TELEVISION

simply explained

By the same author:

RADAR: RADIOLOCATION SIMPLY EXPLAINED

WIRELESS SIMPLY EXPLAINED (*In the press*)

TELEVISION

simply explained

by

R. W. HALLOWS

T D., M.A.Cantab, M.I.E.E.

foreword by

COMMANDER A. B. CAMPBELL, R.D.

LONDON

CHAPMAN & HALL LTD.

37 ESSEX STREET W.C.2

1947

First published, 1947

THIS BOOK IS PRODUCED IN COMPLETE
CONFORMITY WITH THE AUTHORIZED
ECONOMY STANDARDS

Catalogue No. 358/4

Printed in Great Britain by W. & J. Mackay & Co., Ltd., Chatham
Bound by G. & J. Kitcat Ltd., London, Flexiback Binding

To M. H.

for minding, but nobly enduring,

her Peace and Queues

Foreword

I think I can call myself one of the pioneers of television entertainment in this country. I was in the studio televising as far back as 1936 at Alexandra Palace and at the first Radio Television Exhibition at Olympia I took part in transmissions daily.

I am extremely interested in the subject, so am very pleased to write a few words about this book. When I first went to sea—more years ago than I care to remember—wireless was not fitted to ships. I saw it introduced and speedily become of the greatest possible service, besides being one of the biggest factors in safety of life at sea.

Then I came in touch with television and I wondered how this new branch of science could also assist navigation and minimise risks. One day I spoke to Baird about it. Being a technician he saw the difficulties involved but the notion stuck in his mind. We all know what Radar did for our sailors and airmen in the war and Radar owes much to research in the field of television.

I have been seen on the television screen several times since its revival and what impresses me is the great strides made in the technical side of the science. I remember having to stand in front of the camera with two 500-watt lamps about three feet away from me. The heat and glare were terrific. Then in those early days we had our faces painted yellow and our lips blue. Today, except for taking the shine off the skin, the make-up is scarcely noticeable.

I am often asked to explain how television works. Not being an electrical engineer I asked the specialists at Alexandra Palace; but alas their description was always far too technical for a mere layman. I know what to do now when asked about it. I shall tell my questioner to get Major Hallows's book on Television. The art of teaching consists in the ability to impart knowledge and the author has this faculty in a marked degree. You do not need to be an expert or even a technician to follow his explanations. Nor need the mathematics worry you, for both the diagrams and figures are set out simply and plainly.

Some of the figures seem incredible, but the author substantiates them in his book. Although the science has made great strides, there is still a vast field of research for the eager scientist and Major Hallows shows the direction in which this research may prove productive. I agree with him that the future holds great promise. As I write these words I learn that Birmingham is to be fitted with a relay station which will bring central England into the field. I expect Manchester will come next, then Carlisle and soon it will be all over England. I see no reason why it should not become universal.

I congratulate Major Hallows on this book. I shall watch future developments of television with much greater interest and understanding owing to the clarity of the explanations and the easy manner in which he describes features which to the layman seem to border almost on the supernatural.

A. B. CAMPBELL

London, 1947.

Author's Preface

There are already many books on television, not a few of which have been written by eminent authorities on the subject. And there will certainly be more as television progresses and comes to take its rightful place as the most perfect form of domestic entertainment yet devised by man. Other kinds of entertainment in the home appeal to one sense only—books, pictures and the amateur cinematograph to the eye ; musical instruments, the gramophone and the broadcasting of speech and music to the ear. Television, with its accompaniment of sound, appeals to both eye and ear. In the development of the cinematograph vision came a long time before sound. The old silent films achieved, rather slowly, a good deal of popularity, but once the sound track had been added to them and silent films had become " talkies " the ciné theatre galloped into popular favour. In wireless the process was reversed : sound was achieved long before vision. Broadcasting consisting of sound alone is in its way just as imperfect and as unsatisfying as was the silent film. Now that wireless can bring into the home clear and beautiful sights as well as clear and beautiful sounds one needs no prophetic mantle to forecast enormous and rapid development.

Nor need television be confined to the home. At present there are, as we shall see later, technical difficulties about producing large-sized television images ; but " big-screen " television will undoubtedly come, and the day of its coming may not be very far ahead. When it has been achieved television will take its place alongside the talking film in the ciné theatre. Then the newsreels, depicting events which occurred some time before, will largely give place to televised news bulletins, showing events as they actually occur.

My excuse for adding one more to the list of books on television is that hitherto there has been none, so far as I am aware, written in simple language to explain to ordinary non-technical people what television is and how it is accomplished. In this book I am not writing for those who have already a working knowledge of general electricity and of wireless. They are already well catered for. In the pages that follow my aim has been the same as it was in writing my little book on radar* : I have tried to explain a difficult subject in such a way that readers with no previous knowledge of electricity may form a clear picture in broad outline of television as it is today.

This book contains no mathematics beyond the simplest of simple arithmetic and the few technical terms used are all carefully explained as they occur. The reader may therefore take the plunge with the assurance that he is not entering deep waters. He will, in fact, not find himself out of his depth even if he knows no more of electricity than that the turning of a switch causes a lamp to glow or an electric fire to radiate warmth. Perhaps I should not have suggested anything so violent as diving ! Fortified by the promises given, let him wade serenely in.

R.W.H.

* *Radar, Radiolocation Simply Explained,* by R. W. Hallows.

Author's Acknowledgments

My thanks are due to Mr. G. Parr, M.I.E.E., for reading the proofs and for making valuable suggestions ; to Mr. O. S. Puckle, M.I.E.E., for helping to find ways of making several difficult points clear ; to Gwen Webb for turning my rough scrawls into finished drawings ; to Messrs. Pye Radio Ltd., Messrs. Electronic Tubes Ltd., Messrs. Cable and Wireless Ltd., Messrs. Ferranti Ltd., and the B.B.C., for providing photographs, many of which were specially taken for this book ; and last but not least to my wife, for putting up with the appalling hours that I kept during the period of gestation and book-birth. May she have her reward in the knowledge that father and child are both doing well.

Contents

List of Plates

(N.B. The plates are inserted as a section at the end of the book)

CHAPTER I

The Coming of Television

MAN is distinguished from other animals by being an inventive creature, and his inventiveness was mothered by necessity : he had to invent or perish in the struggle for existence. Other animals were provided by nature with powerful offensive and defensive weapons as parts of their bodies. Teeth adapted for slashing or crushing, tusks, horns, claws, poison fangs or stings are amongst the formidable armoury from which nature selected her gifts to them. Those with thin skins were equipped for defensive purposes with great speed, with protective colouring or with limbs specially adapted for burrowing refuges in the soil. The slower animals were given great physical strength and often tough, or even armour-plated hides. Man was superior to all other creatures except the apes in the acuteness of his vision, though his senses of hearing and scent were less good than those possessed by many of the animals. Some of these were eager to prey on him ; others had to be his prey if he was to obtain the food upon which his life depended.

With no natural weapons worth talking about, whether offensive or defensive, as his birthright man could not have survived had he not devised artificial means of overcoming the handicaps of his thin, unprotected skin and his lack of both speed and great strength. That he did survive and became eventually the greatest power in the animal world was due above all to his inventing methods of doing things at a distance.

With very few exceptions (the ant-lion is one and the archer fish another) no animal can do any harm to its intended prey unless it establishes actual physical contact with it : so long as a gazelle can keep one yard out of range of a tiger's teeth and claws, it is perfectly safe. Possibly taking a leaf out of the ant-lion's book, primitive man invented first of all the sharp-edged throwing-stone, which enabled him on the one hand to strike down his animal enemies whilst he was still out of their reach and on the other to kill speedy or wary prey at a distance. Sling, spear, axe, arrow, sword, blow-pipe and gun were invented one by one and as the ages passed man, once one of the weakest and most defenceless of creatures, became lord of the animal kingdom.

Early in his history man realised the necessity of doing other things besides delivering blows at a distance. To warn the community, of which he was by this time a member, of the approach of enemies or of some impending natural danger a means was required of communicating rapidly and certainly at ranges far beyond those of the human voice. He devised the beacon, the smoke signal, the drums of the " bush telegraph " and the megaphone. For thousands of years these remained his only means of rapid long-range communication. When he had discovered how to use metals and to obtain polished surfaces he was able to reflect the sun's rays in a desired direction and to devise a primitive heliograph. Much later came the semaphore erected on a hilltop, whose moving arms spelt out messages that could be read at another semaphore station miles away and passed on if necessary to yet others of a chain.

That was as far as progress in rapid communications had gone up to a hundred years ago. Then Samuel Morse, influenced by the natural urge of the human race to do things at a distance, saw the possibilities of electricity as a means of sending messages. His telegraph was followed by Bell's telephone. Then came wireless, first discovered by Hertz, and developed later by Marconi into a practical commercial system.

With electricity harnessed to the service of communications by enabling code messages and the sounds of the human voice to be sent from place to place over wires, an enormous step forward had been made. A network of telegraph and telephone lines on land and of submarine cables under the seas soon covered the face of the earth. Wireless achieved yet another mighty advance, for it enabled code messages and speech to be sent to the ends of the earth without wires or cables. Two senses—speech and hearing—could now be used at enormous ranges ; but the old urge to do still more things at a distance persisted. There was another sense, sight, to be satisfied and before the days of wireless inventors were at work, endeavouring to make use of electricity to enable the eye to see distant events as they happened. And so television was born.

The word television is one of those rather regrettable mongrels which science so often coins when seeking names for the new things which it gives to the world. " Tele " is Greek and means " far " ; " vision," of Latin origin, means " seeing " or " sight." The word, then, means in itself no more than " seeing at a distance " ; but that will not do for a definition of television. We see at great distances with the unaided eye if we stand on a clear day at the top of a mountain ; we have only to look upwards on a starry night to see at much greater distances than television can possibly encompass. So far away are the stars whose presence the eye records that the light which comes to us from the nearest of them takes more than four years to reach us, though travelling at the speed of 186,000 miles a second. We see the nearest stars not as they are, but as they were over four years ago. Light from some faint stars takes millions of years to reach us, so distant are they from us.

Television, then, is not just seeing at a distance. It has been described as a means of seeing events which occur at places beyond the range of any purely optical aids to the eye ; but that definition is also insufficient. If, for example, we see at the local cinema a film made in Hollywood we are witnessing events that took place thousands of miles away when the actors and actresses played the scenes. The ciné film provides, by optical and mechanical methods, a visible record of distant events some time after their occurrence. Television shows us events not some time after they have happened, but as they happen. It may perhaps be defined as the process of making events as they occur visible at distant places by electrical methods. There is, of course, some minute delay between the occurrence of an action and its appearance on a distant television viewing screen, for wireless waves, like those of light, do not travel in no time at all from one point to another. The speed of both is the same : 186,000 miles a second. If you are watching a television screen at a distance of twenty-five miles from the transmitting station you actually see events in its studio rather more than one ten-thousandth of a second after they take place—a delay so short that for our present purposes we may regard it as virtually non-existent.

As might be expected, television was not born fully-fledged as the result of a single brilliant scientific discovery. Its development is a story of hard, patient work extending over many years.

The first attempt to send images over a wire by electrical means was made nearly a hundred years ago. They were not of course images of events, for many years were still to pass before any kind of moving picture was invented except for such toys as the " Zoetrope " or " Wheel of

Life," whose hand-drawn silhouettes of animals gave the impression of motion when the wheel was spun rapidly and were the direct ancestors of Mickey Mouse, Pluto and Donald Duck. The first steps towards television were made about 1847, when an inventor named Bakewell proposed a method of transmitting simple line-drawings over a pair of wires by electricity. His system proved unworkable, except possibly over very short distances, for no means of amplifying an electric current was then known ; but it contained the seed from which modern methods of still picture transmission and of television were to grow, for Bakewell's invention incorporated the basic principle of both of these : the fact that any image may be broken up into groupings of lines or dots. Or perhaps it would be more correct to say that Bakewell realised that the eye could be deceived into imagining that it saw a genuine image if it was presented with a suitably arranged mass of lines or dots. Sad though it is to have to admit it, the whole technique of still picture transmission today is based on deception, as indeed are both television and cinematography !

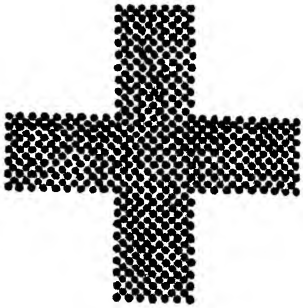


FIG. 1.—Deception of the eye is the basis of still picture transmission and of television. Seen at ordinary reading distance the cross is obviously made up of black dots with white spaces in between them; but viewed from five or six feet away it appears as a solid grey-black figure.

Fig. 1 shows one way in which the eye may be deceived. At ordinary reading distance the cross-shaped figure is clearly made up of a large number of dots, with white spaces in between them. If this page be viewed at a distance of several feet, the eye is no longer conscious of the separate dots : it sends to the brain the impression

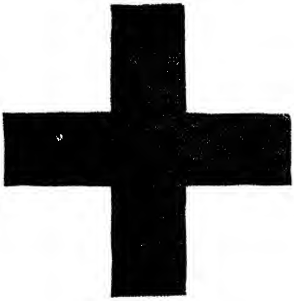


Fig. 2.—Further deception. At reading distance the cross appears to be solidly black. Examine it through a magnifying glass and see what is really there.

of a cross-shaped figure with a continuous greyish black surface. Fig. 2 shows how the process of deception may be carried still further. At reading distance the image recorded by eye and brain is simply that of a black cross. But use a magnifying glass and you will see that once again the surface is in reality by no means continuous or wholly black: it is in fact made up, like that of Fig. 1, of dots with white spaces between them.

The basic problem in still picture transmission and in television is to convert the effects of light into electrical impulses at the transmitter and to reconvert these electrical impulses at the receiver. So far, the only known method of doing this is to break up continuous surfaces into dots or lines. Each little dark or light element of the image is then converted into a corresponding electrical impulse by the transmitting equipment. At the receiving end reconversion of the electrical impulses takes place. They are stippled in, so to speak, in their proper places and the eye, lending itself willingly to the deception, conveys to the brain images that are close counterparts of the originals.

It may be said with truth that any picture, whether it is a painting, an engraving, a drawing, a photograph, a book or newspaper illustration, or a television image, is based on deception of the human eye. To understand why such deception is necessary and how it can be accomplished without exciting the slightest suspicion on the part of the "victim," we must first know something of the eye itself and of the way in which it does its work and enables its owner to see.

CHAPTER II

Sound and the Ear—Light and the Eye

IT has already been indicated that the effect which we know as light is produced by fast-travelling waves. The eye is excited by receiving light waves and sends through the optic nerve a message to the brain which is there converted into the sensation of vision.

Another delicate organ of ours which is excited by waves and sends to the brain messages which are there translated into a sensation is the ear. We can best approach the explanation of the way in which the eye functions by discussing how the ear does its work, for the waves of sound make smaller calls on the imagination than do those of light: we can *feel* the effects of sound waves as well as hear them. They travel through that familiar medium, the air that all of us breathe, and their speed under normal conditions is not greatly in excess of the 600 odd miles an hour achieved by the jet-propelled aeroplanes of today.

Those who had practical experience of the arrival of V1 and V2 bombs during the last war had, though probably they hardly appreciated it at the time, interesting demonstrations of the speed of sound waves. The V1's you heard coming some time before they arrived, for the sound waves set up by their exhausts travelled at over 700 miles an hour and the pilotless planes themselves at some 300 miles per hour. Therefore you heard the flying bomb before it arrived; the sound waves reached you first. But the V2's travelled at over 3,000 miles an hour, far faster than the sound waves produced by their passage through the air. Hence, close to the spot where it landed, the rumble of a V2's travel through the air was not heard until after the noise of its explosion, for the rocket bomb travelled faster than sound waves can travel.

Sound waves are involved in television reception, for they are responsible for the speech, the music or other appropriate noises which the loudspeaker of the television receiver produces as an accompaniment to the images on its screen. We are, therefore, not digressing from our main theme if we spend a few moments in seeing something of their nature and their behaviour

Open the lid of a piano, depress the loud pedal, strike middle C firmly with one fore-finger and then put the other lightly on to the string. You are at once conscious of vibrations which can be felt. Strike the C two octaves below middle and the questing fore-finger of the other hand collects and sends to the brain *via* its sensory nerves vibrations which are obviously much slower. If the C two octaves above middle is struck the brain once more records vibrations from the message received from the fingertip and this time it is conscious that they are far more rapid than those of middle C.

When the key of middle C is struck on the piano the hammer delivers a blow which causes the string to vibrate at what is called its natural frequency : that is, the string swings to and fro, or vibrates a definite number of times each second. The number of vibrations a second is always the same so long as the string remains in tune. It depends upon the length, weight and tension of the string. What the piano tuner does when tuning middle C is to adjust the tension of the wire so that its natural frequency is 256 ; the tuned string vibrates at this frequency when it is excited by a blow from the hammer.

To simplify the explanation of the way in which the vibrations of a piano string cause the ear to hear a musical note we will imagine that the string moves simply first from left to right and then from right to left, as shown in Fig. 3. The movement from left to right (*a* in Fig. 3) compresses the air lying close to the right of the string. When the

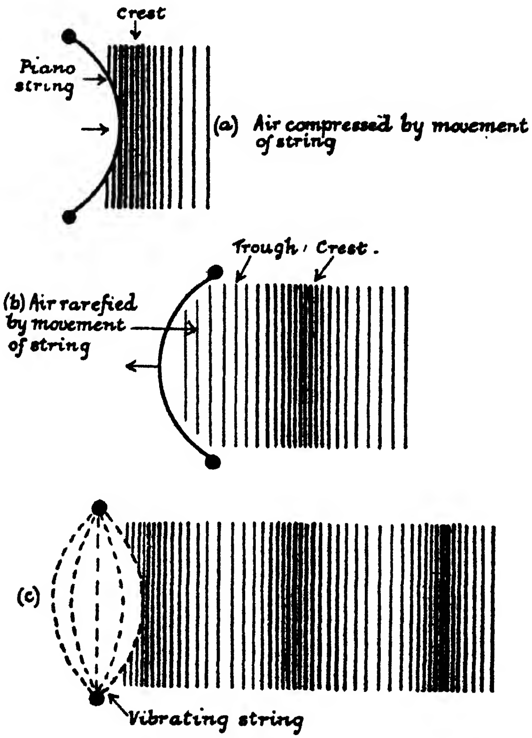


FIG. 3.—The movements of the vibrating string produce alternate compressions and rarefactions of the surrounding air—the crests and troughs of sound waves.

string subsequently moves from right to left the air in the wake of its movement is rarefied (Fig. 3 *b*). Thus each complete swing of the string sets up a compression of the neighbouring air, followed by a rarefaction (Fig. 3 *c*). If we call the maximum compression a CREST, the greatest degree of rarefaction is a TROUGH. One swing of the string sets up in the surrounding air an invisible something very like the familiar wave that we can see on the surface of water when it is agitated by some means. The curves (Fig. 4), which are used for both forms of oscillation are similar.

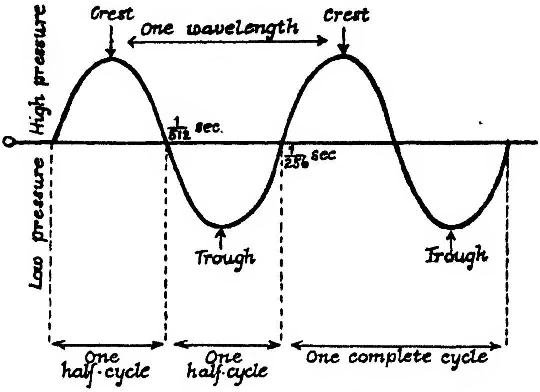


FIG. 4.—A wavelength is the distance between two consecutive crests or troughs. A cycle is the undulation from zero to crest, from crest to trough and from trough to zero which makes up one complete wave.

Throw a stone into a calm pond and what happens? Waves consisting of crests followed by troughs radiate over the surface of the water from the point at which the stone enters. Similar series of crests and troughs—areas of high and low pressure—radiate as shown in Fig. 3 *c*, from the vibrating string. The only marked difference is that sound waves travel *through* the air and not, like those we see on water, over its surface.

We saw that the sound waves corresponding to middle C occurred 256 times a second: in one second when this string vibrates there are 256 crests and 256 troughs. A complete wave consists of a crest and a trough and this

(Fig. 4) is called a CYCLE. Either a crest or a trough is one HALF-CYCLE.

The FREQUENCY, then, of middle C is 256 cycles a second, or, to use the accepted abbreviation, 256 c/s. Double the frequency by using a shorter and lighter string and stretching it more tightly and 512 c/s produce the C above middle. If the frequency is halved by the use of a longer and heavier string less tightly stretched, the corresponding note is the C below middle. Similarly the C two octaves above middle has a frequency of 4 × 256, or 1,024 c/s and that three octaves above, one of 8 × 256, or 2,048. Going down the scale, the one octave C below middle has a frequency of 256 ÷ 2 or 128 c/s, that two octaves below, one of 256 ÷ 4 or 64 c/s and so on.

Each of the other notes of the musical scale has its own natural frequency: doubling that frequency gives the same note an octave higher; halving it produces the same note an octave lower.

Sound waves and other waves are measured in two other ways in addition to their frequency. The average speed at which sound waves travel through air under normal conditions is 1,120 feet a second. If middle C is struck and held down with the loud pedal depressed it will be clear that at the end of one second the leading wave of the train set up will have reached a point 1,120 feet away. Waves extend from the string to that point and as 256 of them occur in one second the length of each must be 1,120 ÷ 256 or $4\frac{3}{8}$ ft. = 4 ft. $4\frac{1}{2}$ in. The WAVELENGTH is usually measured, as indicated in Fig. 4, as the distance between two consecutive crests. A moment's thought will show that this is equivalent to the length of one complete cycle: from crest to zero = $\frac{1}{4}$ cycle; zero to trough = $\frac{1}{4}$ cycle; trough to zero = $\frac{1}{4}$ cycle; zero to crest = $\frac{1}{4}$ cycle; $\frac{1}{4} + \frac{1}{4} + \frac{1}{4} + \frac{1}{4}$ = 1 cycle.

Note that the speed at which waves travel divided by their frequency gives their length and that, similarly, the speed of travel divided by the wavelength gives the frequency: 1,120 ÷ 256 = $4\frac{3}{8}$ and 1,120 ÷ $4\frac{3}{8}$ = 256. Notice too that a higher frequency means a shorter wavelength and a lower frequency means a longer wavelength. Thus for the C above middle, whose frequency is 512, we find a wavelength of 1,120 ÷ 512 = $2\frac{3}{16}$ ft., whilst the C below middle (frequency 128) has a wavelength of 1,120 ÷ 128, or $8\frac{3}{4}$ ft.

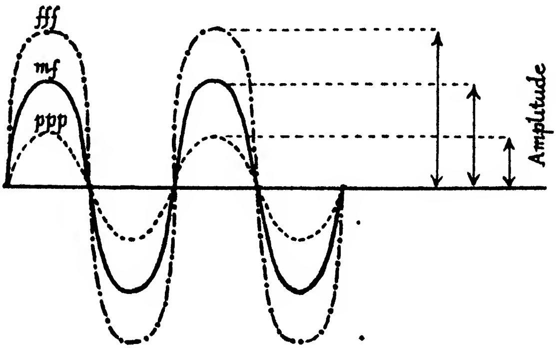


FIG. 5.—The energy conveyed by a wave depends upon its amplitude: the height to which the crests rise and the corresponding depth of the troughs.

If you strike the middle C very gently, the ear hears a soft sound. Strike it more firmly and a louder sound is heard. Strike it more firmly still and a very loud sound is heard. The note is the same in every case; there is no difference in the frequency or in the wavelength. Fig. 5 indicates what happens. The waves produced by the strong vibrations giving rise to the very loud note rise to higher crests and fall to deeper troughs than those of the moderate or soft notes. In technical parlance the vibrations giving rise to the loud note set up waves of large AMPLITUDE; those of the moderate note, waves of medium amplitude and those of the soft note, waves of small amplitude. The amplitude is the measure of the height to which the crests rise above zero and is an indication of the amount of energy conveyed by the wave.

The outward swings of the vibrating string produce areas of air-compression, or crests ; its inward movements, areas of rarefaction, or troughs. The train of successive crests and troughs travelling away from the string reaches the drum of the ear. A crest presses it inwards and a trough pulls it outwards. The result is that the eardrum performs one inward and one outward movement in response to each sound-wave cycle reaching it. In other words it vibrates at the same frequency as the string producing the sound waves. The aural nerve is excited and conveys to the brain impulses at the frequency received. The brain registers the arrival of a sound corresponding to the frequency reaching the eardrums.

In a broadcasting studio sound waves impinge upon the diaphragm of a microphone, their crests causing it to move inwards and their troughs pulling it outwards. The movements of the diaphragm, which vibrates in step with the sound waves, cause an electric current to vary correspondingly. The microphone thus converts sound waves into electrical impulses. A further conversion takes place in the transmitter and the impulses are sent out from the aerial as part and parcel of a train of wireless waves ; we shall see more of the way in which this is done a little later.

The wireless waves set up electric impulses in the receiving aerial which passes these to the receiving set. There they are magnified and the impulses due to the original studio sound waves are sorted out from the rest by the DETECTOR. After further magnification, or AMPLIFICATION, as it is called, these electric impulses are reconverted into sound waves by the loudspeaker.

Wireless waves have certain similarities with those of sound : they have crests and troughs, cycles and half-cycles, frequencies and wavelengths and the amount of energy that they bring depends upon their amplitude. But there the resemblances end, for wireless waves travel not through air but through the ETHER and their fixed and unvarying speed is 186,000 miles a second, about a million times the speed of sound waves. Just what the ether is no one can yet say with any certainty ; but it will suffice for our purposes if we take it to be an invisible and intangible medium filling the whole of Space and all the chinks and crannies between the atoms and molecules of which matter is composed.

Through the ether travel not only wireless waves, but also the whole great family known as the ETHER WAVES, or ELECTRO-MAGNETIC WAVES. Before waves of any kind can produce a recognisable effect they must be DETECTED by something which can interpret their activities to the brain. The detector may be an organ of our bodies or some kind of apparatus specially contrived for the purpose. The ear, for instance, detects sound waves, but cannot detect those of wireless, whose frequencies are far too high to affect it. The radio receiver detects wireless waves, but cannot deal with ether waves of other kinds.

Wireless waves have the lowest frequencies and longest wavelengths of the electro-magnetic family ; in the next group, with higher frequencies and shorter wavelengths, are the waves which produce heat and are detected by our surface nerves. Shorter in wavelength and higher in frequency than heat waves are those of light. The eye detects waves of the frequencies which give rise to what we call visible light ; but there are other light waves—the infra-red and the ultra violet—which are respectively of too low and too high frequency to affect the eye. We know that these must be light waves for another kind of detector, the photographic camera, responds to them. With the aid of infra-red or ultra violet light photographs can be taken in what to the eye seems to be pitch darkness. Of still higher frequency are X-rays, again detectable by the camera, gamma rays and the cosmic rays, detectable only by special laboratory instruments, whose frequencies are the highest known to exist. These last are believed to come to us from the depths of Space and such is their penetrating power that they can traverse many feet of solid lead.

The wavelength of the longer ether waves is always measured in metres : a metre is roughly a yard and a tenth. The speed of ether waves of all kinds is 300,000,000 metres a second. As with sound waves, we can find the frequency of an ether wave if we know its length, or its length if we know its frequency. Thus supposing that the wavelength of a broadcasting station is 200 metres, the corresponding frequency is 300,000,000 ÷ 200, or 1,500,000 cycles a second, or in abbreviated form 1,500,000 c/s. The KILOCYCLE is 1,000 cycles and it is usual to write 1,500 kilocycles a second or 1,500 kc/s as a more compact set of figures. The MEGACYCLE is 1,000,000 cycles, so that the figures can be still further compressed if we write 1.5 Megacycles a second, or 1.5 Mc/s instead of 1,500,000 c/s.

A frequency of 500 kc/s corresponds to a wavelength of 300,000,000 ÷ 500,000, or 600 m. (m., being the abbreviation for metres.)

The longest wireless waves used have a length of about 20,000 m., with a corresponding frequency of 15 kc/s ; the shortest used up to now are about 1 centimetre in length ($\frac{1}{100}$m.) and their frequency reaches the rather staggering figure of 30,000 Mc/s.

But when we come to visible light even these figures pale almost into insignificance. The *longest* waves of visible light are about one thirty-thousandth of an inch in length, the shortest about one sixty-thousandth. The corresponding frequencies are 375,000,000 Mc/s and 750,000,000 Mc/s. Cosmic rays have frequencies of over one hundred billion megacycles a second and a billion is a million million !

And now let us see something of that detector of light waves, the eye, the deception of which must be one of the main themes of any book dealing with television.

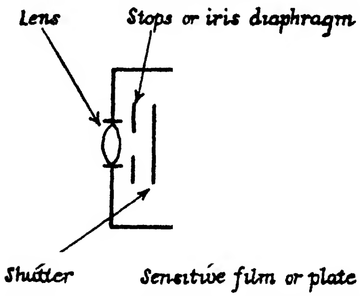


FIG. 6.—The principle of the photographic camera.

The photographic camera (Fig. 6) is actually a fairly close copy of the human eye. Its main parts are the lens, which focuses an image on to the sensitised plate, a set of stops (or an iris diaphragm), the purpose of which is partly to reduce the intensity of very bright illumination by cutting off some of the rays and partly to improve the focus by cutting out the rays from near the edge of the lens, a shutter which excludes light when it is not required and the sensitised plate on which the image is recorded by the effects of light waves on the emulsion covering its surface. Except in simple "fixed-focus" cameras, the image can be focused sharply on the plate by moving the lens nearer to the plate or further from it.

Fig 7 shows the only parts of the eye with which most of us are familiar. Surrounded by the "white" there is a coloured part known as the iris and the middle of this is the pupil. If you look closely at a friend's eye, you will find that the pupil grows larger in dim light and smaller in bright light. This is due to the action of the iris, which, as seen in the diagrammatic section of the eye (Fig. 7), forms a light-stop whose aperture varies to suit the intensity of the light. The iris enlarges or contracts the pupil under the influence of the ciliary muscles.

