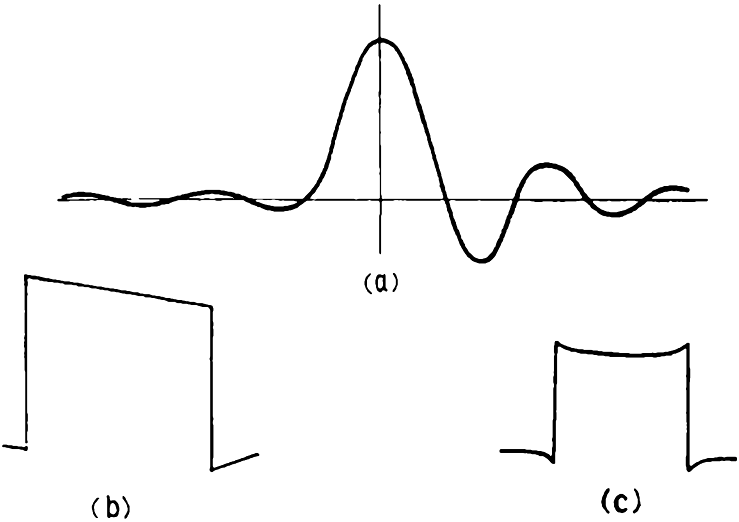


Fig. 6.20. (a) high-frequency attenuation and phase distortion of the pulse signal; (b) low-frequency attenuation of the bar signal; (c) quadrature distortion of the bar signal

than 3 Mc/s it will have negligible effect on the picture but if it occurs at lower frequencies the picture reproduction will be degraded. As a rule severe high-frequency attenuation distortion is accompanied by phase distortion and this is indicated by ringing unsymmetrically disposed before and after the T pulse (Fig. 6.20 (a)). Overshoots may also appear on the edges of the bar waveform.

(3) Low-frequency attenuation distortion (down to about 20 kc/s) is indicated by a departure from constant amplitude of the horizontal portion of the rectangular pulse (Fig. 6.20 (b)).

Non-linear distortion due to overload generally reveals itself by clipping of the bar or synchronising pulses. Another type of distortion (known as quadrature distortion) which may occur on long lines using a vestigial-sideband carrier system can produce 'pigs' ears' on the bar waveform (Fig. 6.20 (c)). A special procedure has been evolved for relating the distortion shown by the pulse and bar waveform to its perceptibility or subjective distortion effect on the picture. The term K-rating is used and different types of distortion having the same K-rating should be equally perceptible on the picture. Definitions of K-rating cover the distortions listed under 1, 2 and 3, and there is an additional K-rating for field shading determined by the tilt of a 50 c/s square wave. Since the K-rating is related to perception or annoyance value it is to be expected that over-all K-rating would be decided by the greatest value of K-rating amongst the individual distortions, and to be almost unaffected by the other distortions of lower K-ratings. A K-rating of 3 per cent is considered to produce just discernible distortion on the picture whereas 5 per cent is very noticeable with appreciable degrading of picture quality.

6.10.2 *Equalising Temporary Vision Circuits*

A variable equaliser is generally used to correct the response of a line carrying television frequencies, the test signal being the pulse and bar waveform. Adjustments are made until any distortion of this waveform is reduced to a minimum. The BBC uses equaliser Types TV/EV/1, 2 and 3 to correct frequency response and Type TV/EQ/6 to correct phase response. The equalisers TV/EV/1, 2 and 3 consist of eight sections each covering a part of the frequency range of the television signal. Thus one section is labelled 17·25 kc/s and it can correct variations of about 2·5 dB over about an actave range centred at 17·25 kc/s. Typical centre frequencies for the other sections are 34·5, 69, 138, 250, 420, 650 kc/s and 1 Mc/s.

With short lengths of line carrying video signals it is possible to use non-resonant equalisers to correct the response up to 3 Mc/s. Beyond 3 Mc/s the combined line plus equaliser loss curve falls off more slowly than the original line curve but eventually the response becomes asymptotic to the original line loss. The reverse is true of a resonant equaliser and the combined line and equaliser loss curve falls off more rapidly above 3 Mc/s than the original line loss curve. There may be a tendency with this type of equaliser to ringing and it often causes deterioration of the phase response of the top end of the pass band. This may be corrected by using a phase equaliser that introduces no attenuation distortion.

REFERENCES

1. 'Studio Engineering for Sound Broadcasting', Chapter 7, BBC Engineering Training Manual, Iliffe Books Ltd. (1955).
2. 'Studio Engineering for Sound Broadcasting', Chapter 9, BBC Engineering Training Manual, Iliffe Books Ltd. (1955).

3. 'Theory of the Hybrid Coil', *BBC Technical Instruction L1, Appendix 1A.*
4. 'Filters used in Carrier (1 + 2) System', *BBC Technical Instruction L1.*
5. 'Equalisers and Repeaters', *BBC Technical Instruction L2.*
6. Macdiarmid, I. F., 'Waveform Distortion in Television Links', *P.O. E.E. Journal, 52,* Parts 2 and 3, pp. 108 and 188.
7. 'Pulse and Bar Testing Methods', *BBC Technical Instruction V5.*

INDEX