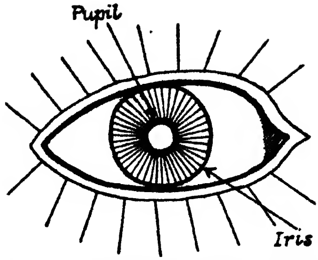


FIG. 7.—The visible parts of the eye.

If you look at an eye from the side you will notice that there is a distinct bulge over the region of the iris. This is the cornea, the transparent, horny cover over the pupil. Fig. 8 shows a sectional view of the eye in simplified form. Between the cornea and the iris is a clear liquid, the aqueous humor. Immediately behind the iris is the lens, about the size of a pea, which is suspended in the thin, transparent capsule. Behind the lens,

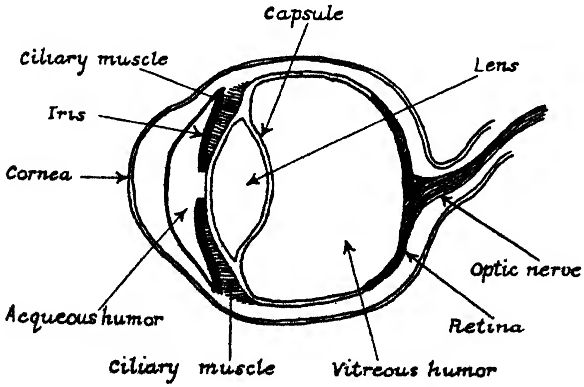


FIG. 8.—The inner components of the eye. Compare its working parts with those of Fig. 6.

and occupying the main part of the eyeball is a transparent substance of stiff jelly-like consistency, known as the vitreous humor. At the back of the eyeball is the retina, whose surface is formed by the tips of a vast number of tiny sensitive rods connected to the optic nerve. You will see that all the parts of the camera are there—shutter (eyelids), stops (iris), lens and plate (retina). The eye has also its own focusing arrangements, which are excellent when we are young, but become less good as we grow older. When you look at a distant object the condition of of the eye is very much as shown in Fig. 8 ; but if you examine something closely at short range the ciliary muscles move the iris outwards. The pressure of the iris on the capsule and the lens within it is relaxed and the lens bulges outwards a little until the object is sharply focused on the retina.

From what has been said it will be agreed that the eye appears to be an almost perfect instrument for the detection of light waves and for the formation of those images which give us the sensation known as sight. How, then, is it possible to deceive it ? Well, there is an old saying that the camera cannot lie. Many " old sayings " are completely untrue and this particular one is about as false as it could be. The camera is, in fact, ready and willing to tell lies that would make Ananias blush. Were it not for this propensity professional photographers who specialise in feminine portraits would find business far less lucrative and cinematograph films would not be so entertaining as they are. Very few photographic or cinematographic masterpieces are produced without making the camera lie heartily.

The eye, from which the camera is copied, can lie just as readily as its offspring. In fact, it would be no exaggeration to say that the eye is always lying, for it sees nothing as it really is. It sees this page, for example, as a still and unbroken white surface, covered with orderly lines of black marks constituting printed letters and words. Actually the page consists of an assembly of billions upon billions of molecules with quite large spaces in between them. And there is no stillness, for round the atoms of each molecule electrons, as we shall see later, are revolving at dizzy speeds.

The eye is deceived in two main ways in the production of television images. The first is that the resolution of the normal eye is no better than one minute of angle. That is a hard saying : let us see if we can find a way of making its meaning clear. Cut out a square of black paper with about one-inch sides and gum it to the middle of a sheet of white paper about a foot square. Pin the sheet to a fence or a tree and move 100 good paces away. You will see the black square as a small, dark "blob" in the middle of the white. Now gum another 1-in. black square on to the white sheet so that it is just 1 in. from the first. Unless your sight is quite abnormally good the two will appear at 100 paces distance not as two black squares with a white space between them, but as a single black mark of not very clearly defined shape. One inch at 100 good paces represents approximately one minute of angle. The ordinary eye cannot resolve the image seen at this distance into two black squares with a white space between them. At ordinary reading distances of 14–15 inches two small black dots $\frac{1}{200}$ inch apart are not sharply resolved into two, but merge into one another. This is clearly brought out by Fig. 2.

On the second way in which the eye can be deceived both television and cinematography depend.

Sitting indoors, look for a second or two at a window at a time when the light outside is strong. Now turn your eyes to the ceiling of the room : you will find that for some little time you continue to see against the white surface the dark horizontal and vertical lines of the window frame. The image formed by the lens of the eye on the retina is not immediately obliterated when the rays of light that give rise to it are cut off; it remains printed, so to speak, on the retina for a little time. How long the image lasts depends to a great extent upon its brilliance, a very bright image remaining visible for some seconds after the eye has ceased to receive it, whilst an image of moderate illumination may be retained for only a fraction of a second.

This effect, the retention of an image on the retina after the rays of light producing it have ceased to reach the eye, is known as PERSISTENCE OF VISION. Another way in which it can be demonstrated is illustrated in Fig. 9, which shows the familiar catherine wheel of firework displays. The catherine wheel consists of a cardboard tube containing inflammable material, which burns with a bright light. The pressure of the gases generated as combustion takes place causes the wheel to revolve. At any instant what is really happening is shown in Fig. 9: a stream of brightly glowing particles is emitted from the end of the cardboard tube. Owing to persistence of vision the eye does not see just a single patch of light. So long as the wheel is revolving rapidly the impression which it conveys to the brain is that of a ring of light.

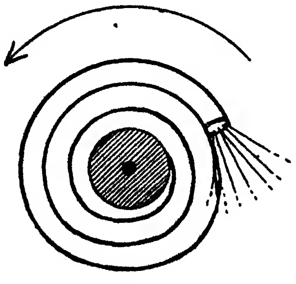


FIG. 9.—The catherine wheel demonstrates the persistence of vision.

A very convincing proof of the reality of persistence of vision frequently comes the way of a railway traveller. He is looking out of the window at the passing landscape when his fast-moving train is met by another moving rapidly in the opposite direction. Though he may be conscious of a certain amount of flicker he can still see the countryside as a continuous picture unrolling before his eyes as his train moves forward.

What, exactly, is happening here? The eye's view of the landscape is cut off for an instant by the locomotive and tender of the other train; then the scene reappears in the gap between the tender and the first coach. This coach again shuts out the view, which is visible once more for a moment through the gap between the first and second coaches. And so, whilst the two trains pass one another, light from the landscape is successively blacked out by the coaches and allowed to pass to the eye by the intervals between them.

What actually reaches the eye is a chain of brief glimpses, separated by blackouts. Each glimpse is slightly different from the one preceding it, for the eye of the traveller has moved some distance forward between the two and therefore sees the landscape from a different angle.

Suppose that the passing train consists of a locomotive and twelve coaches; then whilst this train is crossing his line of vision twelve short-lived images of the landscape reach his eye through the gaps, each a little different from the one before it and the one after it.

Owing to persistence of vision these images merge so as to convey a single continuous image of the landscape; and because each image shows the landscape from a slightly different angle it appears to move across the field of view, just as it would if no passing train intervened.

But there is a limit to the impression of continuous movement that can be conveyed to the brain in this way; this, again, is easily verified whilst travelling by train. Your own train is moving slowly forward and it passes another, stationary on the other track. This time, as you gaze through the window, you are conscious of quite a different effect. Your view is cut off by each coach and a noticeably different view appears as you pass each interval between coaches. Your impression is not of a continuously unrolling view, but of a succession of separate and distinct views. The glimpses afforded by the gaps do not merge into one another ; they are quite obviously separate and disconnected.

Should your train be gathering speed and that on the opposite track be a long one, you will find that as the speed increases the images blend more and more and that eventually a time arrives when you do see a continuous moving picture through the gaps.

When one train is standing still and the other moving slowly, images on the retina fade out during the black-outs caused by the intervening coaches and entirely new images are formed when the gaps between them admit light from the scene beyond ; thence the impression conveyed to the brain is one of disconnected pictures, each from a rather different viewpoint. Not until the speed is such that the image formed on the retina in a gap between coaches has not had time to fade out during the blackout imposed by the passing of a coach before the next gap brings another image is the impression of a continuous, though possibly rather flickering view conveyed to the brain.

This is the underlying principle of the cinematograph. A ciné film consists of a succession of " still " photographs taken at brief intervals. Plate I shows four successive "frames " or pictures on a typical ciné film. It is worth while to examine them with some care and to note the small amounts of movement that have taken place between (*a*) and (*b*), (*b*) and (*c*), and (*c*) and (*d*).

Were your eye undeceived when the four pictures of Plate I were projected on to the screen, it would see first picture (*a*), then a brief blackout as the rotating shutter of the projector cut off all light from the screen, then picture (*b*), then another short blackout, then picture (*c*), another blackout, then picture (*d*). But, as the undeceivable eye does not exist, what it does see is a continuously illuminated screen with moving images upon it.

It has been found by long experience that if sixteen pictures are projected each second on to the screen the eye is so well deceived, owing to persistence of vision, that it conveys to the brain the impression of fairly smooth movement. If the speed is decreased movements become jerky and flicker grows annoying. Sixteen frames a second is normal for home ciné apparatus ; considerably higher speeds are used in professional " talkies."

For the transmission and reception of images by television the proneness of the eye to be deceived is exploited to the full. We shall see much more of this in the pages that follow. Make sure that you have grasped those two outstanding limitations of human sight, the inability of the eye to see closely packed dots as individual dots and the retention on the retina of an image for a short time after the rays of light forming such an image have ceased to reach it. On these two shortcomings of our sight is based the whole technique of television.

CHAPTER III

The Broadcasting of Sound

THE problem of transmitting television images by means of wireless waves cannot be understood without a grasp in broad outline of the way in which the broadcasting of sound is done. For that reason it will be well at this point to see how the sound waves produced in the studio by speakers, singers and instrumentalists are converted into wireless waves, which, after travelling at the speed of light through the ether, are picked up by the receiving aerial and reconverted into the sound waves that issue from the loudspeaker.

Suppose first of all that the transmitter is working but that, for the moment, the studio microphone is not switched on. The frequency of the transmitter, let us take it, is 600 kc/s, which means that its wavelength is 300,000,000 ÷ 600,000, or 500 metres. As the transmitter is not sending out speech or music, it is said to be "idling." Fig. 10 shows diagrammatically what takes place under such conditions: in each second 600,000 wireless waves all of equal amplitude (*see* Fig 5) are sent out from the transmitting aerial. Actually they go out in all directions, but to simplify matters I have shown them in the drawing as leaving the aerial in one direction only.

Switch on the studio microphone (Fig. 11) and let the sound waves of a 1,000-cycle note reach it. Magnified electrical copies of these waves are passed by the amplifier to the MODULATOR, which mingles them with the output of the OSCILLATOR. The oscillator is the wireless valve which generates the power radiated from the aerial in the form of wireless waves. The action of the

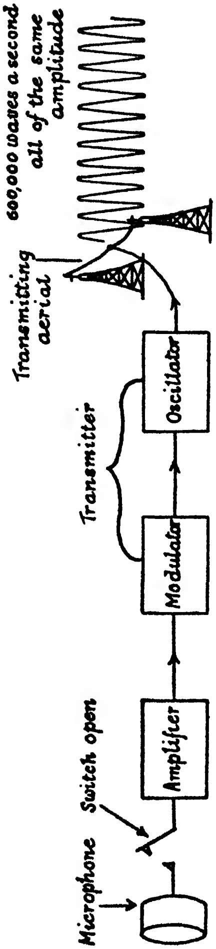


FIG. 10.—The microphone is here switched off and the transmitter is idling.

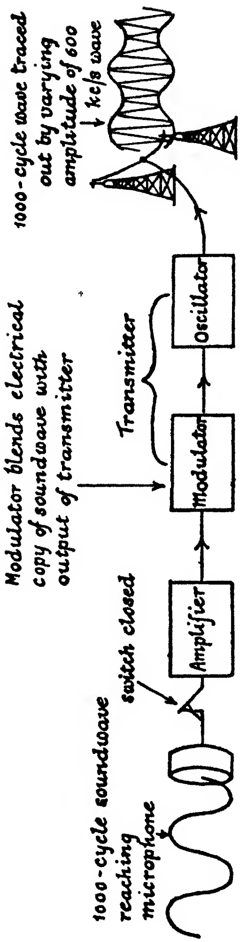


FIG. 11.—The microphone is now in action and the transmitter is sending out a wireless copy of the sound-waves reaching it.

modulator is to cause the amplitude of the wireless waves leaving the aerial to vary. The peaks of these waves trace out by their different heights a copy of the original sound wave. If the frequency of the original sound wave is 1,000 c/s and that of the transmitter 600 kc/s, then the crests of no less than 600 wireless waves trace out the shape of each of the original sound waves.

It will be noticed from an examination of Fig. 11, that the outline of the sound wave is traced out also by the troughs of the wireless waves. You can see why if you consider that, as shown in (Fig. 12), increasing the amplitude of a wave affects both crest and trough: the crest rises higher, the trough sinks lower. In the same way if the amplitude of the wave is reduced both crest and trough are affected, the crest rising less high and the trough being shallower.

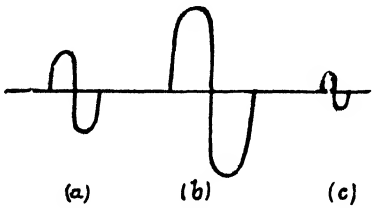


FIG. 12.—If the amplitude of a wave is increased or decreased, both crests and troughs are affected.

As you know, every wireless station has a particular wavelength assigned to it. So long as a broadcasting transmitter is idling (Fig. 10) it radiates on one particular wavelength only, sending out what is known as its CARRIER WAVE. It is called the carrier wave (or simply the carrier) because when the action of the modulator impresses copies of sound waves upon it, it carries them far and wide.

Now let us see what happens in terms of frequency when the modulation causes the amplitude of the carrier to vary. To the carrier wavelength there is, as we have seen, a corresponding frequency—600 kc/s in the case we have been discussing. When the carrier is modulated by the impression upon it of a 1,000-cycle note it ceases to have a single frequency. It now becomes a belt or band of frequencies extending from the carrier frequency *plus* the frequency impressed upon it to the carrier frequency *minus* the frequency impressed upon it. Thus in the condition of affairs illustrated diagrammatically in Fig. 11, the waves radiated from the aerial cover the band between 600,000+1,000 cycles a second=601 kc/s and 600,000−1,000 c/s = 599 kc/s. If the frequency applied *via* microphone and modulator is 2,000 c/s, the band of frequencies transmitted is between 602 and 598 kc/s.

It will be noticed that any sound-wave frequency occurring in the studio and applied to the transmitter results in the radiation by the aerial of a band of frequencies whose width is double that of the sound-wave frequency. Thus in the case under discussion a 1,000-cycle wave in the studio causes the frequency of the radiated waves to range from 501 to 599 kc/s, a BAND-WIDTH of 2,000 cycles a second or 2 kc/s. And when the studio sound wave has a frequency of 2,000 cycles, the aerial's radiation extends from 602 to 598 kc/s, a band-width of 4,000 cycles a second or 4 kc/s.

Each broadcasting station thus requires not a single frequency upon which to work, but a band of frequencies, or a CHANNEL, as it is termed. Ideally, a broadcasting station should have a very wide channel. To enable a receiving set of the highest quality to provide a close approach to perfect reproduction of speech, music and other sounds, all sound frequencies up to at least 12,000–14,000 cycles a second occurring in the studio should be transmitted. That would mean a channel 24–28 kc/s in width for each broadcasting station, which is quite impossible on the medium and the long waves.

If stations are not to interfere with one another, their channels must be clear and distinct with no overlapping. The medium wave band of 200–550 metres extends from 1,500 to 550 kc/s, a total of 950 kc/s. Were channels 24 kc/s wide, only some 40 European stations could be squeezed into it. It has been found that the human ear is a very accommodating piece of mechanism, able to some extent to fill in what is missing if all the sound-wave frequencies in the studio are not transmitted. Actually broadcasting is acceptable to it if no frequencies above 4,500 cycles a second are transmitted. It is thus possible to assign to stations on the medium-wave band channels only 9 kc/s in width and to fit in over a hundred individual channels.

I should, perhaps, mention that the belts of frequencies impressed on the carrier by modulation are known as SIDE-BANDS. If a station has a carrier frequency of 845 kc/s and works on a 9 kc/s channel, its side-bands extend from 849.5 kc/s to 840.5 kc/s. The upper side-band (carrier frequency *plus* impressed frequency) is from 845 to 849.5 kc/s and the lower side-band (carrier frequency *minus* applied frequency) from 845 to 840.5 kc/s.

It is important that the reader should grasp these principles thoroughly, for the technique of television transmission is much concerned with them. To recapitulate briefly :—

(1) Modulation impresses on the carrier wave copies of frequencies occurring in the studio.

(2) The modulated carrier has a total band-width equal to twice the highest frequency impressed on it.

(3) Broadcasting stations therefore require not just single wavelengths or frequencies, but channels upon which to work.

(4) If two stations within range of the receiver have channels which overlap, they will interfere with one another. Should one be much the more powerful, it may drown interference from the other ; but in that case it will not be possible to receive the weaker station without interference from the stronger.

(5) If many stations have to be accommodated in a comparatively narrow band of frequencies such as the

medium-wave band, it is necessary drastically to limit the width of channels.

Figs. 13 and 14 show what happens to the modulated carrier after its arrival at the receiving aerial. Unless the receiving aerial is very close to the transmitter the energy gathered from incoming waves is minute. A big

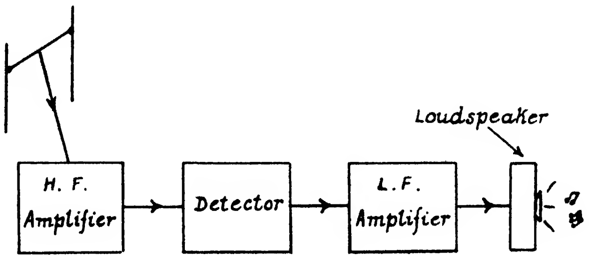


FIG. 13.—The reception of a wireless signal.

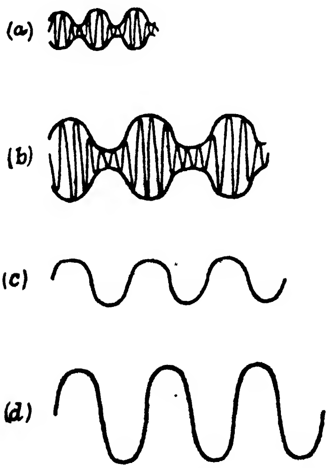


FIG. 14.—The amplitude of the received signal is small (*a*). It is amplified at high frequency (*b*). Then (*c*) the carrier and one side-band are removed and (*d*) low-frequency amplification takes place before it is passed to the loudspeaker.

station's output may be 100 horsepower or more (a kilowatt is 1⅓ horsepower), but it is usually far less than fly-power that reaches the receiving set; magnification, or amplification as it is usually called, is therefore required as the first treatment to which the incoming signal is subjected.

The signal passes through the high-frequency amplifiers in its original form—a carrier wave whose crests and troughs both trace out the sound-wave copies. Then it comes to the detector stage, which removes both the carrier wave and one of the sound-wave copies. Nothing is now left but one copy of the studio sound waves. This passes to the low-frequency amplifier and thence by way of the output valve to the loudspeaker. The loudspeaker's function is to reconvert electrical impulses into sound waves. These impulses cause its cone to vibrate and the vibrations set up sound waves in the surrounding air.

The broadcasting of sound seems a straightforward business. Why can't we accomplish television on the same lines? All that we appear to need is something equivalent to the microphone which will receive light waves and convert them into electrical impulses. Impress these by means of a modulator on the output of the transmitter. And there you are!

Or are you? I am afraid not. Suppose that we could devise something which would do for light waves what the microphone does for those of sound, could we make the crests and troughs of the carrier trace the outlines of their electrical copies? A glance at Fig. 10 will show that here we encounter an insuperable obstacle. The frequency of sound waves is far lower than that of wireless waves: in the example discussed 600 crests and troughs shape the outline of a single 1,000-cycle wave. But the frequencies of light waves are enormously higher than those of wireless. You may remember that we saw that the frequency of the longest visible light waves is 375,000,000 Mc/s, or 375,000,000,000 kc/s, whilst that of the shortest is twice as great. Wireless waves can be modulated only by frequencies much lower than their own and it is therefore quite impossible to make them carry light waves in the same way as they carry those of sound. A completely different method of harnessing wireless waves had to be found in order to make them convey the images of television.

CHAPTER IV

Sending Still Pictures

THE fundamental problems which had to be solved before moving pictures could be produced by either cinematography or television may be summed up briefly in this way :—

First, some means of recording images of still scenes must be devised.

Next, the recording process must be so speeded up that instantaneous shots of objects in motion can be made.

Lastly, a method of reproducing images and of presenting them at a rate of at least sixteen a second must be worked out.

The cinematograph is a logical and natural development from still photography. Its evolution is a story of long and patient endeavour. The first attempts at photography were made more than a century ago and Daguerre then stated that to make a picture of a landscape an exposure of some seven hours was required ! Emulsions steadily became more light-sensitive, lenses more rapid and camera shutters quicker in action. The exposure time dwindled from hours to minutes, from minutes to seconds, from whole seconds to fractions of a second. Before the end of the last century high-speed " instantaneous " photography had become an established fact.

It was then for the first time that men began to realise how fallible a witness of events the eye may be. If you look at old paintings and drawings of galloping horses, you will see that they are invariably shown with both forelegs stretched out in front and both hind legs extended behind. That was how the eye of the artist and of the ordinary man had visualised for centuries the action of a horse in full gallop. The first instantaneous photographs, taken in the 1890's at speeds improving from one-fifth to one two-hundred-and-fiftieth of a second, proved conclusively that no horse was ever, even for an instant, in the previously accepted "full-gallop" position.

As it became possible to take a series of instantaneous photographs of a moving subject at very short intervals it was realised that these pictures might be presented in such a way as to give an impression of motion. The first step was to print, one below the other, successive pictures of the same moving subject taken at intervals of a fraction of a second. Examples of such attempts to portray motion may be found in the files of the monthly magazines and of the illustrated weeklies of the 1890's and the early 1900's. The next step was to bind printed reproductions of the photographs into little books. Each picture had a whole page to itself and only the right hand pages were used. By holding the spine of the book in the left hand and keeping the right thumb on the edges of the pages the pictures could be made to flick into view in rapid succession and to give an impression of rather jerky motion. Finally, when a development of the old magic lantern was used to throw a series of images on to the screen with a momentary "blackout" between one picture and the next, the cinematograph was born.

The camera records images by using the chemical action of light waves to produce black or white spots and patches of appropriate shapes and sizes on a sensitised plate or film. Further, every part of the picture is recorded simultaneously.

Entirely different methods are used for the recording of still images by electrical means. The whole picture is not completed simultaneously but is built up step by step by the process known as SCANNING, which will be discussed in a moment. To make a picture in this way requires an appreciable amount of time and therein lay for many years one of the chief obstacles to the progress of television. Electrical methods of recording and reproducing pictures were devised, but all of them were too slow to meet the needs of television—remember that the *minimum* rate at which images must be made and reproduced if flicker is to be kept down to a reasonable level is sixteen a second. Television of a kind was accomplished a long while ago, but in the early days results were very poor. The dim, hazy and flickering images produced were interesting enough as laboratory curiosities, but they had no entertainment value. For years it seemed that the problem of making bright, detailed pictures speedily enough to enable television to take its place with the cinematograph as a means of entertainment was insoluble. Then one great invention, the iconoscope, appeared and from that moment the future of television was never in doubt. We shall come to the iconoscope in a later chapter. Meantime let us see how a still picture is transmitted over wires or by wireless. The first practical method was devised just a hundred years ago. It is interesting to note that it made use of scanning, which has been the basis of every still-picture and television system from that time to the present day. Scanning, in fact, is still the only satisfactory method known.

When you are reading this page your eyes do not remain still and take in all that is upon it at a single glance. They move from left to right along the top line and, when they come to the end of it, travel much more quickly from right to left to the beginning of the second line. In reading a whole page of this book they make these movements thirty-five times from left to right and thirty-four times from right to left—traversing, incidentally, nearly eleven feet of print as they do so. Your eyes scan the page, conveying its message line by line to the brain.

Fig. 15 shows one method of scanning a sheet of paper by mechanical means. The paper is wrapped round a rotating drum (A) and a pencil (B), whose point touches

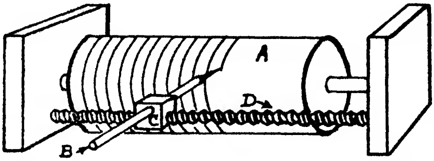


FIG. 15.—Showing how a sheet of paper may be scanned by mechanical methods.

its surface, is driven in a straight line from left to right by the action on the carriage (C) of a revolving screw thread, known as the lead screw (D). A continuous line in the form of a helix is traced on the paper. If now the paper is removed from the drum and flattened out, it is found (Fig. 16) that evenly spaced straight lines, slightly inclined, cover its surface. The pencil point has scanned the sheet of paper. Had the paper been flat when the

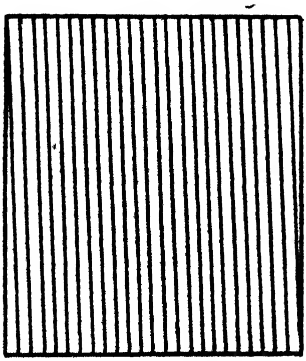


FIG. 16.—When the paper is unwrapped from the drum it is found that the evenly spaced lines shown above have been ruled upon it by the pencil point.

scanning was done some means would have had to be found of lifting the pencil at the bottom of each line and carrying it back to the top of the next. Rolling the paper on to a drum avoids the need for this and the desired effect is produced by one continuous line.

There are large, white spaces between the lines in Fig. 16. A moment's thought will show that by using a screw of very fine pitch the lines could be made so close together that they would be all but touching. Viewed at

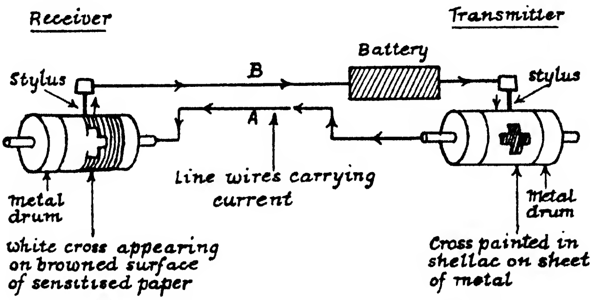


FIG. 17.—The principle of still picture transmitting and receiving apparatus devised a century ago.

arm's length, the surface of the paper would then appear to have been completely blackened by the pencil—the scan would be a very thorough and detailed one.

The eyes move horizontally in reading ; the lines in Fig. 16 are nearly vertical. The first is called a HORIZONTAL SCAN, the second a VERTICAL SCAN.

Fig. 17 shows diagrammatically the principle of the first method devised for sending still pictures from place to place by electrical means. An electric current travels easily through substances such as metals which are " good conductors." It cannot travel through substances known as " non-conductors " or " insulators." Rubber, ebonite, glass, porcelain and shellac are examples of these. Solutions of certain chemicals change colour when an electric current is passed through them ; that of potassium iodide, for instance, becomes reddy-brown.

Now let us paint a cross in shellac varnish on a thin sheet of metal and wrap the sheet round the metal drum of the transmitting instrument. On to the metal drum of the receiving instrument a sheet of paper moistened with potassium iodide solution is rolled. The two instruments and a battery are connected as shown in Fig. 17. A metal stylus rests on the surface of each drum.

The two drums are made to rotate at exactly the same speed. As the stylus of the transmitter passes over bare metal there is a path for current as indicated in the drawing : battery to transmitter stylus, stylus through sheet metal to drum, spindle of drum to line wire A, line wire to spindle of receiving drum, spindle to drum, drum through sensitised paper to receiving stylus, stylus through line wire B to battery. In such conditions current passes and the paper on the receiving drum is stained brown.

When the stylus of the transmitter passes over part of the shellac cross the flow of current is interrupted and no staining of the paper on the receiving drum takes place. As the transmitter stylus scans the metal sheet on the transmitter drum the receiver stylus simultaneously scans the sheet of sensitised paper. Brown lines appear on the paper where the sheet metal on the transmitter drum is blank ; white spaces where the sheet metal is covered with shellac. The net result is that, as seen in Fig. 18, a white cross is produced on a brown background.

Pictures, designs or even handwriting done in shellac on the transmitter drum could, in theory at any rate, be reproduced as white outlines on the receiver paper.

The idea was eminently sound. With many improvements those are in fact the general principles of still picture transmission today. But like so many inventions, this one was born out of due season. The system could not have worked properly a century ago because no suitable apparatus was then available. No means, for example, was then known of making the two drums rotate

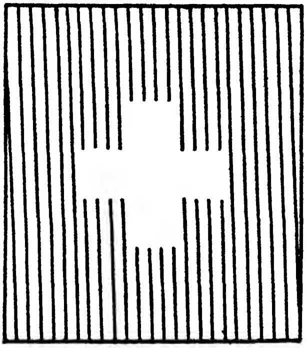


FIG. 18.—When the transmitter stylus is passing over uncovered metal current flows and a brown line is traced on the paper on the receiver drum. No current flows when the transmitter stylus is travelling over any part of the cross drawn in shellac varnish ; hence no line is then traced on the paper. When the process is completed the outline of a white cross surrounded by brown lines appears on the paper.

in different places exactly in synchronism. And a very small difference in their speeds must mean great distortion of the received image.

When it was invented the system could not have worked over more than a short length of wire. Even the best of conductors offer some opposition, or " resistance " to use the technical term, to the passage of an electric current and energy must be expended in overcoming this. The longer the wires the greater their resistance and the larger the amount of energy frittered away as current passes. Nowadays we know how to overcome this by amplifying the current when it is becoming enfeebled : in the long-distance telephone lines of today amplification takes place at every twenty-five miles by means of devices known as repeaters and a conversation over hundreds of miles of wire is as strong and as clear as a local call. But any such thing was beyond the bounds of possibility when this first system of still picture transmission was born before its time.

Sometime later, when methods of synchronising two or more motors had been developed, came a method of transmitting much improved images. When a photographic plate or film is exposed light causes a chemical action to take place in the silver salts which, mixed with gelatine, form the sensitive coating. Very briefly, the greater the amount of light reaching the emulsion during exposure, the denser is the deposit of metallic silver on the glass or celluloid. Heavy deposits of silver appear black on the negative after development and are opaque to light ; less heavy deposits are only partially opaque. Very deep shadows in the subject transmit no light. They produce no deposit of silver on the negative, which is left covered only with transparent gelatine at the points at which they occur. The result is that when a picture is made with the camera the developed negative has a coating of gelatine in which are deposits of silver varying from great density in the high lights to nothing at all in the deepest shadows. From the negative a positive can be made.

Now silver is an excellent conductor and gelatine a very poor one and this suggested a brilliant idea to the French engineer, Charbonelle. Instead of glass or celluloid, he used a thin metal backing for the emulsion of the plates, on which positives were made. A picture was transmitted by wrapping the exposed and developed sheet of coated metal round a drum as in Fig. 15. It was scanned by a metal stylus, made to traverse by a fine screw-thread as in Fig. 15. Dark portions of the picture with their heavy deposits of silver (remember that the pictures were positives) offered little resistance to the flow of current ; the flow was smaller when the stylus passed over brighter portions, where less dense deposits of silver offered more resistance, and there was no flow of current at all where the stylus came to pure gelatine, containing no metallic silver deposits, corresponding to the high lights. Reception was accomplished on the principle already described ; but there was an improvement, for instead of there being nothing but brown lines, all of one shade, and pure white patches, the variations in the strength of the current produced gradations in the tints.

For technical reasons into which we need not enter here this system, promising as it seemed, was not very successful ; but it was a step forward. I shall not describe the many other attempts at still-picture transmission which were made, merely mentioning that, though each registered an advance, nothing entirely successful was produced until use was made of a device known as the

PHOTO-ELECTRIC CELL.

The action of the photo-electric cell will be explained in some detail in a later chapter ; all that we need to know at the moment is that it is a device looking rather like a wireless valve which can be used to make an electric current vary in accordance with the amount of light falling on the cell. It is used in all modern systems of transmitting still pictures.

The latest and most efficient of these was developed by Cable and Wireless Ltd., which conducts regular services of still-picture transmission and reception by wireless between London and the United States, South America, Australia, India, Ceylon, South Africa, Egypt, Canada and many European countries. It is interesting to note it retains several of the features of the earliest method, invented before its time a century ago. The revolving drum is there, as is the lead-screw. For certain kinds of reception chemically impregnated paper is used, on which a dark stain is made by the passage of an electric current.

Fig. 19 explains in simplified diagrammatic form the principle of the method. The picture to be transmitted

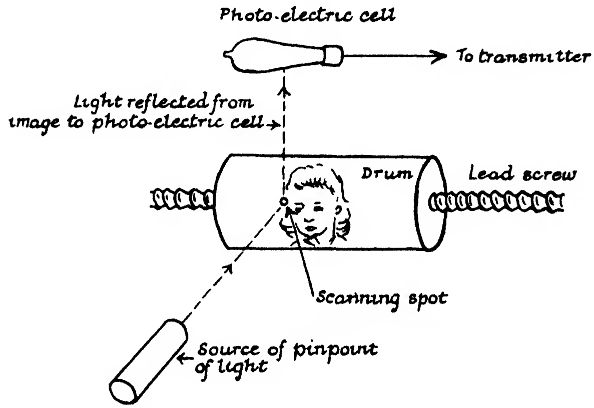


FIG. 19.—Showing in simplified form the modern method of still picture transmission.

is rolled round the drum, which is carried slowly from right to left as it rotates on the lead screw. A pin-point of bright light from a fixed source is focused on to the surface of the drum. In this case the scanning is done by the spot of light, the rotation of the drum and its slow horizontal movement as it travels along the lead screw causing the spot to traverse its surface completely line by line.

From the tiny area of the surface of the picture illuminated at any instant by the spot light is reflected to a photo-electric cell and an electric current is caused in this way to fluctuate in accordance with the fluctuations of the reflected light. A dark part of the picture reflects little or no light and a minimum amount of current is allowed to flow. The large amount of light reflected from a bright part of the picture sends up the flow of current. Since the cell is very sensitive to the amount of light reaching it, the intensity of the current flowing continually undergoes variations large or small that correspond exactly to the gradations of light and shade in the picture which is being transmitted.

The rest of the transmission process is broadly similar to the transmission of speech. Just as the microphone converts sound waves into variations of current which are

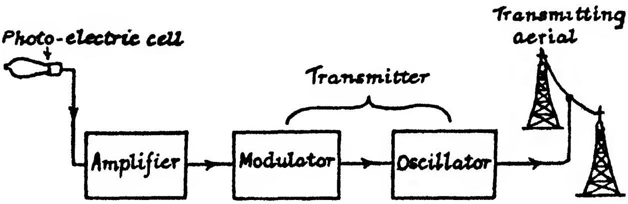


FIG. 20.—From photo-electric cell to transmitting aerial.

electrical copies of them, so the photo-electric cell's output is a fluctuating current which is an electrical copy of the fluctuations of the light reaching it. The output of the photo-electric cell is actually very small indeed and requires a considerable amount of amplification (Fig. 20), before being passed to the modulator. As before, the modulator blends the comparatively slowly varying impulses with a carrier wave of far higher frequency, superimposing them as side-bands upon it.

At the receiving end (Fig. 21) the "signal" consisting of the modulated carrier is picked up by the aerial. In the receiving set it is amplified, detected and re-amplified. But the output of the receiver does not go to a loudspeaker; it is fed instead to a special type of glowlamp whose brilliance varies in accordance with the electrical pressure applied to it. This pressure in the output of the receiver fluctuates in step with the fluctuations of current from the photo-electric cell of the transmitter. As the latter are electrical copies of the variations of the light reflected instant by instant from the transmitting drum,

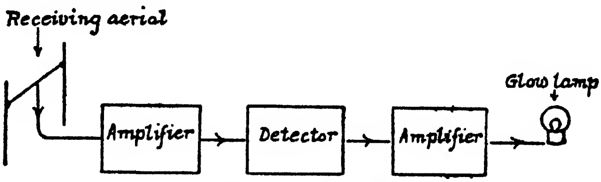


FIG. 21.—The still picture signal's path from receiving aerial to glowlamp.

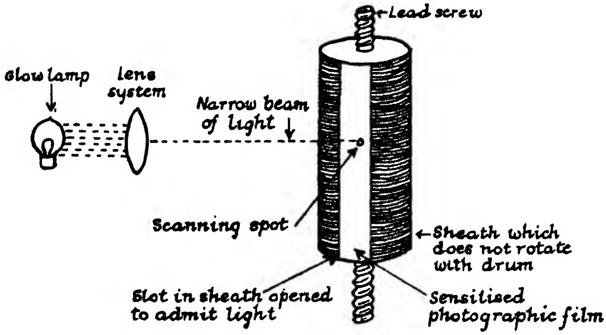


FIG. 22.—The modern method of receiving a still picture.

the flickering light of the glowlamp in the receiver exactly reproduces these variations

Fig. 22 shows the rest of the process in much simplified form. The drum is a metal cylinder, normally covered by a light-tight sheath. In the dark room numbers of drums are charged with films ready for the day's work. Each is covered with its sheath, so that it can be stored in a rack in a lighted room until required.

When a picture is about to come through, a drum is pushed vertically downwards into an aperture in the receiver and a handle is turned, causing a slot to open, as shown in the drawing, from end to end of the sheath. When the apparatus is started the drum carrying the film rotates, but the sheath does not. Then as the drum rotates and moves downwards on the lead screw the fluctuating light from the glowlamp, which is focused into a minute spot by a system of lenses, gradually traverses its entire surface.

Ingenious arrangements cause the receiving drum to run in exact synchronism with that in the transmitter: at any instant the scanning spot of the receiver has travelled precisely as far in its helical path over the film as the transmitter's scanning spot has travelled in its path over the picture that is being sent. The film is thus "exposed" line by line and the picture built up upon it.

When the transmission is completed the handle is turned to close the slot in the sheath and the drum is withdrawn. It then returns to the dark room, where the film is developed. What emerges from the developing and fixing baths, a positive or a negative? Before reading the next paragraph think it out and see if you can find the answer.

Which, I wonder, did you decide upon? Possibly you could not think of any clues and just made a guess. In that case it is likely that you plumped for a positive on the grounds that this is a modern process and a positive is what the recipient of the transmitted picture wants. But, for all that, the film is a negative. The glowlamp *brightens* when bright light from the original picture reaches the photo-electric cell of the transmitter, and *grows dim* when a shaded part of the picture reflects little light. In a camera bright lights produce dark patches on the developed film, dull lights pale ones; and so it is with the film in the still-picture receiver.

And after all it is a negative that is required. The majority of the pictures sent over great distances by wireless are intended for use as newspaper illustrations and a great many copies are wanted. From a negative as many as are required can be printed off rapidly.

The normal size of the received picture is 7 inches by 5 and transmission takes from 7 to 12 minutes. The pitch of the lead screws in ordinary use is such that there are 104 scanning lines to every inch of the picture's width: thus normally 728 lines go to build up a 7 inch × 5 inch picture. More lines can, however, be used by employing a finer screw if greater detail is needed.

Plate II showing an original picture and its reproduction by wireless over the 5,000 miles between London and Bombay demonstrates the remarkable results achieved by modern methods. There remains, however, one serious drawback that has yet to be overcome. Since each picture takes an average of some 10 minutes to come through, the number that can be handled by any particular service is definitely limited. I have no doubt whatever that in the near future television methods will be applied in modified form to the sending of still pictures. Before this can be done some very knotty problems have to be solved. Up to the time of his death the late Mr. J. L. Baird was engaged in research in this direction. He did not live to find a solution of the problem, but there can be no doubt that it will be found. Then still pictures will be transmitted in a matter of seconds, it will be possible to handle vastly greater numbers of them and the cost of sending a picture will be very much reduced.

CHAPTER V

Early Days of Television

ANY form of scanning that we have discussed so far must be a rather slow process. The drum must make one complete revolution for each line traced and if we want, as naturally we do, to have a clear and detailed picture it must be built up by many lines of scanning. Quite apart from the fact that men, women, scenery and other subjects that we may wish to televise cannot be wrapped round drums, it is obvious that these systems are far too slow for television, in which the *maximum* time that can be devoted to the production of each picture in a series is a small fraction of a second.

Long before sound broadcasting or television were thought of (in 1884, to be precise) a much quicker method of scanning was worked out by Nipkow. The device which was to make his name famous is illustrated in Fig. 23. It appears simple enough—just a series of evenly spaced holes punched or drilled in a spiral in a disc of metal. But this was the SCANNING DISC, with which the first successful transmissions and receptions of television were to be made some forty years later.

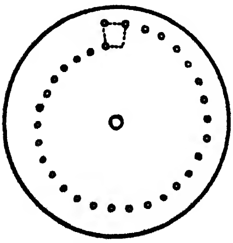


FIG. 23.—The Nipkow scanning disc. The dotted rectangle indicates the shape and relative size of the area scanned. See also Fig. 27.

The scanning disc (Figs. 23 and 24) is a large, thin circular plate, mounted on a spindle and driven by a motor. The standard number of holes in Baird's original system was 30 and as they are evenly spaced the angular distance between them is 12 degrees. When the disc is arranged as in Fig. 24 and rotated hole No. 1 allows a spot of light to traverse the subject. Then, just as hole No. 1 passes out of line, hole No. 2 comes into action, causing a spot of light to move over the image a little lower down. The process is repeated by succeeding holes until the bottom of the image is passed over by the spot of light due to hole No. 30. The process then restarts, hole No. 1 taking up the work again.

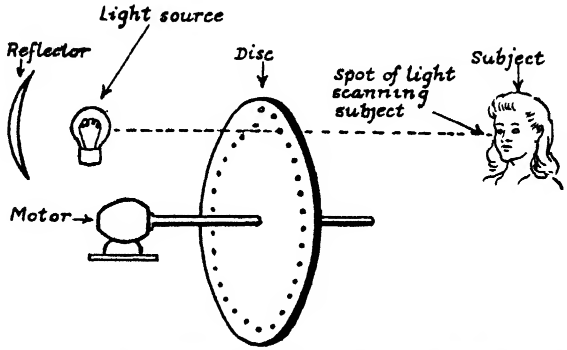


FIG. 24.—Scanning a subject by means of a light-source and a Nipkow disc.

Thus a complete scan of the image is made at every revolution of the disc and as the disc can be rotated at high speed we are well on the way to practical television. Scanning discs rotating 12½ times a second were used in the original Baird system of television.

In Figs 24-27, a horizontal scan is shown, since this makes it easier to draw simple diagrammatic layouts of the processes of transmission and reception. A horizontal scan is obtained if either the top or the bottom of the disc intervenes between the light source and the subject. It the disc is so arranged that either its right- or its left-hand edge come between light and subject, the scan is vertical. Vertical scanning was actually used in the early Baird system. In any system in which the disc or a variation of it is used the scanning is said to be mechanical; the traverse of the spot of light is produced mechanically by the motor-driven rotating disc.

Sixteen pictures a second is, as we have seen, the minimum necessary to produce an impression of smooth move-

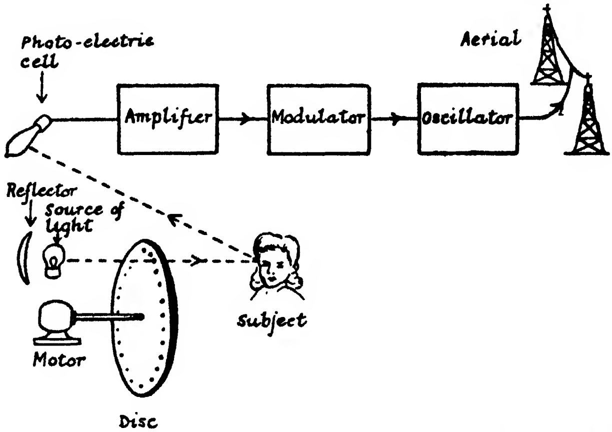


FIG. 25.—The original Baird method—the first working television system ever devised.

ment. Since only 12½ images a second were transmitted and received the early television broadcasts suffered badly from flicker.

Fig. 25 shows the first Baird transmitting system in simplified form. The subject is scanned by a bright spot of light and light is reflected from the subject to the photo-electric cell. The amount of light reflected at any instant depends upon the nature and colour of the part of the surface of the subject over which the scanning spot is travelling at that instant. Suppose that the subject is a man wearing a white collar and a dark tie and that at the moment under discussion the region of the neck is being scanned. As the spot moves over the white collar much light is reflected to the photo-electric cell. Responding to this, the cell allows the maximum of current to pass. Next instant the spot reaches the tie, from which there is much less reflection and the cell cuts down the current. If the tie is dull black material no reflection takes place and the cell, having no light to excite it, cuts off the current altogether.

The process goes on in the same way as each of the 30 lines of the scan is being made. The result is that the output of the cell is a fluctuating current, the fluctuations corresponding to the lights and shades appearing in the subject. In its way the photo-electric cell has done for these lights and shades what the microphone does for different sounds: it has produced electrical copies of them. There is, however, this important difference. The microphone's copies are those of the sound waves themselves; the photo-electric cell produces electrical copies not of the light waves themselves, but of their relative intensity at any moment of the scanning spot's travel.

The rest of the process of transmission by wireless of this simple scanning-disc television is exactly the same as that of transmitting sound by wireless. Like the output of the microphone (Fig. 11), the output of the photo-electric cell passes to an amplifier. Thence it goes to the modulator, which superimposes it on the output of the oscillator, and from the transmitting aerial wireless waves go out carrying the electrical copies of the varying intensity of the light reaching the photo-electric cell.

Fig. 26 indicates how reception is accomplished. In the receiver the incoming impulses are amplified, sorted out from the carrier waves and amplified again. The output of the receiver does not operate a loudspeaker.

Instead it is applied as a fluctuating electric pressure to a special kind of neon lamp.

Most people nowadays are familiar with the neon lamp in one form or another. Its pinkish light, for example, is to be seen everywhere in illuminated signs. The neon lamp used for television had the peculiar property of responding instantly to any change in the electric pressure applied to it. No matter how rapidly the pressure was varied, the light of the lamp fluctuated in step with it.

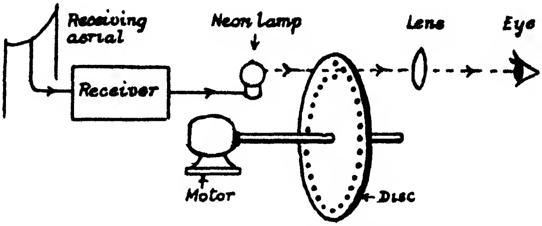


FIG. 26.—Reception by the original Baird system.

The output of the receiving set is a series of fluctuations of electric pressure which correspond exactly with the fluctuations of current produced by the photo-electric cell in the studio under the stimulus of the varying amounts of light which reach it.

By means of an ingenious device the receiving scanning disc is made to rotate at exactly the same speed as the disc in the studio. If the collar and tie which we discussed just now are being scanned in the studio, the beam of light from the neon lamp occupies exactly the same relative position as the scanning spot in the studio. As the scanning spot crosses the white collar the neon lamp glows brightly, becoming dim, or ceasing to glow, when the dark necktie is traversed. Thus the neon lamp flickers in accordance with the amount of light reflected at any instant from the subject as the scanning spot makes its traverse and the *receiving scanning disc light from the neon lamp follows exactly the same path as the scanning spot.*

The image dissected into lines by the disc and spot in the studio, is reconstructed line upon line by the beam of fluctuating light and the scanning disc of the receiver. Watching through the viewing lens, the eye sees the images considerably magnified.

With such a system the late J. L. Baird was the first inventor to accomplish genuine television. Baird television was adopted by the B.B.C., and regular broadcasts continued to be made until improved methods relegated the scanning-disc type of television transmitter to the museums.

Though it was a scientific curiosity rather than a source of real home entertainment, this early Baird system served valuable purposes. No one, least of all Baird himself, regarded it as a complete solution of the problem of television ; it was clearly a stepping stone to better things. It demonstrated that public interest in television was enormous and Baird and other inventors were spurred on to renewed efforts. Time was to show that those who sought to perfect television transmission by improving mechanical methods of scanning were barking up the wrong tree ; but for all that some very remarkable feats were accomplished with its aid.

From what has been said of mechanical scanning methods of transmission it will be realised that they could be used in the studio only : you cannot cause a minute spot of intense light to traverse a group of galloping horses on a race course or the crews of two distant boats on a wide river ; and even if this were possible a photo-electric cell could not be so placed that it would respond to the variations in the reflected light. Nevertheless, both the Derby and the Boat Race were televised by mechanical methods.

It was done by an ingenious use of the ciné-camera. Quite early in the history of practical television it was found possible to transmit cinematograph films made at the rate of 12½ "frames" a second—individual ciné pictures are called frames. Each frame was scanned by the light spot in the studio and a somewhat flickering reproduction was obtained with the receiver. A method was invented of developing and fixing exposed film with extraordinary rapidity. The film passed straight from the camera to successive tanks, in which it was developed and fixed. It was then fed still wet into the television transmitter.

The total time that elapsed between the exposure of a frame in the camera and its arrival before the scanning disc was less than 30 seconds. Film was, of course, an expensive item, but an improvement in the process cut down costs enormously. A comparatively short endless loop of film was used. On leaving the television transmitter the film entered a device in which the used emulsion was removed. Another piece of apparatus covered it with fresh emulsion. Then, after rapid drying, the re-sensitised film passed once more into the camera.

One of the drawbacks of scanning disc transmission and reception can be seen at once by glancing at Fig. 27.

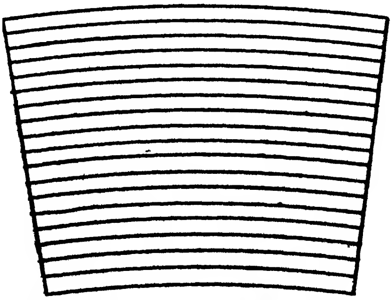


Fig. 27.—Some distortion of the image must result from the use of a scanning disc. The scanning lines are curved and two edges of the picture are slightly inclined. See also Fig. 23.

The images are not rectangular. Two of the sides are formed by radii of a circle—the scanning disc itself. This must cause some distortion of the image and further distortion is introduced by the fact that the other two sides and all of the scanning lines are arcs of circles* and not straight lines.

The image must be small and require magnification unless the scanning disc is of far too large size to be accommodated in a domestic receiver and the pinkish light of the neon lamp is trying to the eyes. In the studio a very bright light must be used to produce a scanning spot of sufficient intensity to allow adequate amounts of reflected light to reach the photo-electric cell. This was most distressing to the subject, as anyone who was televised in the early days of the art can testify.

The most serious shortcoming of all is the poor definition of the image transmitted and received by mechanical scanning methods. It is important to understand what the term " definition " means in television, for unless we do so it is not always easy to see why one system should be superior to another in the quality of the pictures produced.

*Or very nearly so. Actually they are portions of a spiral.

CHAPTER VI

The Meaning of Definition

FOR the photographic illustrations of books, magazines and daily newspapers what are known as half-tone blocks are used. These are made in the following way. The original picture is photographed on to a sensitive film backed, not by glass or celluloid but by copper. Between the camera and the picture is placed a screen. This consists of two glass plates upon each of which diagonally sloping lines are etched. The plates are cemented together face to face and their combined lines form a fine trellis-work pattern. The result of photographing through the screen is to break up the surface of the picture into a multitude of tiny dots, formed by the spaces between the lattice of etched lines.

After development, the block is placed in a bath of acid, which eats away the portions corresponding to high lights and leaves those representing deep shadows almost untouched. The finished block has a surface consisting of thousands of tiny " pimples," the largest of these being in the dark areas and the smallest in the light. When the block is printed the former carry more ink than the latter and therefore produce blacker impressions on the paper.

For daily newspaper illustrations what is called an 80-screen is commonly employed. This has 80 etched lines, sloping in either direction, to the square inch and therefore 80 × 80, or 6,400 pimples to the square inch. The dots made by the pimples are called PICTURE ELEMENTS: they are the elements which build up the picture. The first illustration of Plate III is made with an 80-screen. Even without a magnifying glass the dots can be-seen if the picture is held fairly close to the eye. The picture gives a good general impression of the subject, but it has less detail than the second picture and far less than the third.

The second was made from the same photograph as the first, but with a 100-screen, the type generally employed for the illustrations of shilling weeklies; the number of picture elements is here 100 × 100, or 10,000. For the third a 200-screen was used, the sort of screen required for high quality half-tone illustrations printed on art paper. The 200-screen gives 200 × 200, or 40,000 picture elements per square inch. The number of the screen is thus an indication of the amount of detail or the degree of definition in the picture.

Definition in television images is generally assessed in a similar way by the number of scanning lines: the greater the number of such lines, the better the definition. We shall see presently that this rating is not always strictly accurate, but for the moment we may accept it as adequate. The first 30-line television gave very poor definition, the 180-line images which followed were vastly better and the 405-line television of today leaves little to be desired in the way of definition, provided that viewing is done with first-rate receiving equipment.

There is one important difference to be noted in the definition ratings of half-tone blocks and of television images. The screen numbers refer to the lines per square inch of surface, irrespective of the size of the illustration: thus with a 100-screen a 5-inch by 4-inch block, with 20 square inches of surface, is made with a screen containing 20 × 100 = 2,000 lines sloping in either direction whilst a 10-inch by 8-inch block, with 80 square inches of surface, is made with a screen containing 80 × 100 = 8,000 lines. On the other hand a 5-inch by 4-inch and a 10-inch by 8-inch image are each built up of the same 180 lines if a 180-line television system is in use, or of the same 405 if the system is 405-line. Thus for a given television system enlarging the image means increasing the width of the gaps between lines.

Like a half-tone block, a television image can also be resolved into picture elements and the number of these has an important bearing on transmission and reception technique.

First of all, if the whole surface of a subject in the studio is to be properly scanned the diameter of the spot must be the same as the width of the scanning lines. Fig. 28

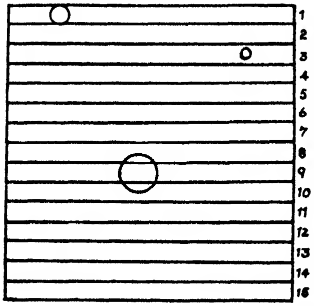


FIG. 28.—If the spot is of the same width as the lines the whole surface is properly scanned. Too small a spot in proportion to the number of lines leaves parts of the image unscanned. If the spot is too large it may overlap two or more lines and lead to poor definition.

shows a square frame divided into 15 belts representing the scanning lines. In line No. 1 a spot of the right diameter is shown. It will be seen that as it travels it covers the whole line. In its passage over the frame it leaves no gaps between lines and does not overlap from one line to another.

The undersized spot shown in line 3 would cover only part of the width of each line and would leave gaps between lines. Overlap would result if too large a spot like that seen in lines 8, 9 and 10 were used.

The smallest thing that a spot can scan properly is something whose size is not less than its own. If the method of transmission illustrated in Fig. 25 is in use, the photo-electric cell always receives the *average* amount of light reflected from the area illuminated at any instant by the scanning spot. At (*a*) in Fig. 29 the spot (represen-

FIG. 29.—The smallest thing that can be scanned properly is something not less in size than the spot itself. As explained in the text the grey patch at (*a*) and the small black square at (*b*) would each be reproduced as a grey picture element if scanned by a spot of the size indicated by the circle.

ted by the circle) is on a shaded patch in the image. The patch is larger than the spot and the moderate amount of light reflected and received by the photo-electric cell gives a sufficiently correct representation of the size and the colour of the patch. A little later the spot has moved to (*b*) and is now covering a black square much smaller than itself. The average amount of light reflected from the area now covered by the spot is the same as that from (*a*). Therefore the photo-electric cell records and causes to be transmitted precisely the same "message" as that due to (*a*). At the receiver (*a*) and (*b*) both look alike; both appear as grey patches. The little black square at (*b*) cannot be dealt with properly because it is smaller than the scanning spot

Hence the greatest possible number of elements into which the picture can be resolved is found by working out how many things of the same size as the spot can be fitted into the frame. Since the diameter of the spot is, or should be, the same as the width of the lines, this is

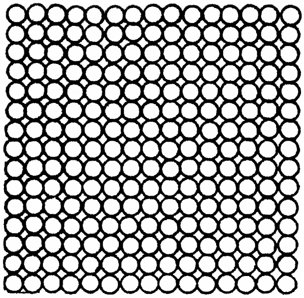


FIG. 30.—If a square image is made up of 15 scanning lines the number of picture elements is 15 × 15, or 225.

done (Fig. 30) in the case of a square frame by squaring the number of lines. Here 15 × 15 = 225 and that is the number of picture elements in a square 15-line image. A 30-line square image contains 30 × 30, or 900 picture elements and so on.

Modern television images are not square. In those transmitted by the B.B.C. the ratio of the horizontal sides to the vertical is 5 to 4; that is, the received images may be 5 × 4 inches, or 7½ × 6 inches or 10 × 8 inches or any size such that the length of the horizontal edges divided by that of the vertical edges comes to 5/4. This figure 5/4 is known as the PICTURE RATIO, sometimes also called the aspect ratio, or form factor. For reasons which will appear later only some 377 lines are used for actual picture making in the B.B.C.'s 405-line transmissions. To discover therefore how many picture elements a 405-line image sent out by the B.B.C. contains, we must first of all multiply 377 by 377 and then multiply the result by 5/4: 377 × 377 × 5/4 = 177,661 picture elements composing the whole image.

Television is classed as "low-definition" or "high-definition" according to the number of picture elements in its images. This number depends, as we have seen, on the number of scanning lines and it is customary to grade television systems simply by the number of lines that they use. Thus 30-line television is classed as low-definition, 180-line as medium definition and 240-line and above as high-definition. The term definition refers to the clearness of the images and that depends largely upon the amount of detail that they contain. But it does not necessarily follow that an increase in the number of scanning lines must lead to improved definition. It can do so only if the size of the spot which makes the scan is reduced accordingly. We have already seen that to do its work properly the spot must be no larger than the smallest thing that it is called upon to scan. Increasing the number of lines increases the number of picture elements and reduces the size of each.

The scanning spot itself presents very important problems in television. Ideally it should be square; in practice its shape, though more nearly circular, is not sharp and regular. Nor is any method so far known of bringing the size down below certain limits. Intensive research is seeking to develop higher-definition television of 1,000 lines or more, but no system employing methods now known could probably go usefully much beyond 600 lines.

We saw that in normal broadcasting of speech and music the carrier wave of the transmitter is modulated by impressing upon it the frequencies due to sound waves ranging up to 4,500 cycles a second. Since these superimposed frequencies appear in both the upper and the lower side-bands the total "band-width" of such a transmission is 4,500 + 4,500, or 9,000 cycles. This is the greatest band-width that can be allowed to European medium-wave stations, since so many have to be fitted into the 200-550 metre, or 1,500-550 kc/s limits of the band.

Let us now see what kind of modulation frequencies are involved in television transmissions. As we have seen, the current passed by the photo-electric cell in the system so far discussed fluctuates in accordance with the light reflected on to the cell from the subject in the studio.

To begin with a simple case we will consider a 10-line horizontal scan. Fig. 31 shows a square image consisting of alternate black and white stripes, each the width of a scanning line. The image contains $10 \times 10 = 100$ picture elements and each line has 10 picture elements

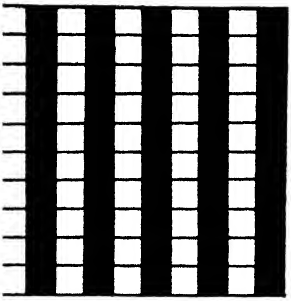


FIG. 31.—A square image consisting of alternate black and white stripes is scanned in 10 lines. The corresponding current fluctuations from the photo-electric cell are as shown in Fig. 32.

grouped in 5 pairs, one element of each pair being black and the other white. As the scanning spot travels over any line the reflected light fluctuates from maximum (white) to minimum (black) 5 times. Corresponding fluctuations, which we may represent as in Fig. 32, occur in the current from photo-electric cell. It will be noticed that each pair of black and white picture elements gives rise to one complete cycle of current. Thus if the entire image consists of alternate black and white picture elements the number of cycles of current corresponding to each frame is half the total number of picture elements.

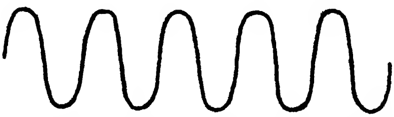


FIG. 32.—The current fluctuations in the output of the photo-electric cell produced by the scan of one line of Fig. 31.

In the present instance there are 100 picture elements and the maximum number of cycles for each frame is 50. Suppose that there are 25 frames a second; then the total number of cycles a second becomes $50 \times 25 = 1{,}250$. The modulation frequency, that is, is 1,250 c/s. For 30-line square images at 12½ a second, the maximum possible modulation frequency is found in the same way: picture elements = 900; half of 900 is 450, and this multiplied by 12½ comes to 5,625 c/s.

This, remember, appears to be the maximum frequency required for transmitting the most exacting of all images, that consisting entirely of alternate black and white picture elements. As we are not likely to spend our time televising huge herds of zebras or crowds of people garbed in sponge-bag suitings, such conditions will seldom, if ever, occur. Will not the actual frequency range, then, be much smaller than has been suggested? It would be but for an important factor which has not yet been mentioned.

So far we have assumed that the modulating impulses applied to the carrier wave have the shape of the current fluctuations shown in Fig. 32. Were this so the results at the receiving end would be somewhat as shown in Fig. 33. Pure whites would occur only at the crests and dead blacks only at the troughs. The outlines of the squares would be blurred and the image would consist largely of different shades of grey.* To reproduce the picture elements sharply on the receiver screen modulating impulses approximating to the square shape shown in Fig. 34 are needed, and to produce such shapes a much greater range of frequencies is necessary.

It will be seen that an impulse rising steeply to maximum, remaining at maximum during the scan of a white

**Note.* The terms "black" and "white" are used throughout this book to denote respectively the darkest and lightest shades on the receiver screen, though these may actually be neither black nor white. Similarly "grey" denotes intermediate shades between "black" and "white."

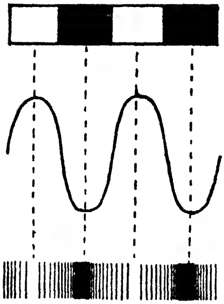


FIG. 33.—If the current fluctuations of Fig. 32 were used in that form to modulate television transmissions the received images would be hazy owing to the poorly defined picture elements.

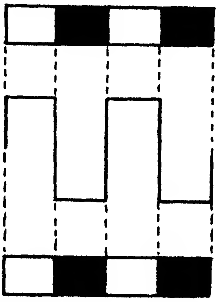


FIG. 34.—The ideal form of modulating impulse would reproduce exact copies of rectangular picture elements.

picture element, then falling steeply to minimum as a black element is reached and remaining there whilst it is being scanned would give perfectly sharp reproduction and therefore excellent definition at the receiver. A fairly close approach to these square shapes can be obtained in the modulating impulses and in those handled by the receiver. To do this use must be made of HARMONICS and to explain what these are we must return for a moment to the vibrating strings of the piano.

It was said in Chapter II that when middle C is struck the corresponding string swings to and fro, or vibrates, 256 times a second. That is not quite the whole story: 256 c/s is known as the FUNDAMENTAL FREQUENCY, but there are other subsidiary vibrations as well and these are the harmonics. Whilst making its fundamental vibrations at 256 a second the string is also vibrating less strongly at 2 × 256 = 512 (the second harmonic), 3 × 256 = 768 (the third harmonic), 4 × 256 = 1,024 (the fourth harmonic) . . . and so on to a great number of harmonics. Notice that the *second* harmonic has *twice* the fundamental frequency, the *third*, *three times* that frequency and so on; the fifteenth harmonic of middle C would have a frequency of 15 × 256 c/s.

No musical instrument produces pure notes, for all consist of the fundamental and many harmonics. The relative intensity of the various harmonics within the audible range differs from instrument to instrument. That is what gives each its characteristic timbre. It explains why middle C on the piano sounds quite different from middle C on the clarinet, the cornet the violin or the xylophone. The fundamental is the same in all cases, but one instrument brings out strongly particular harmonics which are feeble in the notes of another.

Simple regular waves of electric current or pressure like those shown in Figs. 32 and 33 are known as sine waves and fluctuate at the fundamental frequency only. But, like the sound waves produced by the piano string, the waves may consist of combinations of numbers of harmonics. If *all* harmonics right up to infinity are present in the wave its shape is perfectly square. For television scanning we fortunately do not need to go so far as that; for practical purposes the waves that form the modulating impulses are square enough to give adequate definition if they contain harmonics up to the tenth or eleventh.

We saw that half the number of picture elements multiplied by the number of pictures a second represented the highest fundamental modulating frequency that could conceivably be required. No complete image consists of alternate black and white picture elements; there are always considerable areas of black or white or of various greys. The fundamental frequencies needed are found in practice to be not more than about one-tenth of the number found by this calculation; however, as we require not only the fundamentals but all their harmonics up to the tenth or eleventh, the figure gives a close approximation of the frequencies actually needed.

In round figures the B.B.C.'s television images contain 180,000 picture elements, and as there are 25 pictures a second the maximum possible fundamental frequency is 90,000 × 25, or 2,250,000. The B.B.C. actually transmits modulation frequencies up to 2,700,000 c/s, or 2.7 Mc/s in its television service from the Alexandra Palace.

This means that a high definition television transmitter requires a channel 2 × 2.7, or 5.4 Mc/s in width. No such transmission could take place on the medium-wave band used for ordinary broadcasting, for the whole extent of this band is rather under 1,500 kc/s, or 1.5 Mc/s. A single high definition television transmitter would not only monopolise all the channels open to the medium-wave stations of Europe; it would require, if it worked on a wavelength of, say, 400 metres (750 kc/s), a channel far wider than the entire medium-wave band all to itself. Any such thing is, of course, out of the question. High-definition television could never have come into use were such wavelengths the only ones available. It is impracticable on the long, the medium and even the short waves between 10 and 100 metres in length. Fortunately there is plenty of elbow room on the ULTRA-SHORT WAVES below 10 metres in length and it is on these that high-definition television is conducted today.

CHAPTER VII

The Ultra-Short Waves

WIRELESS waves may conveniently be classified in the following way: –

Wavelengths	Classes	Corresponding Frequencies
Above 10,000 m.	The very Long Waves	Below 30 kc/s.
1,000–10,000 m.	The Long Waves	300–30 kc/s.
100–1,000 m.	The Medium Waves	3 Mc/s–300 kc/s.
10–100 m.	The Short Waves	30 Mc/s–3 Mc/s.
1–10 m.	The Ultra-Short Waves	300 Mc/s–30 Mc/s
Below 1 metre	The Micro-waves	Above 300 Mc/s.

Until quite recent times the ultra-short waves were thought to be of no special practical value, for they have certain peculiarities of behaviour which render them (so far, at any rate, as our present knowledge goes) of no use for long-distance communications. They have, though, been found to be almost ideal for the broadcasting of high-definition television. The micro-waves, little used before the war, make precision radar possible and all peace-time radar developments are likely to be upon them.

All readers will have had practical experience of medium- and long-wave wireless and a good many will probably have received distant stations on the short-wave ranges of their radio sets. All will know such things as that atmospherics are worse on the long waves than on the medium in thundery weather, that long-wave stations do not vary much in strength by day or night, that distant medium-wave stations are stronger after dark than in daylight and that both medium-wave and short-wave transmissions (except those of nearby medium-wave stations) are apt at times to suffer from "fading," their signals swinging from a roar to a whisper and back again, often with the accompaniment of very unpleasant distortion.

Waves from a long-wave wireless transmitter follow the contours of the earth's surface as they travel outwards and, as no great changes occur there as night follows day, reception seldom varies very much. But medium waves behave differently.

The earth is surrounded (Fig. 35) by two curious layers

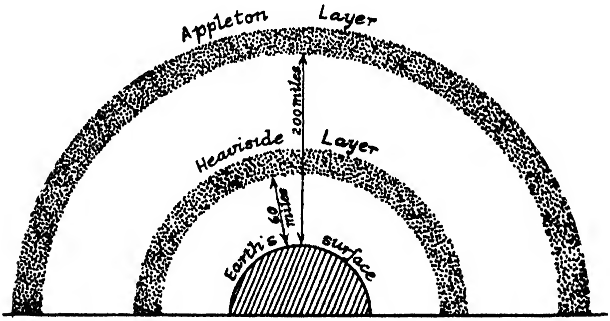


FIG. 35.—High up in the atmosphere are two reflecting layers which turn wireless waves back to earth.

in the atmosphere which have the property of reflecting wireless waves back to earth. The lower of these, the HEAVISIDE LAYER whose height is about 60 miles, is much more effective as a reflector by night than by day. From the aerial of a medium-wave transmitter (A in Fig. 36) two sets of waves, the SKY-WAVE and the GROUND-WAVE, go out. The ground-wave travels over the surface of the earth and is unaffected by conditions of light or darkness. It is upon this wave that we rely for reception at all times in the service area of a medium-wave broadcasting station. The sky-wave travels upwards as well as outwards. By day it is not turned back to earth, but after dark it is reflected by the Heaviside layer as shown in Fig. 36 A–B. The reflected wave does not normally return to earth for some distance from the transmitter and it is not received by aerials moderately close to the

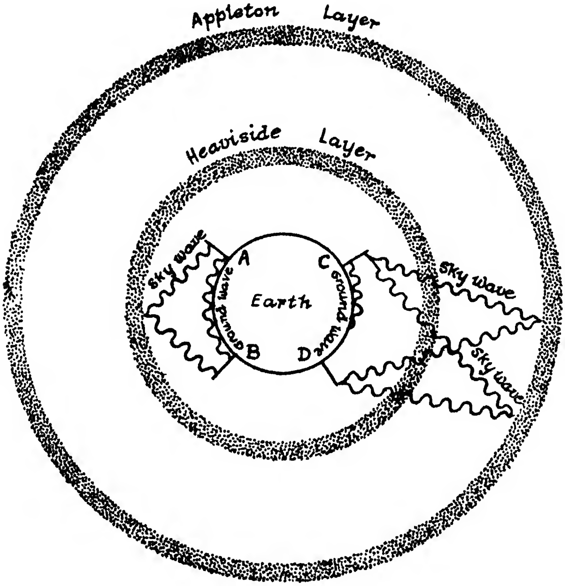


FIG. 36.—Illustrating the paths that may be taken by waves from medium-wave and short-wave transmitters.

sending station. But at a greater distance from the transmitter matters are different. The ground-wave has become weaker, owing to the resistance offered to its passage by the earth's surface. Both ground-wave and sky-wave are received by the more distant aerial as shown at B in Fig. 36.

The path of the sky-wave is longer than that of the ground-wave ; there is thus no knowing whether the two will arrive exactly " in step " (Fig. 37), exactly " out of step " (Fig. 38), or at something intermediate between the two. If crests arrive simultaneously with crests and troughs with troughs, as in Fig. 37, the waves are said

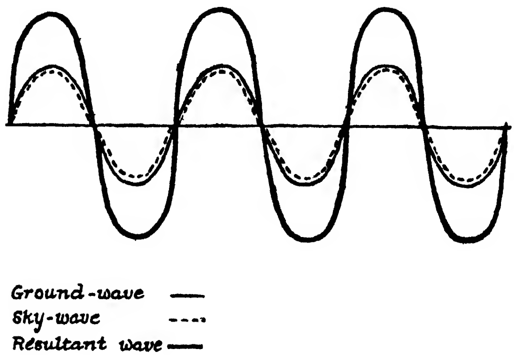


FIG. 37.—If two waves arrive " in step " the strength of the signal is increased.

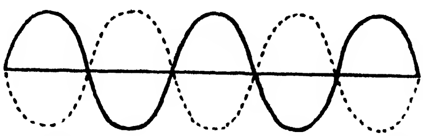


FIG. 38.—When waves of equal amplitude arrive " out of step " they cancel out and no signal is received.

to be IN PHASE. The energy brought to the receiving aerial by one set of waves is added to that brought by the other and signal strength is great. On the other hand when the two waves are directly OUT OF PHASE, as in Fig. 38, their energies are in opposition to one another ; should the two waves be of equal amplitude, no signal is heard. Between in phase and out of phase there is an infinite number of graduations. As the reflecting surface is at times continually changing in character the angle of reflection, and therefore the length of the sky-wave's path, is altering from moment to moment. Hence the phase relationship of the two waves is always varying; signal strength of the combined waves is unsteady and fading occurs.

Reception of distant medium-wave stations is difficult or in many cases impossible by day. The ground-wave is feeble for reasons already given and the sky-wave is not returned to earth. After dark reflection occurs. The sky-wave may then arrive by two or more different paths and fading is liable to occur as before owing to variations in the phase relationship of different sets of waves.

Short-waves travel in another way. Here the ground-wave is so feeble that it peters out within a short distance of the transmitter. The sky-wave passes through the Heaviside layer, but is normally returned to earth by the APPLETON LAYER whose height averages some 200 miles. Fading occurs as above through the interaction of two or more sets of sky-waves.

Further differences are found in the way in which the ultra-short waves travel. At these very high frequencies ground-waves are to all intents and purposes absent and there can be no sky-wave reception since the waves normally pass through both Heaviside and Appleton layers without reflection. Reception is by the DIRECT WAVE, whose path is almost that of the line of sight from the transmitting aerial to the receiving aerial. The range is said to be QUASI-VISUAL because it extends little beyond the horizon as seen (Fig. 39) from the top of the transmitting aerial. As only the direct wave is concerned, fading does not normally occur in the service area of an ultra-short-wave transmitter.

From the television point of view one of the most important aspects of the ultra-short-waves is the enormous

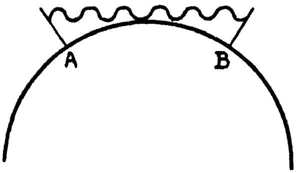


FIG. 39.—The range of ultra-short waves is only a little beyond visual distance. The top of the receiving aerial B must be above, or only a little below, the horizon visible from the top of the transmitting aerial, A.

band of frequencies that they cover. They extend only from 1 to 10 metres in length, but in frequency from 300 to 30 Mc/s—270 Mc/s in all. Compare this with the medium-waves from 100 to 1,000 metres, with a corresponding frequency range of 3,000 to 300 kc/s, a total of 2,700 kc/s, or 2.7 Mc/s. There is a hundred times as much elbow room between 1 and 10 metres as there is between 100 and 1,000 metres. If they were made on the medium-waves the Alexandra Palace transmissions would exactly occupy the whole of the band from 100 to 1,000 metres!

There is actually far more room than that owing to the short ranges of ultra-short-wave transmissions. Medium-wave and long-wave stations working on channels whose separation is too small can and do interfere with one another at ranges of many hundreds of miles. Such interference can normally take place only at short range between ultra-short-wave stations. Several stations, therefore, could use the same frequency, provided that they were not placed too close together.

We have seen that high-definition broadcasting necessitates the transmission of modulation frequencies up to 2.5 or even 3 Mc/s, which means that a channel 5 or 6 Megacycles in width is required—impossible on the medium-waves, but perfectly feasible on the ultra-short. The vision broadcasts from the Alexandra Palace take place on 45 Mc/s, or 6.66 metres. With a band-width of 5 Mc/s, the channel occupied extends from 47.5 to 42.5 Mc/s, or from 6.31 to 7.07 metres.

Ultra-short-wave transmitters are always sited on high ground so that their aerials may have the widest possible " horizon." The direct wave does not in fact travel in a perfectly straight line ; its path is curved gently by its passage through the atmosphere and its horizon is thus rather more distant than the visual horizon. The Alexandra Palace transmitter, rated at only 17 kilowatts, has a service area which is roughly circular in shape with a radius of at least 30 miles. It is intended within the next few years to provide a country-wide television service by means of similar stations and of relay stations.

To obtain the best reception on the ultra-short-waves an aerial of the kind known as a HALF-WAVE DIPOLE is required. Such an aerial may be accurately matched to the wave length upon which it is intended to work, measuring, as its name implies, half the length of one wave overall. For technical reasons into which it is not necessary to enter the actual length of a closely matched aerial is very slightly under half a wavelength. The normal television aerial has to collect both the vision signal on 6.66 metres and the sound signal on 7.23 metres. It is therefore not closely matched to either wavelength. Its length is a compromise which enables it to deal reasonably well with both signals. Behind the half-wave dipole a REFLECTOR is generally used, the combination of aerial and reflector forming the familiar H-shaped equipment. By " behind the aerial " I mean that the reflector is so placed that the aerial is directly in line between it and the transmitting aerial. Its purpose, as its name suggests, is to reflect radiation from the transmitter on to the receiving aerial and so to increase the amount of energy picked up by the latter. The reflector is a metal rod slightly over half a wavelength in length. The aerial is connected to the receiver by a matching transformer and a wire " feeder," both specially designed to ensure that the smallest possible amount of the received energy is wasted on its way from the aerial to the television set.

The aerial should be placed as high as possible for two good reasons. Beyond the " horizon " of the transmitting aerial signal strength falls off very markedly. The higher the aerial within reason, the better its chance of being above this horizon and of not being screened by intervening high ground or tall buildings. The second reason is that a high aerial with a properly designed feeder is much less affected than a low one by the worst form of interference with television reception, that caused by the ignition systems of motor vehicles. The field of such interference extends to a considerable distance on all sides of the source of it, but does not usually extend upwards for more than about 30 feet. An aerial whose height is such that it is above this field should not pick up interference of this kind if used in conjunction with a well-designed screened feeder. The reflector can sometimes be used as an anti-interference shield by so placing it that it stands between the aerial and the main source of interference.

Though the normal range of a well-sited ultra-short-wave transmitter is some 30-50 miles, very much greater distances may be covered under certain conditions. If, for instance, both receiving and transmitting stations are on high ground the horizon may be greatly extended. Again, freak conditions in the upper regions of the atmosphere (the IONOSPHERE), may result in the reflection of ultra-short-waves and their return to earth at great distances. The televised transmission of the victory procession was received at Minehead, over 170 miles from the Alexandra Palace. In the years before the war the London Television transmissions were received on several occasions both in South Africa and New York.

CHAPTER VIII

Introducing the Cathode-Ray Tube

INTERESTING as were the results obtained by mechanical methods of scanning, it was clear that the disc could never provide reception of real value as entertainment. Some of the disadvantages have been mentioned already; in addition to these there is the fact that the image formed by a scanning disc of dimensions suitable for domestic receiving equipment is minute and must be viewed (Fig. 26) through a lens. As distortion must inevitably take place if the line of vision does not pass through the centre of the lens or very near it, this obviously limits the number of viewers at any one time to two or three. An image is required made up of a much larger number of picture elements than the 900 of the 30-line system and of such size that no lens is required.

For the medium-definition 180-line system developed by Baird and worked experimentally from the Crystal Palace it was possible to use a scanning disc in the studio, where its large size was of no particular importance; but to produce a 180-line picture even two inches square at the receiver, a disc of altogether unwieldy size would have been needed. The solution was found by abandoning mechanical scanning in the receiver in the way shown diagrammatically in Fig. 40.

In the studio the methods used did not differ much in principle from those of the original Baird system: the light was more intense, the disc larger, with more apertures and a higher rate of rotation to give an increased number of frames a second. But the receiving equipment contained revolutionary ideas; it was in fact basically the same as that now used for the reception of high-definition television. Both receiving and transmitting apparatus nowadays use the CATHODE-RAY TUBE. The former employ the tube in its normal form ; the latter used a highly specialised form of it.

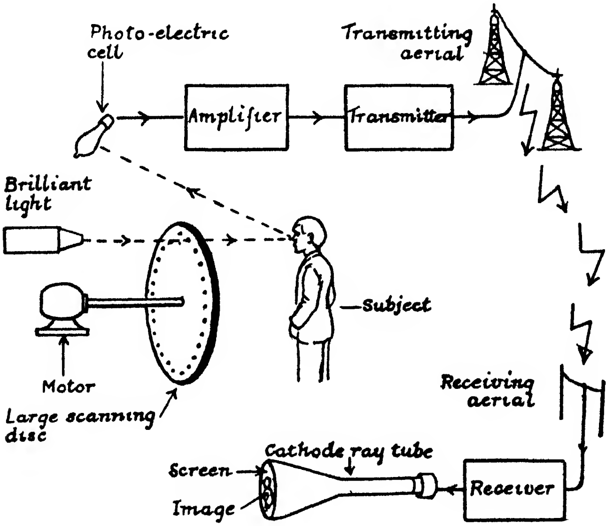


FIG. 40.—The method used in the Baird 180-line system. The cathode-ray tube replaced the scanning disc and neon lamp for reception.

The cathode-ray tube was no new invention ; it had long been in use in the laboratory and to some extent in industry. What was new was the use of its screen as the " canvas " on which are " painted " the images of television by means of a spot of light, moving at almost incredible speed. In the chapters which follow we shall see how the cathode-ray tube (or C.R.T. as it is generally called for short) works. It is important to understand this, for the C.R.T. is the basic component of modern methods of both the transmission and the reception of television.

Before we go on to discuss it in detail it may be well to form a general idea of what the C.R.T. can do. The tube itself (Plates IV, V and VI) looks rather like an enormous wireless valve, with the large end of its somewhat pear-shaped bulb flattened. The inside of this flat end of the bulb is covered with opaque greyish-white material which forms the SCREEN. The screen is the only part of the tube normally seen by the owner of a television receiver.

When the tube is switched on a spot of light appears on the screen. The spot can be focused to a small pin-point and its brightness adjusted as required. By electrical means only and without the use of a single mechanical moving part it can be made to occupy any desired position on the screen or to move rapidly over it without the noise, friction and heat associated with rapid mechanical movements.

In television reception this spot of light is harnessed and made to perform all the operations of scanning. Its movements over the screen, though, are not quite the same as those of the spot of light produced by the scanning disc. You will recall (Fig. 24) that as light is admitted by the first aperture of the scanning disc the spot travels in a gently curved path to " paint " the first line. Then the second aperture admits light and the second line is scanned. The spot is moving always in the same direction, that in which the disc rotates.

The C.R.T. spot takes a different path. Its movements over the screen are illustrated in Fig. 41. It travels first across the screen, tracing out the top line of the image. Then it flashes back at enormous speed to the starting edge and at the proper instant begins to scan the second line. And so the process continues, scan, flyback, scan, flyback, until the "painting" of the whole image is complete. The framework of scanning lines of which the image is built up is called a RASTER.

It will be noticed that in addition to the rapid horizontal movements of the spot there is a much slower downward movement. This causes the scanning lines to slope slightly downwards from left to right ; in a high-definition raster the slope is so slight that it is difficult to detect.

Scanning of the kind illustrated in Fig. 41, in which

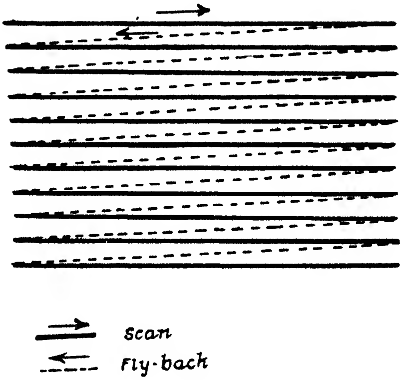


FIG. 41.—The spot of a C.R.T. moves over the screen as shown by the solid lines when making its scan. At the end of each line it flies back to the start of the next.

line 2 follows line 1, line 3 follows line 2 and so on is known as SEQUENTIAL. This system was used in the Baird high-definition system, which conducted broadcasts from the Alexandra Palace alternately with the E.M.I. system during the trial period in 1936. This Baird system was 240-line sequential, with 25 frames a second. With a rather low degree of brightness at the receiver the pictures were satisfactory enough ; but when the brilliance was increased to what most viewers would regard as an acceptable level flicker became apparent.

Then why not cure the flicker by increasing the number of frames a second? There was unfortunately a snag here. The electric current used for domestic supplies in most parts of this country is of the kind known as alternating. Alternating current, or A.C., goes in cycles; it rises to a maximum in one direction, changes direction, reaches a maximum in that direction and changes direction again. In this country these cycles occur 50 times a second and 50 c/s is the standard frequency for A.C. Unless the number of frames a second is 50 or sub-multiple or multiple of 50, serious troubles are experienced in television reception owing to what are called HUM EFFECTS, which may cause light and dark bands to travel across the picture on the screen. The smallest possible increase in the number of frames would therefore have been from 25 (one half of 50) to 50, and the Baird system could not be modified so as to accomplish this.

The E.M.I. system, which was ultimately adopted and is the one now in use, employs a different method of scanning. This is illustrated in Fig. 42, and is known as INTERLACING. The principle is this:—Each complete raster is made up of two FRAMES. In the first frame the scanning lines have double the normal spacing between them; the spot does not, therefore, cover the whole surface of the image, but leaves gaps between the lines. The second scan interleaves with the first set of lines and fills in the gaps. The first scan is done in 202½ lines and the second in the same number. The complete raster consisting of the two frames is thus built up by 405 scanning lines.

Or rather it would be if all of the lines were used for scanning. We saw, though, a few pages back that some were required for other purposes and that the complete image is made up of 377 lines—188½ in each frame.

In the E.M.I. system there are 50 frames a second (25 for each set of lines) and 25 complete images. It is found that even brilliant images show little flicker. The use of 50 interlacing frames a second has, broadly speaking, much the same effect in reducing general flicker as the transmission of 50 complete images a second would have. One undesirable effect is, however, sometimes noticeable. If the eyes follow a person or an object moving

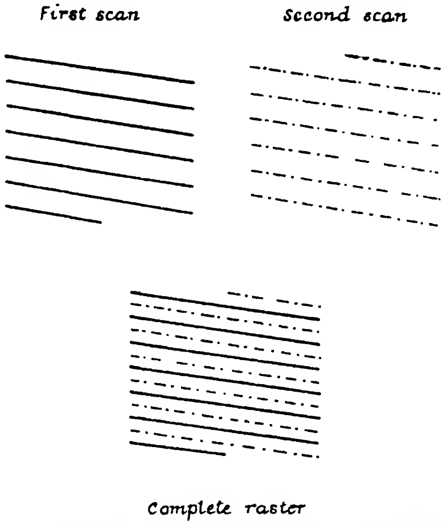


FIG. 42.—Illustrating the principle of interlaced scanning.

rapidly across the screen they may lose momentarily one of the interlacing sets of lines and what is known as INTERLINE FLICKER occurs.

Something of the wonders of which the cathode-ray tube is capable may be realised if we consider what takes place on its screen in every second whilst the receiver is in action. Suppose that the picture is 10 inches by 8. Then in scanning each of the 377 lines that go to make up one image the spot travels 10 inches along the line and flashes back 10 inches to its starting point. The distance travelled whilst one image is being built up is $377 \times 20 = 7{,}540$ inches. In one second there are 25 images so that the distance travelled is $7{,}540 \times 25 = 188{,}500$ inches or just under 3 miles. The average speed of the spot over the screen is about 11,000 miles an hour. Watch a two-hour television programme and the spot which produces the images has travelled in your service a distance nearly equal to the circumference of the earth.

Notice, too, that the scanning spot starts, stops, reverses its direction, stops, and reverses its direction again 377×25 times $= 9{,}425$ times in every second during the actual painting of an image. The movements of this spot continue during the 28 lines which are used for other purposes, so that the total number of starts, stops and changes of direction is $405 \times 25 = 10{,}125$ a second. That is another of the wonders of the C.R.T. Not only can the spot be made to move with enormous velocity to any part of the screen ; it can be stopped short and without any preliminary slowing up and made to restart instantly at full speed in another direction.

CHAPTER IX

Inside the Atom

TO understand how the cathode-ray tube does its remarkable work we must first see something of the ATOM, that fascinating little body which is so much in the news nowadays. In doing so we shall incidentally learn quite painlessly something about the nature of electricity.

The word atom means uncuttable or indivisible. It was coined some 2,500 years ago by a Greek philosopher named Democritus when he formulated the earliest reasonable theory about the constitution of matter. Democritus held that if you went on cutting up a piece of, say, gold or iron into smaller and smaller pieces you would eventually produce minute specks of gold or iron so small that they could not be further divided. Gold, in a word, was made up of tiny particles or atoms all of one kind, iron of tiny particles all of another kind, and so on for matter of all descriptions. Certain modifications were made in the theory as knowledge grew with time ; it was discovered, for instance, that only an ELEMENT consisted of atoms all of one sort ; other substances were COMPOUNDS, being composed of two or more kinds of atoms. The main principles, however were, accepted for nearly twenty-five centuries. Not until the 1890's was it discovered that the atom was very far from being the simple tiny particle imagined by Democritus.

We know now that all atoms are like minute solar systems in which from 1 to 92 minute bodies revolve planet-wise in orbits round a central "sun," much heavier than they. Not to plunge too deeply into the atomic theory, we may regard all matter of whatever kind as built up of three kinds of particles and three only.

The first of these is the ELECTRON, which may be regarded as a minute particle of negative electricity. Next comes the PROTON, which we may think of as a minute particle of positive electricity. The proton is some 2,000 times as heavy as the electron, but its content or *charge* of positive electricity is precisely equal to the negative charge of the electron. If we call the charge of the proton + 1, that of the electron is − 1. The charges of one proton and one electron exactly cancel one another : + 1 − 1 = 0. The third kind of brick is the NEUTRON. This is similar in size and weight to the proton, but it carries no electric charge whatever. Important though its role is in the release of atomic energy, the neutron, having no electric charge of either kind, plays no active part in the great pageant of electricity. It is the protons with their positive charges and the electrons with their negative charges that hold the stage.

Do we now know all the secrets of matter ? Are the neutron, the proton and the electron the ultimate small bricks, or will yet tinier things be discovered one day ? No one can say. My own guess is that physicists of the future may find that the neutron and the proton are highly complex bodies, each made up of about 2,000 parts. It seems hardly logical that a charge of positive electricity should have 2,000 times the weight of a charge of negative electricity. The existence of the POSITRON, a body of size and weight similar to those of the electron and having an equal positive charge, is already known. It may be that a neutron consists of a compact mass of, say, 1,000 positrons and 1,000 electrons, whilst a proton contains 1,000 positrons and 999 electrons tightly bound up together. Were this so the positive and negative charges would exactly cancel out in the neutron, whilst in the proton there would be 999 cancellations and one remaining positive charge. That, however, is pure speculation. What concerns us is that, whether it is a simple body or a conglomerate mass, the proton represents one charge of positive electricity.

The simplest of all atoms is that of hydrogen, illustrated diagrammatically in Fig. 43. In it one electron revolves round one proton. Next in order of simplicity comes the atom of helium (Fig. 44). In all atoms save that of hydro-

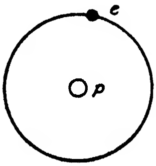


FIG. 43.—Diagrammatic representation of the hydrogen atom.

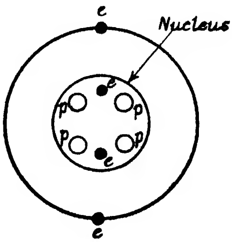


FIG. 44.—The next atom to hydrogen in order of simplicity is that of helium.

gen the central " sun," or NUCLEUS, is a tightly packed bundle of protons and electrons and often of neutrons as well. The nucleus always contains more protons than electrons, with the result that it is positively charged. The helium nucleus has four protons and two electrons; it carries therefore two positive charges ($+4 - 2 = +2$). These positive charges are normally cancelled out by the negative charges of two orbiting electrons.

In the hydrogen atom a single orbiting electron cancels the single positive charge of the proton; the two charges of the nucleus of a helium atom are cancelled by the negative charges of two electrons and so it is with all atoms up to the heaviest and most complex of all those found in nature, that of uranium in which 92 orbiting electrons normally cancel 92 positive charges on the nucleus. When the two sets of charges annul one another an atom is said to be BALANCED or NEUTRAL. Such an atom has no electric charge.

But an atom may lose temporarily one or more of its orbiting electrons. Some atoms, notably those of most metals, part readily with some of these electrons. When this has happened, the atom is no longer neutral; the total of its positive charges exceeds that of its negative charges and the atom is therefore positively charged. In this condition an atom is called a POSITIVE ION. It is also possible for an atom to acquire one or more extra electrons for a time. Its negative charges, then, outnumber its positive charges. The atom is negatively charged and is known as a NEGATIVE ION.

The fundamental rule of electricity (Fig. 45) is that like charges repel one another whilst unlike charges attract

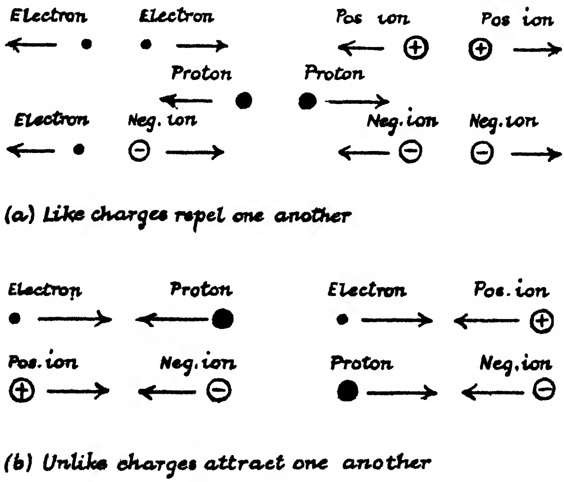


FIG. 45.—In electricity like charges repel one another; unlike charges attract one another.

one another. The forces involved are enormously strong, being vastly greater than that of gravity.

Imagine two metal plates placed a short distance apart with air between them as in Fig. 46. On one plate we have managed by some means to collect a number of detached electrons ; on the other is an equal number of positive ions. The positive ions and the electrons attract one another with tremendous force, but they cannot come together, for there is no path for them to take between

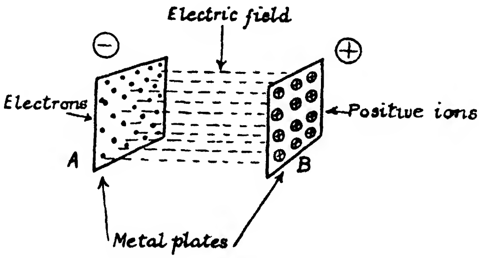


FIG. 46.—The opposite charges on the plates attract one another. The strain of their attraction sets up an electric field.

the plates. Owing to their mutual attraction a strain is set up in the intervening air and this is known as an ELECTRIC FIELD.

Plate A is negatively charged because it contains a surplus of electrons. Plate B is crowded with positive ions, each of which is an atom deficient of an electron. It is this electron deficiency which causes plate B to be positively charged.

An electron surplus means a negative charge ; an electron deficiency means a positive charge.

On plate A there is a negative pressure or POTENTIAL ; plate B has a positive potential. The unit of electric pressure is the VOLT.

What would happen if a wire were connected between the two plates? There would now be a conducting path and the electrons, being far the lighter bodies, would rush through it under the attraction of the heavy protons. Arrived at plate B, each electron would coalesce with a positive ion and neutralise it. There would now be no electron surplus or deficiency on either plate. Neither would have a charge; there would be no POTENTIAL DIFFERENCE, or P.D., between them and the electric field would cease to exist.

Now consider an electric cell connected through a switch to a lamp, as in Fig. 47. When the switch is open there is a P.D., between the positive and negative terminals. Close the switch. The lamp lights up. Why? Electrons rush *via* the wire, the filament and the switch from the negative terminal of the cell, where there is a surplus, to the positive terminal, where there is a deficiency. Such is the commotion caused by the passage of millions of them through the filament that it becomes heated and glows brightly.

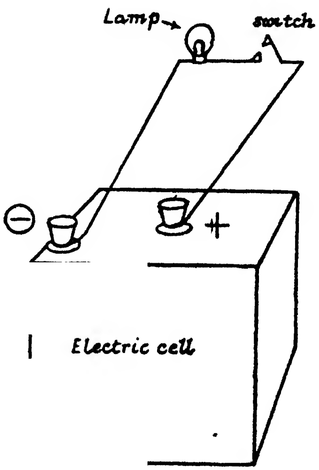


FIG. 47.—An electric cell or battery causes current to flow in a circuit by maintaining an electro-motive force or E.M.F.

The electric cell or battery (a battery is a combination of two or more cells) is a device which by chemical action maintains an electron surplus at its negative terminal and an electron deficiency at its positive. The electric pressure is sustained and keeps electrons on the move. Such a pressure is known as an ELECTROMOTIVE FORCE, or E.M.F.

A flow of electrons driven by an E.M.F. constitutes an electric current. The rate of flow of current is measured in AMPÈRES.

By this time some readers with memories of what they were taught at school will have been growing restive. "Surely," they say, "there is something wrong about all this. An electric current flows from the positive terminal of a battery to the negative and not from negative to positive."

Long years before the existence of the electron was known early investigators of electricity discovered that there was a flow of current. If, they argued, current flows, it must have a direction. They had no reliable means of finding out what that direction was and they made, most unfortunately, exactly the wrong decision. More unfortunate still, school books and many other books on electricity continue to preach this error, even though their writers know that it is an error. It is a sad business and hard to understand, for the conception of a positive current makes difficulties for the student where none really exists. In reality an electric current consists of a stream of electrons flowing from the negative terminal of a battery (or other source of E.M.F.) through a circuit, back to the positive terminal. This true conception of current is used throughout this book.

Figures 46 and 47 raise another interesting point; why cannot current pass from plate A to plate B in Fig. 46 and how does it manage to travel quite easily through the wires of Fig. 47?

We saw just now that the atoms of metals part easily with one or more of their orbiting electrons. What happens when the switch in Fig. 47 is closed is this. An electron from the negative terminal of the cell, travelling fast under the pull of the positive ions on the positive terminal, cannons into an atom of the copper wire, knocks an electron out of its orbit and takes its place. The displaced electron collides with another atom, repeating the process. And so it continues until an electron emerges from the end of the wire attached to the positive terminal. An electron goes in at one end of the wire and an electron issues a tiny fraction of a second later from the other end. Imagine this happening millions upon millions of times a second and you have an idea of the flow of a current through a wire. Substances which part easily with electrons are known as CONDUCTORS because they can convey or conduct an electric current.

Air is a form of matter whose atoms hold on tightly to their orbiting electrons. The orbits of the electrons in the electric field of Fig. 46 are strained by the pressure, but electrons do not leave them. Air is a non-conductor, or an INSULATOR.

There are no perfect conductors.* Work must be done to drive the detachable electrons out of their orbits. Any conductor thus offers RESISTANCE to the passage of an electric current. That resistance is measured in OHMS.

Remember that volts drive ampères through ohms—pressure makes current overcome resistance—and you have advanced a long way towards a grasp of the fundamental laws of electricity.

The ampères of current flowing in a circuit depend directly on the pressure in volts driving the current and the ohms of resistance encountered. One volt drives one ampère through one ohm, or two ampères through half an ohm, or half an ampère through two ohms. Similarly, two volts drive two ampères through one ohm, three volts drive three ampères and so on. Some idea of what these units, volts, ampères and ohms mean may be gained from the following familiar experiences. In a pocket

*Except in the laboratory at temperatures approaching absolute zero.

flashlamp, when the battery is new, 3 volts drive 0.25 ampère through the 12-ohm resistance of the filament of the lamp. The battery runs down because its internal resistance increases as it is used. By the time that this internal resistance has increased to, say, 12 ohms, the lamp gives only a dull glow: 3 volts are then driving only 0.125 ampère through the 24 ohms of resistance of filament and battery combined.

A 40-watt household lamp, worked off 200-volt mains, passes 0.2 ampère through the 1,000-ohm resistance of its filament. You get no shock from a 3-volt flashlamp battery because the resistance of your skin is too great to allow more than a minute current to pass under this pressure; but the 200-250 volts of lighting mains drive enough current through that resistance to give a most unpleasant shock to the careless.

Just as there are no perfect conductors, so there are no perfect insulators. If the potential difference between the plates in Fig. 46 were increased sufficiently, the strain of the electric field would eventually tear electrons from their orbits. The insulation would break down and electrons would rush from plate A to plate B. That is what actually happens in a thunderstorm. The P.D. between a cloud and earth, amounting to millions of volts, breaks down the insulation of the intervening air and the consequent rush of electrons causes a flash of lightning.

CHAPTER X

How the Cathode-Ray Tube Works

CERTAIN curious things happen inside the bulb of the electric lamp that we were discussing at the end of the last chapter. After the simultaneous invention by Swan in this country and Edison in the United States of electric lighting by means of a filament brought to incandescence in an evacuated glass bulb some mysterious and highly unwelcome effects were observed. Electric lighting was having a hard struggle in those days to obtain a footing in homes where gas lighting had been established for years. One of its most serious handicaps in its infancy was the short useful life of the lamps which then cost so much. After a comparatively brief period of use these lamps began to give less and less illumination, though their filaments passed almost as much as ever of the then very expensive electric current supplied by the mains.

Inspection of a lamp that had been in service for some time showed a distinct blackening of the inside surface of the glass bulb. The process was found to be progressive, the bulb becoming more and more nearly opaque with extended use.

Investigating the matter with his usual thoroughness, Edison made two discoveries. Neither of them could be properly explained at the time, because the existence of the electron was then unknown; but one of them was destined, years later, to open up an entirely new and unsuspected field in the science of electricity.

Edison concluded that the blackening of the glass was due to a bombardment of its inner surface by fast-moving particles. We know to-day that the hot filament

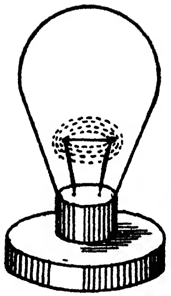


FIG. 48. — The glowing filament of an electric bulb is surrounded by a swarm of ejected electrons.

of a lamp is surrounded by a swarm of dancing electrons as indicated in Fig. 48. So violent is the commotion caused in the orbital electrons of certain substances by high temperatures that when a piece of one of these is placed in a vacuum and sufficiently heated, electrons are actually ejected from it. In an electric lamp of today these electrons return to the tungsten filament after making short free journeys. Edison's early lamps had filaments of carbon. Minute fragments of the carbon were torn out by the violent movements of the electrons and projected on to the glass.

His second discovery was one of the most remarkable ever made, though he had then no idea of what it meant. He found that if he sealed a metal plate into the bulb and gave it a positive potential as shown in Fig. 49, a

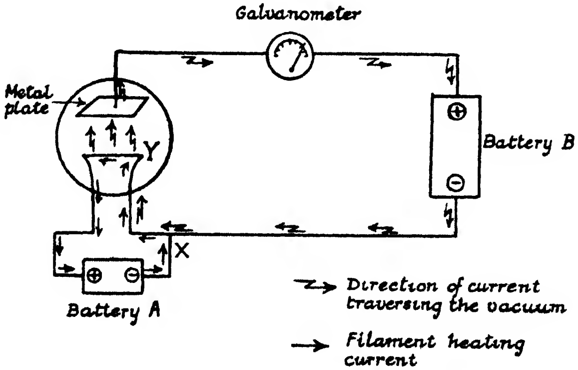


FIG. 49.—Showing how a current can be made to pass from cathode to anode through an evacuated bulb.

flow of current was registered by a measuring instrument, the galvanometer. Current must, so to speak, leap across the vacuum from filament to plate.

As he then knew nothing of the electron Edison was puzzled; but from what we have seen in Chapter IX of the behaviour of electrons it is not now difficult to understand what happens in such cases. Connected to the positive terminal of battery B, the plate has a positive potential, or an electron deficiency. The positive ions exercise their attractive force on the electrons dancing round the filament and many of them are drawn across the vacuum. As electrons leave the filament for the plate their places are taken by fresh supplies coming from the negative terminal of battery B. This battery thus keeps the plate positive and maintains the supply of electrons to the filament. A stream of electrons forming an electric current flows across from filament to plate and so from the negative terminal of battery B back again to the positive terminal, as shown by the wavy arrows in Fig. 49.

The function of battery A is solely to keep the filament hot by driving a current of electrons through it. Some people find it hard to understand how two distinct currents can flow simultaneously through the same wire as they do between X and Y in the drawing. Think of it in this way. Suppose that at any instant there are 100 positive ions on the plate and 1,000 at the positive terminal of battery A.* Then 1,000 electrons start out from the negative terminal of battery A under the attraction of the 1,000 positive ions at the positive terminal and 100 electrons leave the negative terminal of battery B to fill the deficiency on the plate. Eleven hundred electrons arrive at X and journey to Y. At Y there is a "demand" for 1,000 to go through the filament to the positive terminal of battery A and for 100 to cross the vacuum to the plate.

*Actually the numbers run to millions upon millions.

It does not matter from which of the batteries a particular electron comes ; all that each positive ion calls for is *an* electron. And so of the 1,100 electrons reaching point Y any 1,000 take one path to the 1,000 positive ions at the positive terminal of battery A and any 100 travel across the vacuum to the 100 positive ions on the plate.

No use could be found for this effect when Edison first discovered it. Years later, Sir Ambrose Fleming perceived its possibilities and produced the first WIRELESS VALVE, whose arrangement was exactly as shown in Fig. 49. He called it a valve because current from battery B can pass in one direction only—from filament to plate. If the battery is turned round and the plate made negative, no current can flow across the valve ; the negative potential on the plate repels the dancing electrons round the filament.

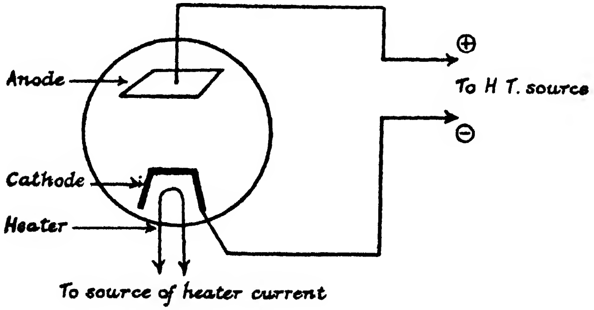


FIG. 50.—Nowadays many kinds of wireless valves have indirectly heated cathodes, from which the electrons start their journey across the vacuum. The plate is called the anode, or point of arrival.

The part of a valve (Fig. 50) from which electrons start on their journey across the vacuum is called the CATHODE or place of departure and the plate is now known as the ANODE, or place of arrival. The directly heated filament is often replaced by an indirectly heated cathode.

All appliances in which electrons leave a cathode and travel to an anode either through a vacuum or through an inert gas are classed under the term ELECTRONIC. ELECTRONICS is the department of electricity which is concerned with such apparatus. Examples of electronic appliances are the wireless valve, the X-ray tube, the photo-electric cell and the cathode-ray tube.

The PHOTO-ELECTRIC CELL (Fig. 51) differs

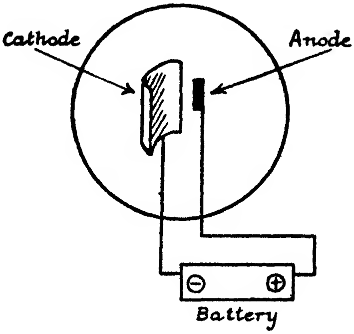


FIG. 51.—The principle of the photo-electric cell.

from other electronic devices in that it is light and not heat which causes its cathode to emit electrons. Certain "alkali metals," such as caesium and rubidium, have the property of emitting some of their orbital electrons for brief free journeys when light falls upon them; the stronger the light, the denser the swarm of electrons ejected.

In the photo-electric cell the cathode, coated with one of these metals, is connected to the negative terminal of a small battery and the anode to the positive terminal. When no light falls on the cathode no electrons are emitted and no current from the battery can pass through the vacuum for there is nothing to convey it. But when the cathode emits electrons under the influence of light a stream of them is drawn to the positive anode and current passes as in the wireless valve. If the light fluctuates the current fluctuates in accordance with it. Actually the fluctuating current is very small, but it can be amplified as required by means of wireless valves.

The cathode-ray tube is really a very large valve containing certain special parts. Suppose that we apply a

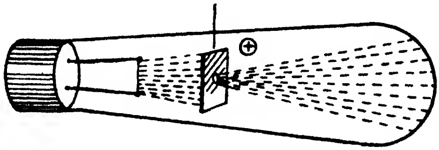


FIG. 52.—If a hole is drilled in the positively charged anode, some of the electrons pass through it.

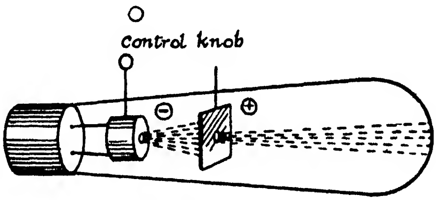


FIG. 53.—The beam becomes less diffuse if a negatively charged cylinder with a small hole at its outer end is placed round the cathode.

high positive potential to an anode in which a hole has been drilled, as in Fig. 52. Owing to their high speed a good many of the electrons pass through the hole and continue their journey until they strike the glass at the end of the bulb. The beam of electrons reaching the end of the bulb is very diffuse. We can narrow it down to some extent by placing round the cathode (Fig. 53) a cylinder closed at its outer end except for a small round aperture and kept at a negative potential. This cylinder is called the GRID and arrangements are made so that the negative potential on it can be increased or reduced by turning a CONTROL KNOB in one direction or the other.

The effect of a moderate negative potential on the grid is to concentrate to some extent the electrons that leave the cathode, since they are repelled towards the middle of the grid by the electron surplus on its walls. The beam of electrons crossing the bulb of the tube thus becomes less diffuse.

The most important function of the grid, however, is that it enables the density of the beam of electrons to be controlled. Make the grid more and more negative and the beam of electrons is eventually cut off completely, for the repulsive force becomes strong enough to counteract the pull of the anode and to dam back all electrons. Make the grid less negative ; the repulsion is reduced and more and more electrons are drawn through the hole in the grid by the anode.

Fig. 54 shows the next stages in the development of a cathode-ray tube. In order to focus the beam of electrons into a fine pencil a system of three anodes is used instead of a single one. To explain the way in which this team of anodes functions would introduce complications outside the scope of a book such as this. All that the reader need

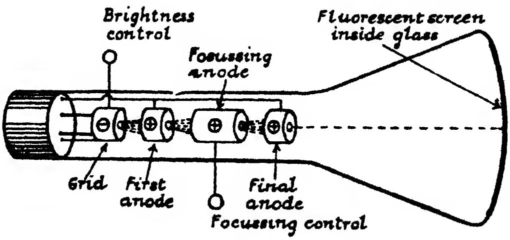


FIG. 54.—By using the triple anode system seen in the drawing the beam o electrons can be focused into a narrow pencil.

know is that the electric fields of the anodes in combination have much the same effect on the beam of electrons as a lens has on a beam of light (Fig. 55). They enable it to be concentrated or focused. Adjustment of the focus is done by means of a control knob, which allows the positive potential of the middle anode, usually known as the FOCUSING ANODE, to be varied.

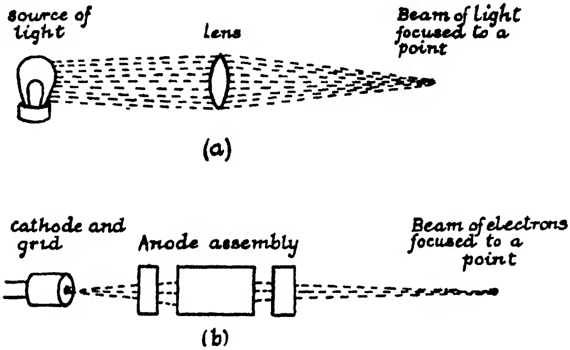


FIG. 55.—The three anodes in combination have much the same effect on the electron beam as a convex lens has a beam of light.

The parts so far mentioned—cathode, grid and anode system—form the ELECTRON GUN of the tube, so called because it fires a hail of electrons at the end of the tube. This end (Fig. 54) is flattened and it is coated on the inside with a thin layer of a material which glows under the impact of the electrons fired from the gun. Such material is said to be FLUORESCENT and the end of the bulb coated with it is known as the FLUORESCENT SCREEN.

By proper use of the focusing knob a luminous spot of small dimensions can be produced at the centre of the screen. There is, however, one important factor which limits the reduction in the size of the spot that can be brought about by any known method of focusing the beam ; this is the mutual repulsion existing between the electrons, which causes the spot to " spread " to some extent. The brightness control enables the spot to be increased or decreased in brilliance or even to be extinguished altogether.

To sum up, what we have accomplished so far is this : we have found a means of producing in the middle of the screen a stationary spot of light which can be sharply focused and whose brightness can be adjusted at will. The next step is to discover a way of making the spot move about the screen and of controlling its movements exactly as may be necessary.

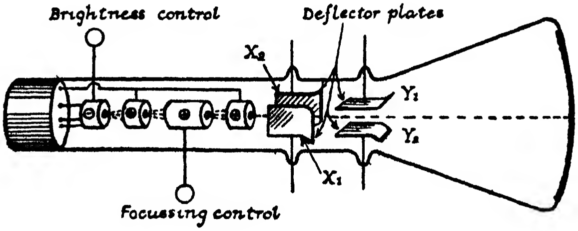


FIG. 56.—As explained in the text, the deflector plates enable the spot to be moved to any position on the screen.

This is accomplished by placing in the tube the two pairs of metal plates shown in Fig. 56. In tubes used for radar purposes the connecting wires to these plates are often brought out through glass " horns" sealed into the walls of the tube, as indicated in the drawing ; but in television tubes the connecting wires run usually from the plates to metal contact points in the cap of the tube.

Since the function of the plates is to bend or deflect the electron beam and thus to make the spot move about the screen they are called the DEFLECTOR PLATES. The screen at the end of the tube is opaque ; but if we

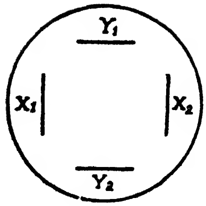


FIG. 57.—The deflector plates as they would be seen from the large end of the tube if the fluorescent screen were transparent.

imagine it to be transparent so that the deflector plates are visible, these would appear as in Fig. 57. The vertical pair are known as the X plates, X1 being on the left as seen from the screen end of the tube and X2 on the right. The horizontal plates are Y1 at the top and Y2 at the bottom.

Suppose that a positive potential is applied *via* its connecting wire to the X1 plate in Figs. 56 and 57. What will happen to the luminous spot on the screen? The beam giving rise to the spot consists of a flow of electrons, which are attracted towards the X1 plate by the positive potential (electron deficiency) upon it. Therefore the spot moves towards the viewer's left. The more positive the potential on X1, the greater will be the spot's leftward movement. The same result could be achieved by giving X2 a negative potential (electron surplus), whose repulsive force would deflect the beam to the viewer's left. The X plates, then, provide a means of making the spot move horizontally across the screen from left to right or from right to left.

Vertical movement of the spot is obtained in similar ways by means of the Y plates. Make Y1 positive (or Y2 negative) and the beam is pulled (or pushed) upwards. It can be pulled or pushed downwards by making Y2 positive or Y1 negative.

It is important to realise that the distance which the spot moves over the screen depends directly upon the value of the positive or negative potentials on the deflector plates. If there is no potential on any plate, the electron beam is neither attracted nor repelled and the spot is in the centre of the screen. The same result could be achieved by making all the plates equally positive or equally negative. In the first instance the electron beam would be pulled equally in all directions ; in the second it would be repelled equally from all directions : there would be no movement of the spot from its normal central position.

Suppose, though, that there is no potential, positive or negative, applied to X1, Y1 or Y2 and that a positive potential of steadily increasing value is applied to X2. The spot is drawn further and further towards the right as the positive potential on X2 increases. If the positive potential on X2 is suddenly relaxed, the spot will fly back to its central position.

We can make the normal " rest " position of the spot near the left-hand edge of the screen by applying a sufficient fixed positive potential to X1. If then a progressively increasing potential is applied to X2, the spot will be drawn from the left-hand edge across the screen to the right. Relax the positive potential on X2 just as the spot nears the right-hand edge of the screen and, under the pull of the fixed positive potential on X1, the spot flies back to the left-hand edge.

So far we have considered only the action of the X plates, which may cause the spot to traverse the screen from left to right and then to fly back to the left edge. Similar vertical movements of the spot may be brought about by applying appropriate potentials to the Y plates.

If, for example, we give Y1 the necessary fixed positive potential, the starting point of the spot in the vertical sense will be near the top edge of the screen. By applying to Y2 an increasing positive potential the spot can be drawn downwards and when this potential is relaxed the spot will fly back to its starting point near the top edge.

Consider now the effect of applying a fixed positive

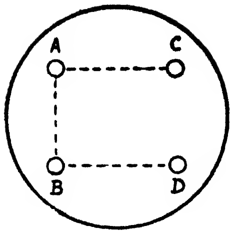


Fig. 58.—Illustrating the starting point of the spot and its movements under the pulls of the X and Y plates.

potential to both X_1 and Y_1. The rest position of the spot, under the combined pull of these plates, is as shown at A in Fig. 58. If an increasing positive potential is also applied to Y_2, the spot will travel downwards towards B. Can we so arrange matters that the downward journey of the spot from A to B is made in 1/25 second or 1/50 second as may be required? We can, and the methods of so doing will be described in the next chapter.

We can also devise means of using the X plates to draw the spot horizontally across the screen from A to C much more rapidly if we wish to do so. At the end of each horizontal journey from left to right the spot flies back to the left-hand edge of the screen owing to the sudden relaxation of the positive potential on X_2.

Let us make arrangements for the X plates to cause the spot to travel from left to right and to fly back 405 times in every twenty-fifth of a second and for the Y plates to cause the spot to move downwards from near the top edge of the screen to near the lower and then to fly back, all in 1/25 second. What will be the resulting path taken by the spot?

Starting from A in Fig. 58, it travels to C. C is not quite on the same level as A, for the steady pull of Y_2 has drawn the spot a little downwards during its journey across the tube. This same downward pull ensures that after the fly-back the spot re-starts its journey to the right from a point a little below A. Each subsequent traverse from left to right starts from a point progressively lower than A and finishes at a point progressively lower than C.

At the end of the 405th line the spot reaches D. At that instant it performs a double fly-back. The potential on X2 being relaxed, the fixed potential on X1 draws it at immense speed from right to left. Simultaneously the fixed potential on Y1 causes it to flash upwards as the potential on Y2 is relaxed. The spot therefore flies back from D to A and the process starts all over again.

A moment's thought will show that in its passage from A to D the spot has performed a sequential 405-line scan of the screen in 1/25 second. An interlacing scan in 1/50 second with half the number of lines could be accomplished by making the downward movement of the spot twice as fast.

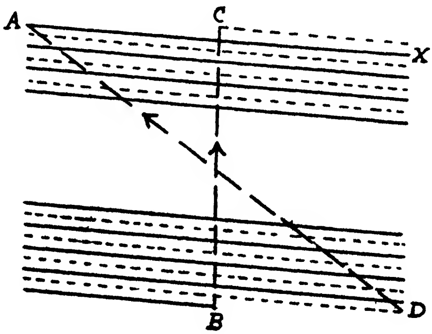


FIG. 59.—Showing why half-lines are needed in an interlaced scan.

It may be as well to deal here with one point which has probably puzzled the reader if he has given it any thought. Why is it necessary to make each interlacing scan so many and a half lines? Why cannot one set of whole lines be scanned first and then the second set of whole lines? What is the sense of those halves? Fig. 59 will help to explain. When in making its first set of scans the spot has travelled from A to B it has reached the limit of the downward pull exercised by Y2. It then flies back under the influence of the fixed potential on Y_1 to the upper limit of the image. If the first line of the next frame were a whole one the spot would have to start at A and this line would coincide with AX. As it is, the spot starts the second scan at the same horizontal level as A, but half-way along the line. When it reaches D it is at the same horizontal level as B, but half a line further on. The two sets of scanning lines therefore interlace.

By using the X plates and the Y plates in the way described we have succeeded in making the spot trace out either a sequential or an interlaced scan on the screen of the C.R.T. But since we have so far found no means of making the brilliance of the spot fluctuate in accordance with the light fluctuations in the studio it could not " paint " an image on the receiver screen if nothing more were done. All that the spot would do is to trace a series of fine, glowing lines on the screen and the viewer's eye would receive the impression simply of a white rectangle. Some means must be found of making the individual picture elements representing the subject in the studio register themselves on the screen as a multitude of points of black or white or intermediate grey tones.

This is done by making use of the properties of the grid of the C.R.T. We have seen that the density of the electron beam is increased if the grid is made less negative (or more positive) and decreased if it is made more negative. The brilliance of the spot on the screen depends directly on the density of the beam of electrons. By varying the density of the beam, therefore, we can cause the spot to be bright or dull or to be blacked out altogether. Such variations in the spot's brilliance give the eye the impression of whites, greys of various tones and blacks.

Light fluctuations in the studio reach the receiver as voltage fluctuations. These, after amplification, are applied to the grid of the C.R.T., causing the brilliance of the scanning spot on the screen to vary in accordance with them. The spot thus travels over the screen, painting in in their right places the thousands of white, grey and black points which together give the eye the impression of a complete picture.

CHAPTER XI

The Magnetically Controlled Cathode-Ray Tube

IN cathode-ray tubes of the kind described in the last chapter all forms of control are accomplished by making use of *electric* fields. The brightness of the spot is varied by varying the potential of the grid ; focusing of the spot is done by adjusting the potential of the middle anode ; the movements of the spot over the screen result from variations in the potentials on the X plates and the Y plates. Such a C.R.T. is said to be ELECTROSTATICALLY CONTROLLED.

There is another kind of C.R.T., which for television reception purposes is rapidly ousting the electrostatically-controlled tube, if, indeed, it has not already entirely supplanted it. This is the MAGNETICALLY-CONTROLLED tube. The name, like too many of the terms used in electricity, is actually a misnomer, for in the magnetically-controlled tube one of the most important of the controls still remains electrostatic : the brightness of the scanning spot is varied from instant to instant—from picture element to picture element—by variations of the potential applied to the grid of the tube. But the movements of the spot over the screen, line by line to form the frame, and frame by frame to form the image, are effected by magnetic means. Focusing, too, is done magnetically.

To be able to follow the way in which the magnetically controlled C.R.T. operates, it is necessary to grasp one or two simple facts about the phenomena of magnetism.

This is not the place for any lengthy discussion of magnetism ; I deal with the subject in greater detail in another book.* All that I want to do now is to explain one or two points which are the keys to understanding how focusing and deflection of the beam are accomplished magnetically.

A permanent magnet is surrounded by a magnetic field, consisting of " lines of force," which may be mapped by the familiar experiment illustrated in Fig. 60. A bar magnet is placed on a sheet of paper lying on a level table-top and fine iron filings are sprinkled over the paper, the table being tapped gently during the process. The filings arrange themselves along the lines of force, as shown in the drawing. The field has a definite direction, as indicated by the arrows, which is not shown by the filings. Conventionally the direction of the field is regarded as being from the north pole of the magnet to the south. Note that the filings show the field in two dimensions only. Its real shape is something like that of a lemon, with a hollow at each end.

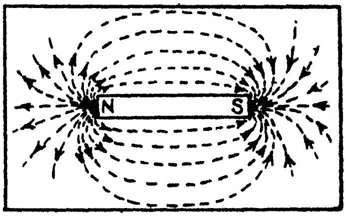


FIG. 60.—A map of the magnetic field round a bar magnet may be made with the aid of fine iron filings.

When an electric current flows through a conductor a magnetic field (Fig. 61) surrounds the conductor like a kind of invisible sleeve. If current (remember

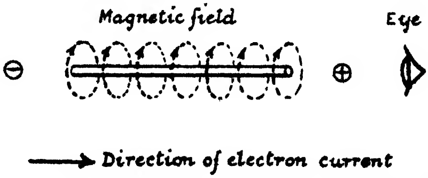


FIG. 61.—Round any conductor carrying a current there is a magnetic field, resembling a kind of invisible sleeve.

* *Wireless Simply Explained*, by R. W. Hallows.

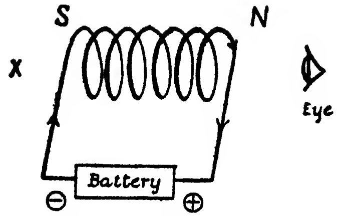


FIG. 62.—If current flows clockwise round the turns of a coil at the end nearest the eye, that end is the north pole of an electro-magnet.

that we look on a current in the true way as a flow of electrons from negative to positive) is flowing towards you as you look along the conductor, then the field has a clockwise direction.

Wind the wire into a coil, as in Fig. 62, and it becomes an electro-magnet so long as current is passing through it. The magnetic field of a coil can also be mapped by means of iron filings. That of a cylindrical coil, or solenoid, is shaped much like the field of the bar magnet in Fig. 60. Look at one end of the coil. If, as in Fig 62, the flow of current appears clockwise to the eye looking at one end of the coil, that end is the north pole ; if it is counter-clockwise, as it would appear to an eye placed at X, that end is the south pole. You cannot, of course, see the current, but you can see how the wires run and note which end is connected to the negative terminal of the battery, or other source of current. Note that the polarity of the coil, that is the positions of its north and south poles, can be reversed by reversing the battery connections and so changing the direction of the flow of current through the windings.

For a given number of turns of wire the strength of the magnetic field depends upon the current flowing in the coil. In other words, if the current is increased the coil has a greater magnetic pull ; reducing the current lessens the pull. If the current is switched off, the magnetic field collapses and there is no pull at all until current is switched on again and the field is rebuilt.

We have seen that like charges of electricity repel one another and that unlike charges attract one another. The rule about magnetic poles is similar. Like poles repel like ; unlike poles attract each other. The north pole of a permanent or electro-magnet attracts and is attracted by the south pole of another magnet of either kind ; but there is mutual repulsion between two north poles or two south poles. We may put this in another way by saying that the lines of force in the neighbourhood of two unlike poles represent a force of attraction and those in the neighbourhood of two like poles a force of repulsion.

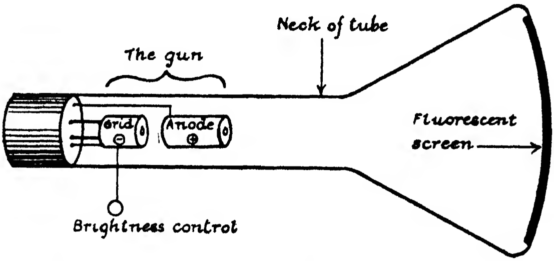


FIG. 63.—The internal make-up of the magnetically-controlled C.R.T. is simple. It contains nothing but the electron gun and the fluorescent screen.

Keeping in mind this brief description of certain of the effects associated with magnetism, we are now ready to tackle the magnetically-controlled C.R.T. which is depicted diagrammatically in Fig. 63. It will be seen that in comparison with the electrostatically-controlled tube its internal construction is very simple. There is, in fact, nothing within the bulb but the electron gun (consisting of heater and cathode, surrounded by grid, and anode) and the fluorescent screen. The focusing and deflecting components are built into the electrostatically-controlled tube ; they are external to its magnetic counterpart.

Focusing is done (Fig. 64) by means of a coil mounted concentrically on the neck of the tube. The focus control

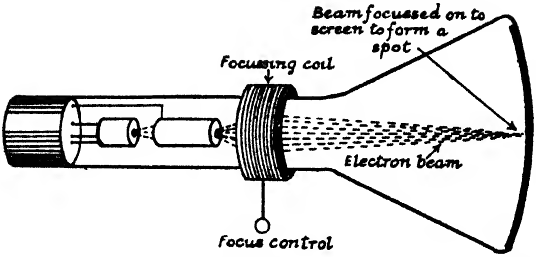


FIG. 64.—Focusing in the magnetically-controlled C.R.T. is done by means of a coil concentric with the neck, of the tube.

knob regulates the amount of current flowing through the turns of the coil, and therefore the intensity of its magnetic field, or it may allow the position of the coil to be altered. The lines of force in the densest part of the field are parallel with the beam of electrons. These lines may be regarded as forming the walls of a kind of invisible pipe surrounding the beam. As they leave the hole in the anode, electrons tend to spread or diverge from the straight path to the screen. An electron in motion is, so to speak, a minute particle of electric current and as such it has its own little magnetic field. This field and that formed by the lines of force of the coil's field are mutually repulsive. Hence any electron straying from the straight path between anode and screen and approaching the walls of the invisible surrounding " pipe " is driven back to the path of duty. Since its own speed is very high and the walls of the repelling " pipe " of lines of force are circular in section, the erring electron actually takes (Fig. 65) what may be

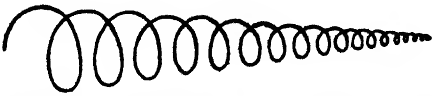


FIG. 65.—An electron straying from the straight path between cathode and fluorescent screen is forced by the magnetic field of the focusing coil to take a " tapering corkscrew " path.

described as a tapering corkscrew route to the focal point on the screen.

All this may seem rather complicated, but the result is simple enough : turning the focus control knob one way or the other causes all the millions upon millions of electrons forming the beam to arrive in one tiny area of the screen and so to form a small luminous spot upon it.

For line-scanning we require the spot to move horizontally over the screen. A pair of coils, placed horizontally above and below the neck of the tube with current flowing in the same direction through each, would produce a magnetic field of the kind seen in Fig. 66. In the densest

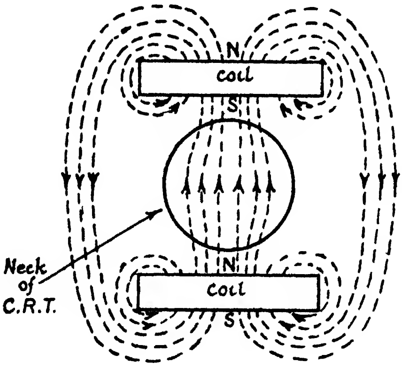


FIG. 66.—A pair of coils placed one above and one below the neck of the C.R.T. would furnish a magnetic field of the kind shown diagrammatically in the drawing.

part of the field lines of force pass almost vertically through the neck. Now imagine (Fig. 67*a*) that you are looking from the screen end of the tube at the end of the beam of electrons (represented by the large black dot) which is coming towards you. The beam is an electric current and it has therefore a magnetic field with a clockwise direction.

The left-hand half of this field is repelled by the field of the coils, which is there in the same direction. The right-hand half of the field of the beam is attracted by the field of the coils, which is there in the opposite direction. The beam is therefore deflected to the right and the spot moves over the screen from left to right. If current through the coils is reversed in direction, as in Fig. 67*b*,

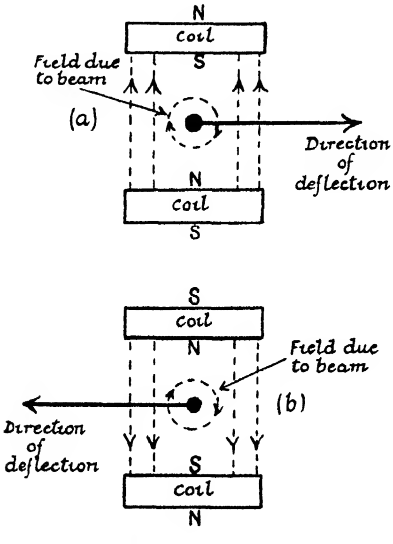


FIG. 67.—Showing how the magnetic field of the deflector coils of a magnetically-controlled C.R.T. causes the spot to move to the right (*a*), or to the left (*b*).

the field of the beam is repelled on the right and attracted on the left and the spot travels from right to left over the screen.

In practice coils of the type shown in Fig. 66 have two disadvantages ; they do not produce a very dense magnetic field inside the neck of the tube and they take up too much room. For these reasons it is usual to shape the DEFLECTOR coils as shown in Fig. 68. They then fit closely over the neck, take up little space and provide a field of the density required.

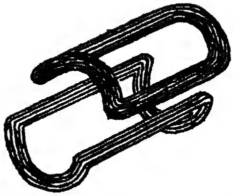


FIG. 68.—To produce a denser magnetic field inside the neck of the tube the deflector coils of a magnetically controlled C.R.T. are usually shaped as shown above. Such coils also occupy far less space than flat ones.

For vertical deflection a second set of coils is used arranged so as to provide a horizontal magnetic field in the neck of the tube. These coils are shaped like the first pair and often one pair is made to fit on to the neck outside the other pair.

To effect a scan of the screen a steadily rising current is applied to the coils responsible for horizontal deflection. At the end of each line the current reverses its direction, its rapid fall bringing about a quick fly-back of the spot. Meantime, the current in the vertical deflector coils is slowly rising and drawing the spot gradually further and further down the screen. This continues until at the end of 202½ lines (of which only 188½ are picture-painting or " active " lines) current through the coils is reversed and the fly-back takes place.

In the last paragraph, by the way, the words " slowly " and " gradually " are used purely relatively. The drawing of the spot from top to bottom of the screen and its flash-back to the top occupy in reality only 1/50 second altogether. But as each line-scan with its subsequent fly-back is completed in less than 1/10,000 second the vertical frame-scan is slow and gradual in comparison with the horizontal line-scan.

As in the electrostatically-controlled C.R.T., voltage fluctuations corresponding to the fluctuations of light as the subject in the studio is scanned are applied to the grid. Thus the spot in the receiver's magnetically-controlled

C.R.T. is continually varying in brightness as the attractions and repulsions between magnetic fields move it over the screen ; again the picture is built up element by element, line by line and frame by frame.

It is interesting to note how entirely dependent any kind of television C.R.T. is on the phenomenon of persistence of vision for its success as a presenter of images. At no instant is there anything more on the screen than one tiny speck of light. Just behind the actual position of the spot there may be a small patch of luminosity where the glow produced by the electron bombardment has not yet faded out ; but in television tubes this " afterglow," as it is called, is of very short duration. On the retina of the eye, however, the light received from the flying spot makes an impression which persists for a fraction of a second. The eye thus sees not the spot, but the images which its light fluctuations and its rapid movements build up.

CHAPTER XII

Time-Bases

WE have now seen how a spot of light can be produced on the screen of the cathode-ray tube and made to move to any point on the surface of the screen by the action of the X or Y Plates in the electrostatically-controlled C.R.T., or of the deflector coils in the magnetically-controlled tube. We have seen, too, that the image on the screen is " painted " by the fluctuating light of the fast-travelling spot.

It is clear that what appears on the receiving screen cannot be a perfect reproduction of what is transmitted from the studio unless at any instant the position of the scanning spot on the screen of the receiver is identical with that of the scanning spot in the studio. Since the received image is built up picture element by picture element the scanning spot at the receiving end must " paint " each element in precisely its proper place on the screen if the image is to be a recognisable representation.

This is accomplished by using in the receiver devices known as TIME-BASES. In case you should shy at the name, fearing it to betoken something abstruse and hard to understand, let me hasten to say that you have certainly been familiar all your life with at least one form of time-base, though possibly you have not heard that term applied to it. Most probably there are time-bases in your pocket, on your wrist or on the mantelpiece of the room in which you are sitting at this moment. The dial and hands of a clock or a watch are examples of the most widely used type of time-base.

A time-base may be defined as a device in which an indicator repeatedly travels over the same course in precisely the same time. Clocks and watches contain two time-bases—three, if they have second hands. The hour hand makes one complete circuit of the dial in 12 hours, moving through 360 degrees in 12 hours, or 30 degrees every hour. The minute hand travels through 360 degrees in each hour, or 6 degrees in every minute of time.

The "zero" position of both hands is the vertical, which is marked 12 o'clock on the dial. The angular distance that the hands have moved from the vertical indicates the time that has elapsed at any instant since the preceding 12 o'clock. Suppose, for example, that you had a clock with a completely blank dial, you could always tell the time by it if you had a circular protractor—a simple instrument for measuring angles. At the present moment the hour hand of my watch has travelled 300 degrees and a little bit from 12 o'clock; the time therefore is a little after 300 ÷ 30, or 10 o'clock. The minute hand tells me how much that "little bit" is. It has travelled 36 degrees from 12 o'clock, so that 36 ÷ 6, or 6 minutes have passed since that particular hour started. The time, as shown by the dual time-base of the watch, is thus 6 minutes past 10 o'clock.

Clock and watch time-bases being of circular form, the motion of the indicators (the hands) is continuous. Neither hand has to fly back to zero when it reaches 12 o'clock on completing a circuit of the dial, for 12 o'clock is both the finishing point of one circuit and the starting point of the next. If, though, the scale were a straight line instead of a circle, matters would be different. Let us imagine a straight scale 12 inches in length with two indicators traversing it as shown in Fig. 69. One of them moves an inch an hour, the other an inch every five minutes. At the moment depicted in the drawing the time indicated is 4.30; the hour indicator has travelled

$4\frac{1}{2}$ inches and the minute indicator 6 inches from zero. Either indicator on reaching the right-hand end of the scale must flash back to zero and restart.

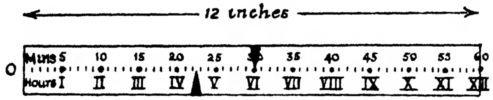


FIG. 69.—The face of a watch or clock contains two circular time-bases, one indicated hours and the other minutes. Here is a dual straight-line time-base with indicators showing hours and minutes.

The television receiver's scanning spot is the indicator of a straight line time-base. As it moves from left to right making the scan the distance travelled from the starting point is at any instant a measure of the time that has elapsed since the scan of that particular line started. It is not, of course, actually used to measure time ; but it must keep time, just as do the hands of a good watch : it must not run too fast or too slow. If it keeps time it will paint the picture elements always in their proper places.

In the line-scan the spot has to move pretty fast. In 1/50 second it has to scan $202\frac{1}{2}$ lines and to fly back at the end of each. The time for each scan and fly-back works out at 98.8 millionths of a second, but we will use the round figure 99. " Millionths of a second " is rather a cumbersome phrase and as there is a single word, MICROSECOND, meaning the same thing we may as well use it. The prefix micro—in electrical terms means millionth.* Then the scan of each line plus the ensuing fly-back occupies 99 microseconds.

A microsecond is an amount of time so tiny that it is almost beyond the powers of human imagination to form any idea of it. An express train travelling at 60 miles an

*Almost always, but not quite. A microphone is *not* the millionth of a phone.

hour needs 947 microseconds to move one inch on its way. In one microsecond such a train covers a distance equal to less than the thickness of a single sheet of the finest India paper. Yet the microsecond is in wireless, in radar and in television a very real and important amount of time. Television designers work in fractions of microseconds: in fact we shall be doing so ourselves in the next chapter.

For the moment we will take it that during the line-scan the spot travels from left to right in a nice round 84 microseconds and flies back to its starting point in 15. The extent of the time-base is thus 84 microseconds and we need something corresponding to the " works " of a watch to make the spot move and fly back at exactly the right speed and to keep on doing it. The spot, remember, has to scan and fly back $50 \times 202\frac{1}{2}$, or 10,125 times in every second. Such a device is properly known as a time-base generator, though more often than not it is loosely called just a time-base.

The key component of an electrical time-base generator is a device properly known as a CAPACITOR; CONDENSER is, however, a more familiar and less forbidding name and for that reason we shall use it.

The simplest form of condenser, illustrated in Fig. 70 (*a*), consists of two flat metal plates, separated by air or

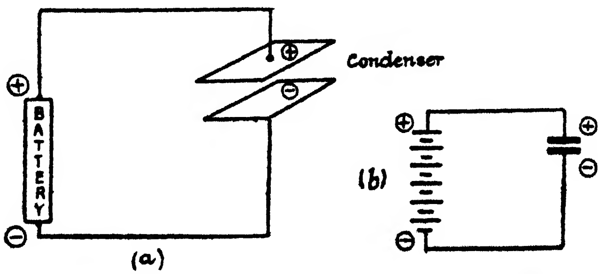


FIG. 70.—Illustrating the principle of the capacitor or condenser. Note the symbols for a battery and a condenser seen at (*b*).

by some other insulating substance. Note the symbols for a battery and a condenser shown in Fig. 70 (*b*); we shall use them in the figures that follow.

When a condenser is connected to a battery as in Fig. 70, current flows into it: that is, a stream of electrons flows from the negative terminal of the battery on to the plate of the condenser to which it is connected. At the same time an equal number of electrons passes from the other plate to the positive terminal of the battery. Current continues to flow into the condenser until the potential between its plates is equal to the E.M.F. of the battery. Suppose that we use a 60-volt battery. Current flows from it into the condenser until there are sufficient electrons on one plate, with an equal number of positive ions on the other, to make the potential difference between the plates 60 volts. The condenser is then CHARGED and current ceases to flow.

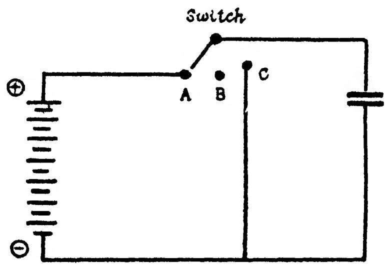


FIG. 71.—Showing how a condenser may be charged and discharged by means of a switch.

Insert into the circuit a 3-way switch as in Fig. 71. With the switch at position A the condenser charges. If when it is charged the switch is moved to B, the condenser remains charged, ideally it would do so for ever, but, as we have seen, there are no perfect insulators and the charge gradually leaks away. Turn the switch to C when the condenser is charged. There is now a conducting path between the plates. Electrons rush to neutralise the positive ions and the condenser is rapidly discharged.

When a condenser is charging the potential difference between its plates does not rise evenly and steadily from zero to the full amount. A close analogy to the process is the inflation of a bicycle tyre which is flat to start with. At first the work is easy. There is nothing inside to oppose the entry of air driven by the pump. Air flows in and the pressure inside the tyre begins to make itself felt by the pumper. He has to work harder and harder to make more air go in and each pound of pressure takes longer to produce than the preceding one. If we draw a curve showing the rise of pressure plotted against time its shape will be much as shown in Fig. 72.

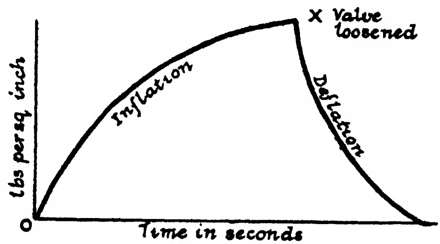


FIG. 72.—If a curve is drawn showing the pounds of pressure produced in a bicycle tyre, which is being pumped up from complete flatness, against the time occupied in pumping, its shape is very much as shown in the drawing.

So with the condenser. The rising electrical pressure within it opposes the inflow of current more and more strongly and its charging curve is like that of Fig. 73.

If the valve of a tyre is loosened, air rushes out. Under the high initial pressure the outflow is at first rapid ; but as the pressure falls less and less air is driven out by it in a given time. The rate at which the pressure falls is thus reduced until finally it becomes very small, as shown in

Fig. 72. The same kind of thing happens in the discharge of a condenser: the electrical pressure, measured in volts, falls rapidly at first (Fig. 73) and then more and more slowly.

The time taken by a given condenser to charge or to discharge can be regulated precisely by placing the correct

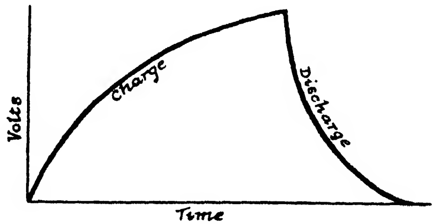


FIG. 73.—The electrical pressure of a charging condenser rises in the same way as that of the bicycle tyre which is being pumped up.

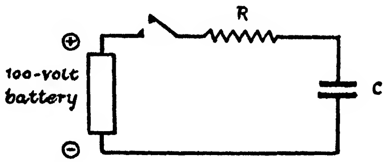


FIG. 74.—If a condenser, a resistor and a source of E.M.F. are connected as shown, the condenser will always charge to 63 per cent of the applied voltage in a number of seconds equal to the farads of capacity multiplied by the ohms of resistance.

amount of resistance in the path by which current enters or leaves it. What may be termed the "electrical size" of a condenser is called its CAPACITY and is measured in FARADS; resistance, we know, is measured in ohms. If a condenser, a RESISTOR (a component designed to have a definite number of ohms of resistance) and a battery are connected as shown in Fig. 74, the condenser will always charge up to 63 per cent of the voltage applied to its plates in a number of seconds equal to the ohms of resistance multiplied by the farads of capacity.

Suppose that in Fig. 74 the battery has an E.M.F. of 100 volts, that the resistance is 200,000 ohms and the capacity of the condenser is 3 microfarads (remember the prefix micro-). Sixty-three per cent of 100 is 63 ; then the charge of the condenser will reach 63 volts in 200,000 $\times \frac{3}{1,000,000}$ =6/10, or 0.6 second. No matter what voltage is applied from a battery or any other source of steady E.M.F., a 3-microfarad condenser will always charge to 63 per cent of it if 200,000 ohms of resistance are in the circuit. The figure obtained by multiplying resistance and capacity together in ohms and farads is known as the TIME CONSTANT of the circuit.

We can make the time constant of the Fig. 74 circuit greater by increasing either the resistance of the resistor or the capacity of the condenser, or both ; similarly it can be made less by reducing either resistance or capacity, or both. The rate at which a condenser of given capacity discharges can be regulated exactly by using the required amount of resistance in the path through which the discharge takes place.

Now examine the circuit shown in Fig. 75. Can you work out before reading further how long the condenser C takes to charge to 63 volts if the switch is in position A ?

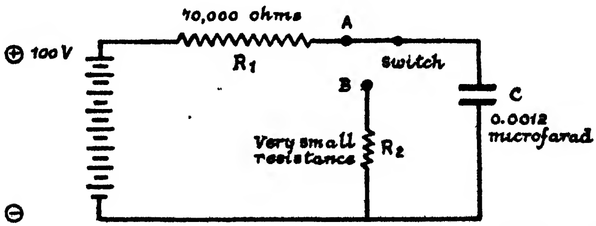


FIG. 75.—The time constant of this circuit is 84 microseconds, as explained in the text.

Well 0.0012 microfarad is 0.0000000012 farad and that multiplied by 70,000 comes to 0.000084 second = 84 millionths of a second, or 84 microseconds. It saves trouble, by the way, to write such terms as microfarad and microsecond in the abbreviated forms μF and μsec ; μ (pronounced mew) is the Greek letter corresponding to m and *micros* is Greek for small.

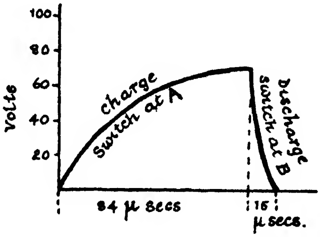


FIG. 76.—Showing how a condenser could be made by means of the switch to charge in 84 microsceonds and to discharge in 15.

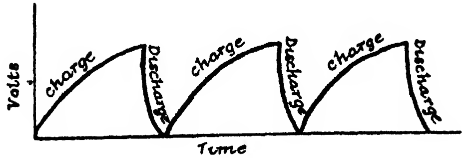


FIG. 77.—The drawing shows the saw-toothed waves of voltage that the charge and discharge of the condenser would produce if the switch could be moved with sufficient rapidity.

Fig. 76 shows both the charge of the condenser when the switch is in position A and its discharge when the switch is in position B. By choosing the right small value for R2 in Fig. 76 (there is no need to go into the calculation here), we can make the condenser discharge in 15 μsec.

If we were able to move the switch sufficiently rapidly voltage changes producing the SAW-TOOTHED waves illustrated in Fig. 77 would occur between the plates of the condenser. It is such saw-toothed voltages that we require for reasons that will appear in a moment ; but with all the good will in the world no one could operate the switch thousands of times a second. We must find some means of getting that staunch ally the electron (which is always ready to do things millions of times a second, if need be) to perform the work for us.

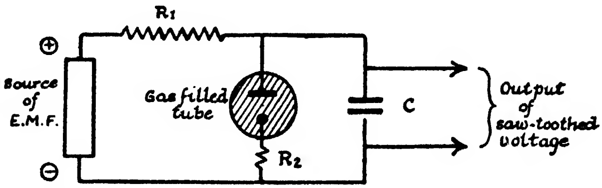


FIG. 78.—Showing a simple way in which the electron can be made to do the necessary switching.

Fig. 78 shows one simple way in which this may be done. A tube filled with an inert gas such as neon and provided with a cathode and an anode has one interesting and useful characteristic. No current can pass from cathode to anode until the E.M.F. applied to the tube reaches a certain figure, which depends upon the particular type of gas-filled tube in use. As soon as the applied voltage reaches that figure the tube "fires" : it suddenly allows current to pass through it. If the voltage is now reduced current continues to pass until a comparatively low figure is reached : once it has "fired" the tube does not "extinguish" until a considerable drop in the voltage between its anode and cathode has occurred.

It will be seen that in the Fig. 78 circuit the anode of the tube is connected to one condenser plate and its cathode to the other ; the E.M.F. between the anode and cathode of the tube is therefore at any instant the same as that between the plates of the condenser.

Beginning with the tube "extinguished," the cycle of operations is as follows. The condenser charges through R1 and no current passes through the tube. The voltage increases until the "firing point" of the tube is reached. The tube then allows current to pass freely and the condenser discharges through it and R2, the discharge continuing until the "extinguishing point" is reached by the fall in the voltage between the condenser plates. The tube then ceases to pass current, the condenser begins to charge and the cycle is repeated.

With the values of R1 and C the same as in Fig. 75 and a suitable value for R2 the output of the condenser is the saw-toothed voltage of Fig. 77, rising in 84 μsec and falling in 15 μsec. It will continue to rise and fall with unfailing regularity in this way.

The arrangement seen in Fig. 78 is, in fact, a simple time-base generator. Its output can be amplified by means of one or more wireless valves and applied as shown

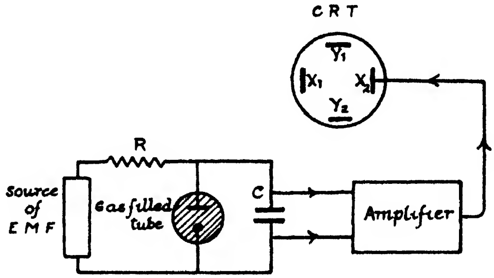


FIG. 79.—The application to the C.R.T. of the saw-toothed voltage of the time-base generator.

in Fig. 79 to the X2 plate of a C.R.T. Then the increasing positive voltage on X2 will draw the spot from left to right for 84 μsec across the screen and the spot will fly back from right to left during the 15 μsec in which the condenser's discharge relaxes the voltage on X2.

We have produced a time-base on the screen ; but will it do for television purposes ? Is it just the right kind of time-base ? The duration of the scanning stroke is 84 μsec and that is correct ; 15 μsec is also correct for the fly-back. What then can be amiss ? The nigger in the wood-pile is the curved shape of the " teeth " seen in Fig. 77. If the voltage on X2 rose rapidly at first and then more and more slowly, as Fig. 76 shows that it does in each tooth, the scanning spot would not be drawn at an even rate across the screen. The picture elements would be compressed at one end of the screen and elongated at the other, with the result that the image would be horribly distorted. Something must clearly be done about this.

FIG. 80.—Showing how a saw-toothed voltage with straight-edged " teeth " can be obtained.

The key to the problem is indicated in Fig. 80 (*a*). It consists in using a much higher supply voltage and allowing the condenser to charge not to 63 per cent of it, but only to, say, 10 per cent.* The early part of the curve in Fig. 80(*a*), when the condenser is charging rapidly, is almost a straight line. It is not difficult to arrange for only the early part of the charging curve to be used in this way. Suppose that in Fig. 78 the applied E.M.F. is 600 volts and that the gas-filled tube employed " fires " at

*The actual value may be from 5 to 20 per cent according to the requirements of the designer.

60 volts; then as soon as the condenser has charged to 60 volts the tube fires and the condenser discharges. The discharge being through a very low resistance path, is so rapid that it, too, has a curve that is almost straight. The result is the saw-toothed voltage variations seen in Fig. 80(*b*). Naturally a combination of capacitance and resistance with a larger time constant is required, but it is easy to calculate the necessary values.

Considerable amplification is needed before this voltage is applied to the C.R.T., for the potential on the X2 plate of the C.R.T. must increase from 0 to 1,000 volts or more to draw the scanning spot the 10 inches across the screen which is the length of the lines of a good television image nowadays. The amplifier is often made to work in what is called " push-pull." This means that the output is from a pair of valves, so arranged that one is delivering a positive voltage whilst the other is delivering a negative voltage.

The application of push-pull is illustrated diagrammatically in Fig. 81. During the scanning stroke X1 is made increasingly negative and the growing electron surplus on it repels the beam of electrons further and

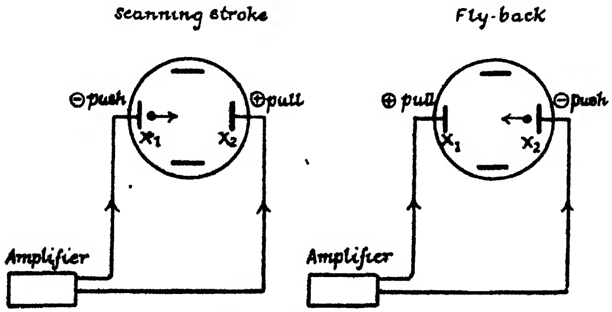


Fig. 81.—Illustrating the push-pull system of deflection with the electrostatically controlled C.R.T.

further. At the same time the growing electron deficiency on X2, as it becomes more and more positive, attracts the beam more and more strongly. Hence the spot receives, so to speak, a push behind and a pull in front as it makes its scanning stroke. During the fly-back the process is reversed, the beam of electrons being repelled by X2 and attracted by X1.

For the line scan there must be $202\frac{1}{2} \times 50$, or 10,125 saw teeth every second; that figure is known as the REPETITION FREQUENCY, or simply the frequency of the time-base generator. The frame scan takes place only 50 times a second, so that the time-base generator regulating the voltages applied to the Y plates, has a repetition frequency of 50 per second.

The general principles are the same in the magnetically controlled tube, line and frame time-base generators producing saw-toothed wave forms being used. But to operate the deflector coils we require current changes in-instead of voltage changes. There is no difficulty here, since the valves of the amplifier can be so arranged that their output consists of saw-toothed current changes.

So far, then, we have found a way of making the spot on the screen of the receiving C.R.T. travel from left to right across the screen and flash back 10,125 times a second and of making it travel downwards and flash back 50 times a second. With both time-bases at work a combination of the two sets of movements takes place and the spot traces out the rectangular raster which will build up the picture. But before we can make a television picture appear on the screen there is still a good deal to be done. We must make the brilliance of the scanning spot on the receiver screen vary in accordance with the lights and shades encountered by the scanning spot in the studio. We must make sure that the receiver scanning spot starts and finishes its lines at the exact instants when they are started and finished in the studio. The frames must also start and finish precisely in accordance with what is happening in the studio. Should the receiver spot become by even a minute amount " out of step " with the studio spot an image cannot be formed properly. Lastly, we have to find a means of making the receiver spot perform that interlacing of the scanning lines which we discussed a little way back. The signals received from the transmitting station help to ensure that these things are done and in the next chapter we shall see what reaches the aerial of a television receiver when a programme is coming through.

CHAPTER XIII

The Television Signal (1)

Blacks, Whites and Greys

THE term SIGNAL is used to denote the modulated carrier wave as sent out from the transmitting aerial and picked up by the receiving aerial. The modulation conveys to the receiver all the directions in the form of electrical impulses that are necessary to make it do its work properly. It will, perhaps, help if we think of the modulation as ordering the receiver about. If the receiver is a good one it obeys the orders exactly and the result is a faithful copy of what is taking place in the studio. In the case of sound the process is fairly straightforward, for, speaking broadly, only two kinds of order are needed : the receiver must be told how rapidly to make the cone of the loudspeaker vibrate in order to reproduce the pitch of a sound and it must be told how violently to make it vibrate in order to reproduce the sound with the right degree of loudness.

The first part of the information is conveyed, as we saw in Chapter II, by superimposing the sound-wave frequency on the carrier-wave frequency : the crests and troughs of many cycles of the carrier trace out the shape of each complete sound wave. In the receiver an electrical copy of the original sound wave is reconstituted and compels the cone of the louds peaker to vibrate at the required speed.

Orders to make the loudspeaker's cone vibrate more or less violently so as to reproduce loud or soft sounds are conveyed, as shown in Fig. 82, by the amount of the variation in the carrier-wave amplitude. A soft sound causes the crests and troughs of the carrier to rise and fall only a little above and below their normal level. But a very loud sound causes large alterations in the amplitude. When the troughs due to the loudest sounds in the studio cause the carrier to fall to zero, as in Fig. 82(*b*), the carrier is said to be modulated 100 per cent.

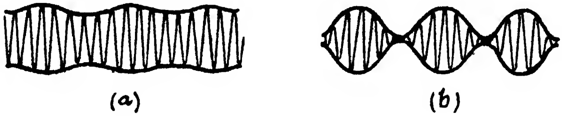


FIG. 82.—The amount by which the modulation causes the amplitude of the carrier to vary depends upon the loudness or softness of the sound.

The television signal has orders of quite another kind to convey and, as might be expected, its modulation takes a very different form.

What it has to do in the first place is to ensure that the receiver scanning spot is at any instant of exactly the right brilliance. The television image is painted on the screen in black and white ;* and between these two extremes the number of gradations of shade, varying from the darkest to the palest grey, is infinite. If the image on the screen is to be perfect every one of the thousands of picture elements which build it up must be of the right shade. When the scanning spot is very bright the eye of the viewer registers the impression of pure whiteness. If the spot is extinguished, the impression is of dead blackness. All the differences of shade between pure white and dead black are produced on the screen by varying the illumination caused by the spot between extreme brilliance and complete extinction.

This is done by means of the grid of the cathode-ray

*See note on page 73.

tube, to which that part of the modulation responsible for controlling the brilliance of the scanning spot is applied in the form of variations in voltage. You will remember that in our discussion of the C.R.T. we saw that the grid controls the density of the beam of electrons which gives rise to the spot by bombarding the fluorescent screen. Making the grid more positive increases the density of the beam and brightens the spot. Making it more negative reduces the density and dims the spot ; the spot can be extinguished altogether if the grid is made so negative that the beam is completely dammed back.

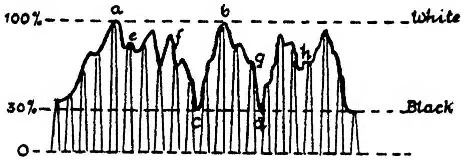


FIG. 83.—The basic principle of television modulation. For the sake of simplicity, the drawing shows only one side-band.

Fig. 83 illustrates the basic principle of television modulation. The amplitude of the carrier-wave is varied in accordance with the shade that the scanning spot in the studio encounters at any instant as it traverses the subject. Pure whites leave the carrier at its normal amplitude ; dead blacks reduce it to 30 per cent of its normal amplitude. In television parlance white corresponds to 100 per cent carrier and black to 30 per cent. Every gradation between black and white varies the amplitude of the carrier by an appropriate amount between 30 per cent and 100 per cent. You will see that at *a* and *b* in the drawing the modulation corresponds to pure white and *c* and *d* to dead black. At *e*, *f*, *g* and *h* it corresponds to different shades of grey.

Fig. 84 shows in simplified form the modulation corresponding to one whole scanning line. The carrier has been omitted, only the modulation ENVELOPE being shown. This is in fact the form of the signal after it has passed through the detector stage of the receiver. You may remember that we saw in Chapter XII that the whole time allotted to the scan of one line and the subsequent fly-back is 99 microseconds. Fig. 84 indicates how this tiny period of time is divided up.

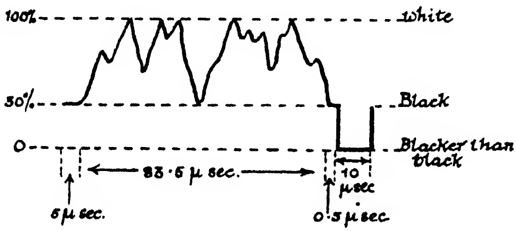


FIG. 84.—The signal corresponding to one scanning line of a television image.

The line starts always with black lasting for 5 microseconds. Then the actual painting of lights and shades begins and lasts for 83.5 microseconds. At the end of that time there is black again for half a microsecond. Then something apparently rather queer happens : the modulation forces the carrier steeply to zero and keeps it there for 10 microseconds. If 30 per cent carrier amplitude is dead black, what can zero be ? Actually it produces no shade at all on the screen, for the spot has finished painting the line and is engaged in its fly-back during those 10 microseconds. That 10-microsecond patch of " blacker than black " has a very important part indeed to play. It forms what is called the SYNCHRONISING PULSE, whose functions we shall discuss in the next chapter.

Meantime make sure that you are clear about the time divisions of the scanning line :—

Initial black	5.0	microsecs.
Active scan	83.5	"
Final black	0.5	"
Synchronising pulse	10.0	"
	99.0	"

One other point about the line scan ; can you see why black always occurs at the beginning and end of a line. The reason is simply that at either end of the line or at both there may be pure white picture elements. It would be almost impossible to make the amplitude of the carrier rise instantly from the zero level of the synchronising pulse to 100 per cent. Such a large rise would take a little time, with the result that greys instead of whites would appear at the left-hand edges of the picture. At the right-hand edge a fall from 100 per cent to zero could not be accomplished rapidly enough to make the pulse truly rectangular. The blacks at the beginning and end of a line do away with these difficulties since the amplitude has less far to rise and fall.

CHAPTER XIV

The Television Signal (2)

Synchronisation

AMONGST the most important of the messages which the television signal has to convey are those which ensure that the time-bases of the receiver C.R.T. run correctly. The process is called synchronisation and it is carried out by the SYNCHRONISING PULSES. Synchronisation and synchronising are long and rather clumsy words; both are abbreviated in television parlance to SYNC (pronounced sink) and we shall use the shorter and handier term from now on.

A little thought will show that there are several essential conditions affecting the travel of the spot as it scans a line if it is to reproduce properly what is sent out from the television studio. First, it must start its scan at exactly the instant when the studio scanning spot starts. If it does not the whole line will be displaced. The two spots must also finish a line and fly back together. You can imagine what would happen to the image on the screen if the receiver spot was out of step with the spot in the studio. Again, having started at the right instant, the receiver spot must make each and every scanning journey at the same speed as the spot in the studio; only differences in speed so minute that they are hardly to be imagined can be tolerated if the picture is not to show striking and unpleasant signs of distortion.

We saw in Chapter XII that the fundamental principle of the television time-base is the charging of a condenser through a resistor; we saw, too, how the time constant of such a combination could be worked out by multiplying the farads of capacity by the ohms of resistance. If it is true that a condenser of a certain capacity charging through a resistor of a certain resistance will always charge to 63 per cent of the applied voltage in a certain definite time, why should any sync be necessary? If the values are properly chosen surely the spot will always be drawn from right to left for 89 microseconds and will then fly back in 10. In that case why do we need anything more than some signal at the very beginning of a television broadcast that will make the receiver spot start at the same instant as the spot in the studio? If they start together, will not the spots continue to keep in step? The answer is this. All that was said about the time constant is perfectly true. There would be no variation in it or in the travel of the receiver scanning spot if the capacity and the resistance involved always remained at exactly their original values. Unfortunately both are liable to undergo minute alterations for reasons into which we need not enter here and the tiniest change in either may be sufficient to upset the working of the receiver.

The timing must be accurate. As you will realise by referring again to Fig. 84, we are working not even in whole microseconds but in *half*-microseconds. And that necessitates an extraordinary degree of precision. Half-microseconds are important in television, but it is difficult to form any idea of so small a quantity of time. If a watch gained half a microsecond a day, it could never become a whole second fast. For it to do so would require over five thousand years and it would be worn out long before that!

The best of clocks and watches must have their hands reset every now and then; to ensure perfect accuracy the television line-scan time-base, which has to measure far smaller intervals of time with a degree of accuracy that is difficult to conceive, is reset by the sync pulse 10,125 times in every second.

Now let us see how this can be done. We have already seen how a grid inserted between the cathode and the anode of a C.R.T. controls the flow of electrons. A grid may also be placed between the cathode and the anode of the gas-filled tube which we used in Fig. 78 as part of a time-base generator. What is going to be the effect of applying a positive voltage to the grid of a gas-filled tube? Owing to the short distance between the two a positive voltage on the grid exerts a strong attractive force on the mass of electrons at the cathode. The pull of the positive grid voltage helps the pull of the positive anode voltage; it is not, therefore, surprising to find that, with the grid positive, a lower anode voltage is needed to cause the tube to "fire."

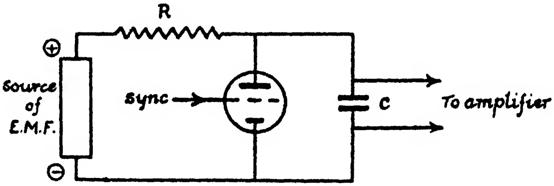


Fig. 85.—Showing how the sync pulse may be used to control the action of the time-base generator.

Consider the arrangement shown in Fig. 85, which is similar to that of Fig. 78, except that the gas-filled tube now has a grid, indicated by the broken line. So long as no voltage is applied to the grid the condenser charges through the resistance R until the voltage across its plates reaches the normal value required to make the tube fire. The tube then allows current to pass from cathode to anode and the condenser discharges through it.

Suppose, now, that a little before the condenser has charged to the requisite amount we apply a positive voltage to the grid of the tube. It fires and the condenser discharges earlier than it otherwise would. In fact, by ensuring that the positive voltage applied to the grid is large enough, we can ensure that the tube fires and the condenser discharges the instant it arrives.

In television receiver the line sync pulse may be made to produce a sudden " whiff" of positive voltage, lasting for 10 microseconds, on the grid of the tube of the line time-base generator. The result is that when this voltage arrives the tube fires, the condenser discharges and the spot on the screen flies back. Nor can the tube extinguish and the condenser start charging again until the sudden ending of the sync pulse removes the positive voltage on the grid. In other words the spot cannot restart its scan until the ending of the sync pulse releases it.

If the condenser is charging too rapidly, the sync pulse cannot do its work properly, for the condenser will have charged and caused the tube to fire before the pulse arrives. It can take complete command of the situation only if the condenser is charging a tiny bit too slowly. Then it exercises complete control over the stopping and starting of the spot at every line of the scan. The golden rule is, therefore, to adjust the time-base so that it is very slightly on the slow side. The line sync pulse then pulls it exactly into step and keeps it there.

The frame scan must also be synchronised and this is done in a similar way by means of the frame sync pulses. These pulses differ from the line sync pulses by being four times as long. This difference enables a special circuit in the receiving set to sort out the pulses, causing the line syncs to be delivered to the line time-base generator and the frame syncs to the frame time-base generator. We shall see more about this in the next chapter.

At the end of each frame a series of frame sync pulses comes in. The number of these appears to vary a little.

In the B.B.C.'s original specification of the Alexandra Palace transmissions it is given as not less than 6 or more than 12. Between the end of one frame and the beginning of the next the vision signal remains at black or " blacker than black " for at least 10 lines. This number seems also to vary; before the war it was 10 and at the time that this is being written it is 14 lines. The purpose of this rather lengthy blackout between frames is to allow the frame fly-back to take place and to get the spot into the right position for interlacing before it starts its line scan of the next frame.

The complete television signal is shown in Fig. 86. You will be well advised to puzzle it out with the help of the explanation which follows.

At A in the drawing the last line (No. 405) of an image comes to an end. Eight frame-sync pulses now follow, occupying the time of half that number of scanning lines. Now comes at B a line sync pulse followed by alternate blacked out lines and line sync pulses for 10 lines and then the start of the vision signal at C.

Since the first 14 lines of the frame are blacked out, the scan actually starts at the beginning of line 15. Then it goes on, line by line, until the point D is reached in the middle of line 203. The frame has therefore been made up of 202½ lines, 14 of them blacked out and the other 188½ " active " lines in which the picture scan takes place.

At the point D a frame-sync pulse arrives, starting the frame fly-back and blacking out the screen of the C.R.T. As before, 14 lines in all are blacked out and the scan of the second frame of the image starts at E, half-way along line 217, that is at line 216½. Once more there are 188½ active lines and the second frame of the image ends at line 405.

You will see that by means of the half-lines at the end

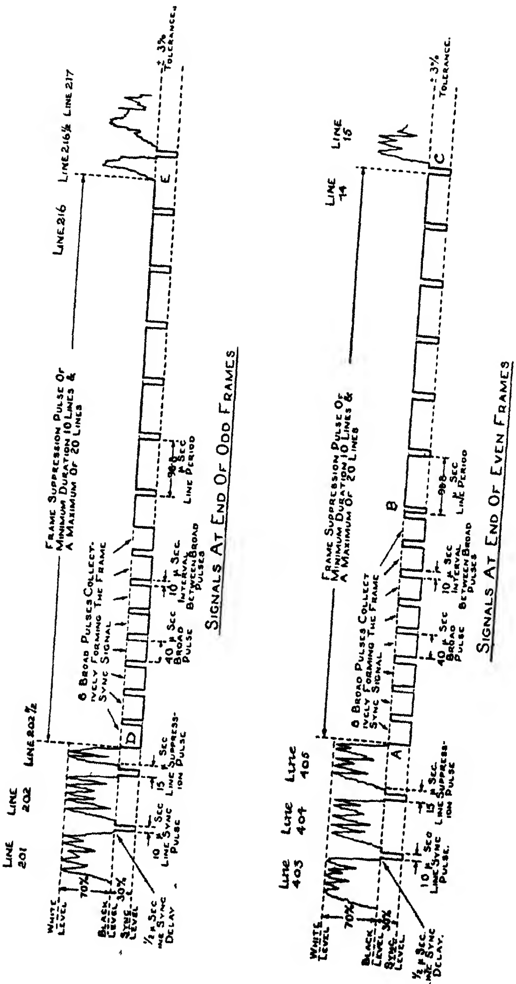


Fig. 86.—The complete television signal.

of the first frame and the beginning of the second the frame-sync pulses cause proper interlacing to be done. The line-scan time-base generator is at work all the time, but no spot appears on the screen until the blackout is lifted. This last point will be made clearer in the next chapter on the television receiver.

The time-base generator, often called the saw-tooth oscillator, is seldom quite so simple as the type described here; the underlying principle, however, is the same in all cases. Voltage, if the C.R.T. is electrostatic and current if it is magnetic, of saw-toothed wave form is generated with the help of the charge and discharge of a condenser. By means of these voltages or currents the spot is made to trace out the raster which builds up the picture. The line-scan requires 10,125 "teeth" each second; the frame-scan, 50. Both line and frame saw-tooth oscillators are synchronised by the sync pulses, which ensure that neither line-scan nor frame-scan last too long and keep the spot on the receiver screen exactly in step with that in the studio.

CHAPTER XV

The Television Receiver (1)

The Circuits and What They Do

IN Fig. 87 is seen a considerably simplified block diagram of a complete television receiver, containing both sound and vision departments. Television receivers take many different forms according to the price at which they are to be sold and to the views of particular designers. The type shown in the diagram uses "straight" or tuned radio-frequency (T.R.F.) receivers for both sound and vision. In some television sets both are of the superheterodyne type; other sets use the superheterodyne for sound and T.R.F. for vision. All of these combinations have their particular advantages and drawbacks and none can be described as being the unqualified best. Speaking broadly, though, rather better definition is obtained in the picture by the use of T.R.F. on the vision side.

The receiving aerial picks up both trains of wireless waves that are sent out from the transmitting station. At the time of writing the only television broadcasting station is that at the Alexandra Palace in London, which transmits sound on 7.2 metres (41.5 Mc/s) and vision on 6.7 metres (45 Mc/s). The sound receiver, being tuned to 41.5 Mc/s, accepts that frequency and rejects others. Similarly the vision receiver, tuned to 45 Mc/s, accepts the vision signal, but will have no dealings with other frequencies. The twin signals received by the aerial are thus sorted out and made to go to their proper destinations in the television set.

In its general lines the sound receiver of the television set does not differ greatly from that used for ordinary

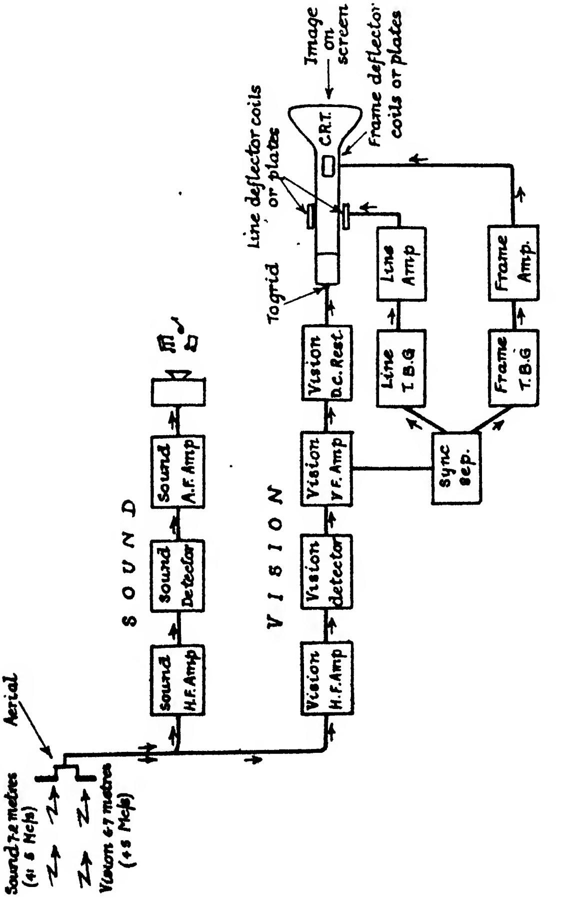


FIG. 87.—Simplified block diagram of the complete sound and vision receiver.

broadcast reception. There is, in fact, in the cheaper television sets no difference except that it is designed to work upon the much shorter wavelength. But the more expensive sets, whose designers have not to consider every penny, can be a revelation to their users in the wonderful quality of their reproduction of sound.

It was explained in an earlier chapter that the number of stations which must be fitted in on the medium-wave band between 200 and 550 metres limits very strictly the range of audio frequencies that any of such stations can transmit. On the medium-wave and long-wave bands no sound whose frequency is much beyond 4,500 c/s can be transmitted. The human ear is so accommodating that it accepts from the loudspeaker of the broadcast receiver reproduction thus limited in its frequency range without registering any marked protest at its inadequacy. The owner of the ear may realise that there is a difference between the broadcast receiver's reproduction of music and music heard direct in the hotel lounge or the concert hall; but in course of time he has become habituated to the idea that "wireless must sound like that." Patrons of saloon bars in the roaring days of the Wild West were urged by notices displayed on the walls not to shoot the pianist, who was doing his best. Believing that his broadcast wireless set is doing its best, the listener is not unduly critical of its performances.

That best, however, does not represent the highest achievement in the way of sound reproduction of which wireless is capable. On the ultra short-waves used by television there is no hard and fast limit to the sound frequencies which can be transmitted. The Alexandra Palace station does in fact transmit all of them up to 12,000—14,000 cycles a second, which is about all that can be dealt with by any but very youthful human ears—our ears gradually loose the power of responding to highly pitched sounds (high frequencies) as we grow older.

This means that if the sound receiver and the loudspeaker of the television set are first-rate, reproduction by means of them far surpasses anything obtainable on the medium-wave and long-wave bands from the best of broadcast receivers. Unfortunately, the most expensive thing in a wireless receiving set is good reproduction of sound. It is a simple and not very costly business to make a receiver which will bring in any number of distant stations and the purchaser is too often prone to select a set purely on its performance in this field, forgetting that, once it is installed in his home, the set will spend 99 per cent of its time in reproducing the programmes of the local stations.

The sound part of the television receiver can give reproduction that is far and away more pleasing than that of the broadcast receiver; but this is possible only if it is of first-class design and make-up. Remembering what has been said about the relative costliness of good wireless reproduction, you will see one reason why the television receiver which is to do justice to the transmissions cannot be a cheap instrument.

So much for the sound department of the television receiver; now let us examine the vision side of it.

Even at short range the energy picked up by the aerial is minute. Amplification at high frequency is therefore necessary before the signal is strong enough to give its orders to the various parts of the receiver. Then follows detection, in the course of which the carrier wave and one side-band are removed and the signal is left in the form shown in Figs. 84 and 86. It is still too feeble to do the work required of it, so it now undergoes further vision-frequency amplification.

The output of the vision-frequency (V.F.) amplifier travels along each of the two paths open to it, leading to the grid of the C.R.T. and to the sync separator. The part which takes the path towards the grid is not, on leaving the V.F. amplifier, quite in the form needed for it to do its work properly. Fig. 88 illustrates this diagrammatically. It will be seen that at this stage the vision signal consists of varying voltages which are sometimes positive and sometimes negative. To operate the tube properly (the reasons will be made plain in a moment)

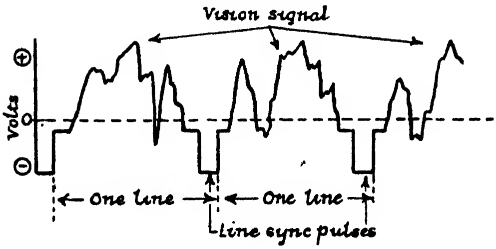


FIG. 88.—The output of the vision-frequency amplifier consists of voltage impulses of the kind seen above.

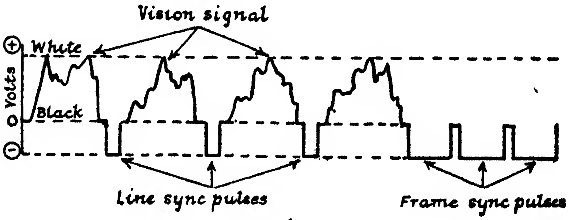


FIG. 89.—The signal after the D.C. restorer has dealt with it. Note the difference between this drawing and Fig. 88.

these voltages must vary between zero and a positive value, but must not have negative values. The whole of the vision signal is made positive by a stage called the D.C. (Direct Current) RESTORER, whose output is illustrated in Fig. 89.

Let us see what happens when the output of the D.C., Restorer is applied to the grid of the C.R.T. The grid is normally kept at a negative potential sufficient to dam back the electron beam completely. No spot of light can therefore appear on the screen until something comes along to neutralise the prohibition exercised by the standing negative potential on the grid and to allow the electron beam to come into being. When the voltage applied to the grid from the output of the D.C. Restorer is positive the standing negative potential, or BIAS as it is called, is overcome ; the gates are unlocked and a beam of electrons forms a spot of light on the screen. The brightness of the spot depends upon the density of the electron beam and that depends upon the intensity of the positive voltage : the higher positive voltage, the brighter the spot. Zero voltage (no spot at all) thus represents black and maximum positive voltage (the brightest spot) white.

But for the action of the D.C. Restorer the lights and shades of the picture would be lacking in contrast. The voltage on the grid of the C.R.T. would not become sufficiently positive to make the whites really white—they would appear as pale greys. Since the spot is extinguished at zero grid potential the darker shades of grey would all appear as blacks. The fine gradations of light and shade needed to build up a clear, "contrasty" picture would be lacking and the image would give somewhat the same impression as a badly over-exposed photograph. By its action the D.C. Restorer sets all this right.

Voltages dropping from zero to negative have no effect whatever on the spot. It is killed by a zero voltage—and you cannot kill anything deader than dead ! Hence the effective input from the D.C. Restorer to the grid of the C.R.T. is as shown in Fig. 90. The scanning spot varies in brilliance as the voltage applied to the grid of the C.R.T. varies from anything above zero to maximum positive. At zero volts or at any negative voltage there is no spot at all and the screen of the C.R.T. is blacked out.

The second part of the output of the V.F. amplifier goes to the SYNC SEPARATOR, whose duty is to remove the vision part of the signal seen in Fig. 88 and to pass on only the line and frame sync pulses to the two time-base generators.

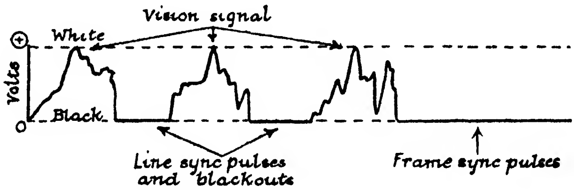


FIG. 90.—The effective input from the D.C. restorer to the grid of the C.R.T. is as illustrated.

The way in which this is done is ingenious and interesting and it is a good example of the multifarious uses to which wireless valves can be put. Certain types of valve can be so arranged that they are paralysed when a positive voltage is applied to them and produce no response to it. On the other hand they do respond to the application of a reasonable amount of negative voltage. When a varying voltage of the kind seen in Fig. 88 is applied to such a valve, it suppresses all the part that lies on the positive side of zero and responds only to the part lying on the negative side of zero. Such a valve, then, will eliminate all the purely vision part of the signal, which ranges between zero and maximum positive volts, and will give an output corresponding to the negative part of the signal—the line sync and frame sync pulses. Its output will, in fact, be as seen in Fig. 91.

But wait a minute, you may say; surely Fig. 91 is drawn all wrong. The line and frame sync pulses were shown in Fig. 88 as negative and in Fig. 91 they are positive. Positive pulses are needed to synchronise the two time-base generators, but the signal contains negative pulses. Those negative pulses are, in fact, shown in Fig. 89 as blacking out the C.R.T. How is that to be explained?

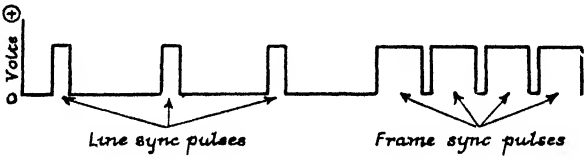


FIG. 91.—The output of the sync separator to the line and frame time-base generators.

One of the peculiarities of the wireless valve is that it reverses, or turns inside out, any voltage variation applied to it. Put into a valve a cycle consisting of a rise to maximum positive followed by a fall to maximum negative and its output is just the opposite: a fall to maximum negative followed by a rise to maximum positive. Apply the output of the first valve to a second valve and a reversal again takes place, and so on for any number of valves. If, therefore, you have one, three, five or any odd number of valves a positive input appears as a negative output. With two, four, six or any even number of valves the voltage output is of the same nature as the input. This is a most convenient characteristic of the wireless valve, for it means that by employing the right number we can either make the voltage output of the same kind as the input or reverse it to meet particular requirements. We want the sync separator to produce an output of positive pulses and it is easy to make it do so.

The next business is to see that the short line sync pulses and the long frame sync pulses are delivered to the proper places. The line sync pulses must go to the line sync time-base generator and the frame sync pulses to the frame time-base generator. It is also necessary to ensure that there can be no leakage ; the whole working of the receiver would be upset if the wrong sort of pulse reached one of the time-base generators and triggered it off at the wrong instant.

This is done by the use of some form of high-pass and low-pass filters. A HIGH-PASS FILTER allows high frequencies to go their way, but strains out low frequencies by offering opposition to their passage. Similarly, a LOW-PASS FILTER accepts low frequencies but refuses admittance to high frequencies. The short, rapidly recurring line sync pulses are high frequencies and are allowed by a high-pass filter to travel to the line T.B.G. The long, frame sync pulses of slower recurrence are low frequencies and find that path barred to them. On the way between the sync separator and the frame T.B.G. a low-pass filter admits the frame sync pulses but not the line sync pulses.

You will have realised by now how many different instructions are conveyed to the sound and vision receivers by the signals reaching the aerial and how much sorting out of these instructions must take place so that every one can be obeyed by the proper part of each receiver. These sortings out are tabulated below and you will find it well worth while to follow out, with the aid of Figs. 86-91, those concerned with vision, so as to make quite sure that you have a clear general idea of the way in which the television set does its work.

Sorting out Point	Sorting out needed	Method used
1. Output of aerial	Sound signal from vision signal	Separate receivers tuned to appropriate frequencies
2. Output of sound H.F. Amplifier	Removal of sound carrier and one side-band	Detector stage of sound receiver
3. Output of sound A .F. Amplifier	Loud and soft sounds	Varying strength of current delivered to loudspeaker
4. Output of sound A.F. Amplifier	High, medium and low-pitched sounds	Varying frequencies delivered to loudspeaker
5. Output of vision H.F. Amplifier	Removal of vision carrier and one side-band	Detector stage of vision receiver
6. Output of D.C. Restorer	Vision signal from sync pulses	Standing negative potential on grid of C.R.T.
7. Output of V.F. Amplifier	Sync pulses from vision signal	Wireless valve used in special way in sync separator
8. Output of Sync Separator	Line sync pulses from frame sync pulses	High-pass and low-pass filters
9. Grid of C.R.T.	Whites, greys and blacks	Effect of voltages varying from zero to maximum positive valve on the grid's, controlling action of the density of the electron beam

CHAPTER XVI

The Television Receiver (2)

High-Quality Reproduction

DESPITE the complex nature of what goes on inside it when it is in action, the television receiver of today is actually one of the simplest of domestic electric appliances to operate. Often it has fewer control knobs than the ordinary broadcast wireless receiving set and, provided that it is properly adjusted when it is installed, the only one of these that needs more than occasional use will probably be the on-off switch for the current supply from the lighting mains !

In larger sets of the console type the normal arrangement is to place the vision part of the apparatus near the top and the sound part below it. Usually the tube lies horizontally, so that its screen is vertical and the image upon it is viewed direct. Sometimes, however, the tube is mounted vertically and the image on its then horizontal screen is seen in a mirror placed at right angles to it. In table models the viewing screen and the loudspeaker are usually side by side. The few control knobs are arranged in convenient positions at the front of the instrument.

Apart from the mains switch, the visible control knobs are sometimes reduced to two only : a knob allowing the brightness of the image to be regulated as required and a second controlling the volume of sound from the loudspeaker. As only one station can be received (more stations are to be erected in the near future, but as all will transmit the same programme only the one which is best received will be used in any locality) there is no bother about tuning-in in order to bring on television. The set is tuned to both sound and vision transmissions when it is installed and should need no further attention in that way except during its occasional overhauls by the service-man.

Several other adjustments made at the time of installation may require no more than the same occasional expert attention and their knobs may be in concealed positions. Amongst these are the contrast control, by means of which the proper degree of light and shade is obtained in the image, the focus control and the line-hold and frame-hold. These last two enable the speeds of the line and frame time-bases to be properly regulated and ensure that the sync pulses are taking charge as they should.

Many sets have four visible knobs for vision control: brightness, focus, line-hold and frame-hold. They are there if wanted, but it is not likely that any but the first will need to be used very often.

The picture size ranges from $2\frac{1}{2} \times 2$ inches, or a little bigger, in midget receivers to some $12\frac{1}{2} \times 10$ inches in the largest. The cost of a receiver may be anything from about £25 to over £100. Whilst it is true that the least expensive sets usually have smallish viewing-screens and the most expensive large ones, it by no means follows that all that one gets by paying a higher price is a bigger picture. Large cathode-ray tubes certainly cost more than small ones and require roomier cabinets to house them; but there is much more in it than that.

We saw in Chapter IV that in order to transmit the full detail of an image a very wide band of frequencies must be broadcast. Plainly, the receiver cannot do entire justice to the transmissions unless it is capable of dealing properly with an equal range of frequencies. The Alexandra Palace station transmits modulation frequencies ranging up to 2.7 Mc/s and it is a difficult and expensive business to produce a vision receiver whose amplifiers respond satisfactorily to so wide a band; elaborate circuits and carefully chosen components of the highest grade must be used. If the receiver's response is incomplete an image still appears on the screen of the C.R.T.; but this image lacks much of the detail that should be present.

The B.B.C.'s regular test transmissions provide a ready means of checking the response of a vision receiver. Amongst these tests is a number of sets of black lines with white spaces in between them. The sets range from thick, widely spaced lines to very fine lines lying close together and the frequency response necessary in the receiver to bring out the lines and spaces of each set is indicated. A receiver whose response is no wider than 1 Mc/s reproduces the coarsest lines well enough, but to do justice to the finest the receiver must be able to deal with frequencies up to 3 Mc/s. By noting at which set of lines a vision receiver reaches the limits of its performance the quality of its frequency response can be gauged.

If distortion of the image is to be avoided, both the line-scan and the frame-scan must be LINEAR; that is to say, each must be performed throughout at a uniform speed. We saw in Chapter XII that a scan starting at a rapid speed and then slowing down must result if the outlines of the saw-tooth impulses from the time-base generator are pronounced curves and not straight, or very nearly straight, lines. Completely linear scanning, with the accompanying absence of distortion, is neither easy nor cheap to provide in a vision receiver.

Another of the B.B.C.'s tests provides a means of discovering whether distortion due to defective scanning is present in the image. This test is the transmission of a perfect circle and if no scanning distortion occurs it should be reproduced without any deformation on the viewing screen.

There are other ways in which a good set shows its superiority over one that is not so good—the interlacing of the lines, for example, may be imperfect in a poor set—but enough has been said to show that the mere size of the image is not a complete criterion of the quality of a television receiver.

There may be great differences in the matter of sound reproduction between good and indifferent television sets, for, as we saw in Chapter XV, it is neither an easy nor an inexpensive business to evolve a sound receiver which does real justice to the wide range of radio frequencies broadcast. The quality of the sound reproduction should be made an important consideration in the choice of a television receiver.

Do not imagine that I am suggesting that a low-priced television receiver is necessarily a poor performer. Far from it; even the cheapest provides sound and vision of good entertainment value. The prospective viewer must choose his set according to the length of his purse; but he will do well to invest, not in the cheapest set he can find, but in the best that he can afford to buy. In television, as in so many other things, you get what you pay for.

CHAPTER XVII

The Emitron Electric Eye

FOR years those engaged in the development of television sought to find some means of producing an electrical counterpart of the eye ; something that should be the optical equivalent of the acoustic microphone. The problem proved an exceedingly difficult one for though both are excited by waves and transmit to the brain messages recording the sensations produced by such waves, the ways in which the eye and the ear do their work are fundamentally different. In Chapter II we saw something of the working of both eye and ear and now a little more must be added.

When a complex sound, such as a musical chord, reaches the ear the drum does not make separate sets of vibrations at different frequencies corresponding to the individual components of the sound. Instead, it makes a highly complicated series of vibrations, corresponding to a mixture of all the sound waves reaching it at any instant. Moment by moment it sends to the brain *via* the aural nerve messages conveying the sum total of the impressions made by the simultaneous arrival of many different sound waves.

The same is true of the microphone and the loudspeaker. The diaphragm of the one and the cone of the other always make movements which correspond with the sum total of the sound-wave impulses (microphone) or the electric-wave impulses (loudspeaker) applied to them at any one time.

If the eye worked in the same way, vision would be a sensation very different from that which we actually experience in looking at things. When, for example, we let our eyes stray over an herbaceous flower bed at high summer we see a glorious riot of different colours. If the optic nerve sent to the brain nothing but a medley of the impression conveyed by the simultaneous arrival of light waves of different wavelength (each shade of colour has its own corresponding wavelength), we might see the flower bed as a rather indefinite black and white picture. As we shall see in discussing colour television, the shade that we know as white is a combination of the primary colours red, green and blue. Black may at times be a red so dark that the eye cannot respond to it as a colour.

The fact that it does not transmit to the brain a blend of the impressions recorded upon it by incoming light waves enables the eye not only to see different colours but also to form sharply focused images.

The surface of the retina of the eye, on which images are focused by the lens, is made up of the tips of a vast number of tiny light-sensitive rods. Each of these rods has its own small nerve fibre and the optic nerve is a cable made up of thousands of such individual fibres.

When the lens of the eye focuses an image on the retina each of the rods may be regarded as recording a picture element. Through the fibres of the optic nerve the thousands of picture elements are conveyed simultaneously to the brain, which reconstitutes the complete image from the multitude of separate messages received all at the same time. If the optic nerve consisted of one large, single channel and not of many small individual channels, the brain would receive a message consisting of a jumble of colours and of lights and shades and would build up no clear image. The vast number of separate and distinct messages received simultaneously from the rods of the retina through the individual nerve fibres enables it to form a clear picture of all that the eye sees.

Not long after the discovery that certain substances such as caesium became electrically active when light fell upon them the first attempts at making an electrical copy of the eye were made. A light-sensitive or photo-electric cell with a pair of wires attached to it can be made to function in much the same way as one rod of the retina and its associated nerve fibre. Now suppose that we have a frame containing 36 such cells, as shown in Fig. 92, and that a simple figure such as a black cross is projected upon them. The cells covered by the dark shadow of the figure receive no light and therefore allow no current to pass; but those on which the shadow does not fall receive light and allow current to pass. If each pair of wires leads to some kind of relay which switches on a light when the corresponding cell is activated, it is clear that by arranging 36 lamps in a similar frame at the receiving end a representation of the cross could be obtained. No less than 37 wires, however, are needed to connect the two frames able to transmit and receive such very simple designs—36 individual outward paths and a common return path. If a picture were to be transmitted with any detail, the number of wires would run into hundreds of thousands. To transmit and receive even a simple figure in this way by wireless means would be no easy business.

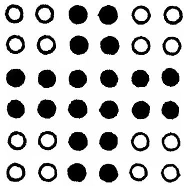


Fig. 92.—A simple pattern, such as a cross, could be transmitted by means of a frame containing a number of light-sensitive cells, each with its own pair of wires.

The American inventor V. K. Zworykin solved the problem in a most ingenious way by discovering a means which allowed the messages of a vast number of photo-sensitive cells to be conveyed, not all at once but in regular sequence, over a single pair of wires to a radio transmitter. He called his device the Iconoscope, or "image-seer."

Its British form is the Emitron, which is used for all B.B.C. television transmissions.

The Emitron contains a "retina" consisting of an enormous number of minute photo-sensitive elements lying in the form of a mosaic on the surface of a sheet of insulating material. This sheet is a very thin piece of mica, one of the best insulators. Its other side is covered with a thin layer of metal, forming the plate shown in the diagrammatic representation of Fig. 93. The mosaic

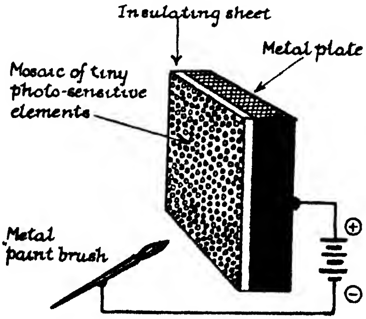


FIG. 93.—Explaining the principle of the "retina" of the emitron electric eye.

consists actually of tiny globules of silver combined with caesium. Each globule forms part of a miniature photo-sensitive cell. The whole of this artificial retina is enclosed in an evacuated glass bulb and by means of a lens, exactly similar to that used in photographic and ciné cameras, an image can be focused upon it.

When this is done those elements of the mosaic upon which strong light falls emit electrons at a rapid rate. You will recall that an electron deficiency means a positive charge; hence by throwing out electrons and developing an electron deficiency such cells acquire a relatively large positive charge. Cells upon which dimmer light falls become positively charged to a lesser degree, the amount of the charge of each depending upon the intensity of the light reaching it. Those in the black parts of the image acquire no charge at all, since they are not activated, and no emission of electrons takes place.

Each little caesium-silver globule with the mica insulating sheet and the metal backing forms a miniature condenser. One " plate " of the condenser is the globule ; the other is the metal backing. When, then, an image is focused on the mosaic we have thousands of tiny condensers, each carrying a charge corresponding to the intensity of the light falling upon it. In such circumstances the mosaic carries an invisible but detailed and complete electrical record of the image focused upon it.

Now suppose that we have connected to the metal backing, as seen in Fig. 93, a battery and a metal paint-brush, with bristles made of fine wire. What will happen if we pass the tip of the brush over the mosaic, cell by cell ? Touch the cell in the top left-hand corner with the point of the brush ; if it is positively charged, electrons from the battery rush through the wire and the brush to make up the deficiency upon it. The number of electrons flowing is governed by the magnitude of the positive charge ; the greater it is, the larger the number of electrons required to make good the deficiency. A flow of electrons constitutes an electric current. When we touch the positive " plate " of the little condenser with the brush it is discharged by a flow of current.

Now touch other cells of the mosaic one by one with the point of the brush. Each condenser is discharged by a flow of electrons and in every case the amount of current flowing during the discharge depends upon the intensity of the light that reached that particular cell.

If we scan the mosaic with the brush a fluctuating current will flow from the backing plate through the wire, the fluctuations corresponding to the charges of the cells as each is touched and discharged. Minute as they are, such current fluctuations, transformed into fluctuations of voltage, could readily be amplified to the necessary extent and used to modulate the carrier wave of a television transmitter.

But the moving paint-brush, or any mechanical equivalent of it will never do. To scan a line in the maximum time allowable for a high-definition image the brush would have to move outwards and to fly back at speeds far greater than those of a rifle bullet and to stop dead at the end of each movement. A bullet brought up short by an iron plate is smashed to pieces, with an accompanying generation of considerable heat. You can imagine what would happen if the much more rapidly moving brush had to stop short, reverse its direction, stop once more and then restart 10,125 times a second. Still, if the mosaic system is to work, some kind of paint-brush must be found to discharge the vast number of little condensers at the necessary rate. Zworykin found the solution in that same beam of electrons that paints the television images on the screen of the cathode-ray tube of the receiving set.

Fig. 94 shows in much simplified form the working

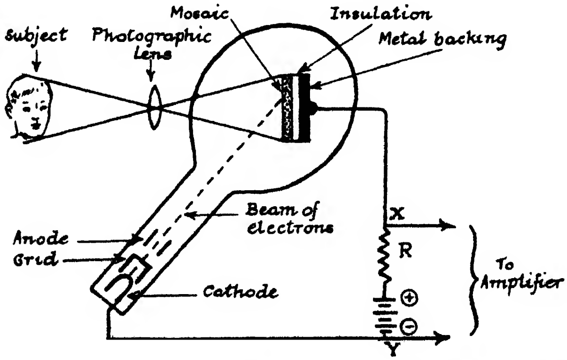


FIG. 94.—Showing in simplified form the action of the emitron.

principle of the iconoscope and its British form, the emitron. The mosaic is mounted inside the bulb of a special form of cathode-ray tube and the electron beam from the gun is projected on to it. By means of a photographic lens the image is focused on to the mosaic, which is scanned by the beam. The focusing and deflecting arrangements are not shown in Fig. 94, but they are quite normal and like those we discussed in our investigations of the receiving C.R.T.

The beam, remember, consists of a throng of electrons; it acts, therefore, in the same way as the hypothetical paint-brush, discharging the cells of the mosaic successively as it makes its scan by supplying electrons to those which have a deficiency of them. The negative pole of the battery seen in the drawing is connected to the grid of the emitron. This battery supplies those electrons which are taken from the beam to discharge the cells of the mosaic.

What is the purpose of the resistor R in Fig. 94? The discharge of each tiny cell of the mosaic consists of a flow of current between the metal backing and the cell in question and that current flows through the resistor. We saw in an earlier chapter that volts drive ampères or (milliampères, or microampères) through ohms. The amount of current that can be driven through a given number of ohms depends upon the volts available. If the number of ohms is fixed and the current is varying, as it is when the cells of the mosaic are discharged one by one, the volts at the point X in the drawing must vary accordingly. If, therefore, we pick up the output of the emitron from points X and Y, we can transfer it to an amplifier as a fluctuating voltage, varying according to the charges of the cells forming the mosaic.

The emitron, then, is a copy of the eye in that the image is recorded on the mosaic just as an image is recorded on the retina of the eye. But that ends the similarity between the two. Messages corresponding to all the picture elements of the image on the retina are transmitted simultaneously to the brain by the immense number of individual fibres of the optic nerve. The messages, however, which correspond to the picture elements of the image on the mosaic are transmitted one by one in regular sequence over a single pair of wires to the amplifier.

One highly desirable effect, by the way, occurs as a direct consequence of the use of the scanning system. Each cell of the mosaic is charged by the emission of electrons whilst light is falling upon it and so long as light reaches the cell the emission continues. The longer a cell is emitting electrons, the greater is the electron deficiency built up. In other words, the longer the time each cell is allowed to continue charging, the higher the voltage to which it charges. In the scanning process each individual element of a picture is scanned once and once only every fiftieth of a second : each cell has nearly one-fiftieth of a second in which to charge up before it is discharged. And that is a long time in television, for it represents more than 19,999 microseconds. The result is that the voltage fluctuations in the output of the emitron are of respectable size and represent good contrasts of light and shade.

The tube, mounted in a metal case containing the lens and other necessary parts, forms the television camera, which is clearly seen in Plate VII. A duplicate lens and a ground glass screen are included, so that the operator has a view-finder enabling him to see all the time what kind of image is being projected on to the mosaic for transmission and to focus it perfectly.

The original emitrons were not very sensitive and could be used only with fast lenses and in a strong light. This shortcoming has been eliminated ; the tubes now in use are so sensitive that any lens suitable for the ciné camera, including the telephoto lens, can be used in the emitron. Ordinary daylight, even on a dull day, gives ample illumination and broadcasts of outdoor scenes with a telephoto lens are now regular features in the television programmes.

The path from the emitron to the transmitting aerial lies through many complicated stages; it is shown in much simplified form in Fig. 95.

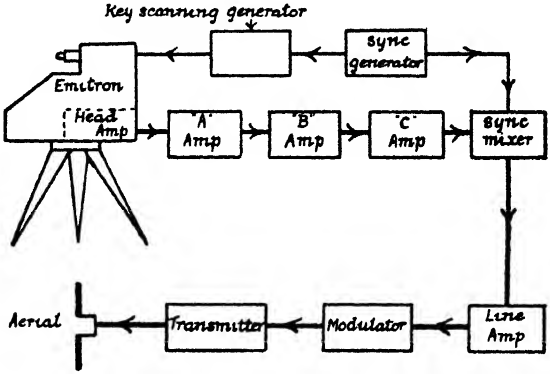


FIG. 95.—The main stages between the emitron and the transmitting aerial.

Built into the emitron itself is the head amplifier, which gives their first magnification to the impulses from the tube. This is followed by three further amplifiers, "A," "B" and "C." The first corrects certain errors in illumination which occur in the emitron; in the second and third the signal is purged of unwanted impulses due to the fly-back of the spot in line and frame sync periods. Further "cleaning up" of the signal is done by the suppression generator and the suppression mixer, which are not shown on the drawing. Not until all interfering impulses have been removed from it does the signal pass to the sync mixer, where the line and frame sync pulses are added to it in their proper places.

These pulses emanate from the sync generator, which is also linked with the key scanning generator. In this way absolute synchronism is ensured between the scanning spot on the mosaic of the emitron and that on the screen of the receiving C.R.T.

The signal is now complete, containing the picture impulses and the line and frame sync pulses. After amplification by the line amplifier it passes to the modulator which impresses it on the carrier generated in the transmitter proper.

In the studio two or more cameras may be used. The producer has before him monitor C.R.T.s showing the vision output of any camera at any instant. He can " fade-out " one camera and " fade-in " another to allow the scene to be projected from different angles and at different distances. " Close-ups," " pans " or " dolly-shots " are all readily possible. Pan is short for panorama and means a slow sweep from side to side by the camera. A dolly-shot is obtained by moving a camera, mounted on a wheeled trolley, towards or away from the scene, so that a distant view gradually changes into a close-up or *vice versa*. The television cameraman can, in fact, do most of the things done by the ciné cameraman in the film studio.

Outside broadcasts of television are done in several different ways. In London a special cable has been laid connecting the Alexandra Palace with various points from which good views of public and sporting events can be obtained. Into this cable the emitron is " tapped " whenever it can conveniently be used.

For events farther afield mobile transmitting equipment is used. This consists of three large vans. The first of these contains a complete control room ; the second, a transmitter, with folding "fire-escape" aerial, which can be raised to a height of 80 feet; the third, a current generating plant, which is used only if suitable main supplies are not available.

The signals sent from the transmitter are received either direct at the Alexandra Palace, or at a receiving station in Highgate from which they go by way of the cable already mentioned to the Alexandra Palace. The reason for the use of indirect reception is that when signals come from certain points of the compass direct reception at the Alexandra Palace is unsatisfactory, and better results are obtained in such cases by the use of the Highgate relay. By whichever route they come in, they are then fed to the main transmitter and broadcast.

CHAPTER XVIII

Colour Television

FOR many years inventors have been striving to find a means of televising images in colour. Colour cinematography came into being some time ago and as television in black and white can do so many of the things done by the ciné camera and projector it seems natural to expect that it should not lag far behind them in the matter of reproducing images in colours. Innumerable patents concerned with colour television have been filed and, though it can hardly be said that any complete solution of the problem has been discovered, there exist today at least two practicable methods of transmitting and receiving images in colour.

Notice that I have avoided saying " in their natural colours." That would imply that every shade of colour in the subject was perfectly reproduced on the ciné screen or that of the television C.R.T. For highly technical reasons, into which it would be out of place to enter here, complete fidelity in the reproduction of colours by methods now used in cinematography and television is not possible. The hues of the average colour-film are nearly as harsh as those of the old chromo-lithograph and the same is true of the television image in colour. But the eye, like the ear, is very accommodating. After the mild shock of the first few moments of a colour film it settles down to accept what is offered to it as no bad imitation of reality ; the imitation is at any rate nearer the truth, and therefore more acceptable, than those in black and white, which are devoid of all colour.

The sensation of colour is produced in a curious and interesting way. What we call white light is in reality a mixture of all the colours. You can see that by passing sunlight through a prism, or, more easily, by looking at a rainbow. The effect of the prism, or of the droplets of water in a cloud, is to sort out the various wave lengths of which sunlight is composed and to present them in an orderly and unvarying sequence, ranging from those of deep red at one end to those of violet at the other.

A sheet of paper appears white because its surface reflects all the rays of visible light ; but many surfaces absorb all kinds of these rays save one. A rose appears red because its petals absorb the rays of all colours except red : it reflects only the red part of the white light falling upon it. Similarly a delphinium is blue because it reflects blue rays and absorbs the rest. If we view the rose through a screen of blue or green glass, it appears black, for the former absorbs all rays but blue ones and the latter all rays but green ones. Similarly the delphinium is seen as a black shape if viewed through a red or a green glass.

Now, if separate black-and-white photographs are made of a bed of roses of various colours through red, blue and green screens the pictures all show the same outlines, but in each of the three there are different gradations of light and shade, corresponding to the kinds of light that the screens have allowed to reach the sensitised film. Suppose that a positive is printed from each of the films and that from each positive a half-tone block is made. The block made from the " red " image is inked red ; that from the " blue " image, blue ; and that from the " green " image green. The three blocks are then used to print a picture, care being taken to superimpose the images so that they exactly coincide with one another. What will the result be ?

Provided that photographer, blockmaker and printer have done their work well, the result is a colour print, showing a pretty good representation of the natural colours of the rose-bed. That is, in fact, the outline of the three-colour process, which is so widely used nowadays.

When the photographs are made the screens break up the picture into tiny elements representing red and green and blue, each in their proper proportions. The elements are re-combined when the print is made by superimposing the three images. From combinations of red, green and blue in their correct proportions approximations to all colours can be obtained, so good that the eye accepts them as satisfying. These three colours can also be made to combine so as to give white.

The first successful attempt at colour television was made by J. L. Baird in the early days of the art when the mechanical scanning disc was still the only known means of transmitting a television image and of reconstituting it in the receiver. At the transmitter Baird used a scanning disc containing three sets of holes arranged as a triple spiral. One set of holes had a red screen, the second a green screen and the third a blue screen. Each image was thus scanned three times.

When a red hole covered a green or a blue element in the image a " black " was transmitted, since there was no reflected light ; a red hole covering a red picture element, however, caused light to be reflected and a " white " was transmitted. Similarly the green and blue scanning holes caused " blacks " to be transmitted for all but green and blue picture elements respectively.

A similar triple scanning disc was used in the receiver. You will remember that in the scanning disc receiver a " white " caused a gas-filled lamp to light up, whilst a black allowed it to remain dark. Suppose that a blue picture element was being transmitted at one instant. When a blue hole in the transmitter scanning-disc was in front of it a " white " was transmitted. The receiver scanning disc was synchronised with that of the transmitter. Hence when this " white " was received the lamp lit up and the eye of the viewer saw a speck of blue through a blue hole in his disc.

The basic principle was perfectly sound. It contained the principle of the high-definition colour television systems of today.

Up to the time of his death in 1946 Baird was engaged in the development of a new and ingenious system of his own, which seems to have considerable promise. It uses a triple iconoscope, the receiver type of which is seen in simplified form in Fig. 96.

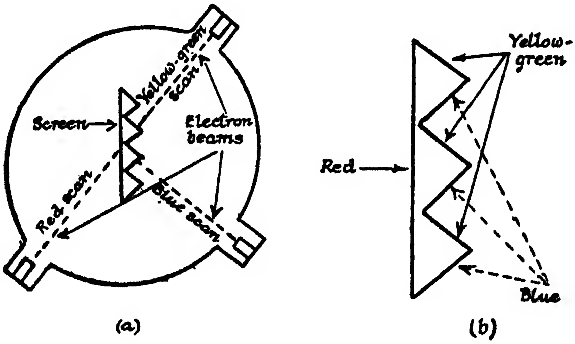


FIG. 96.—The Baird colour system: (a) principle of receiving tube; (b) detail of screen.

Several kinds of chemicals have the property of fluorescence and among them are substances which glow with red, blue or green light under the impact of electron bombardment. The front of the transparent screen, placed in the middle of the tube, is flat and it is lightly coated with a substance which fluoresces red. The back of the screen consists of numbers of tiny corrugations, shown in much exaggerated form in the drawing. The upper face of each corrugation is coated with material which fluoresces yellowish-green ; the lower face of each with material which fluoresces blue.

There are three electron guns, each aimed at one particular fluorescent surface. Three separate scans are made for each frame. During the " red " scan the red picture elements glow on the red surface. The " yellow-green " and " blue " scans cause glows to occur in the appropriate places on the yellow-green and blue surfaces. The whole image is thus built up of three superimposed images and as in three-colour printing, the result is an acceptable reproduction of the original colours.

Amongst the merits of the Baird colour system is that it uses no mechanical parts, but paints its pictures entirely by electric scanning. It is, to the best of my knowledge, the first practical system of colour television in which this has been accomplished.*

A method on entirely different lines has been developed by the Columbia Broadcasting System of America. In the receiver a mechanical device, synchronised with the transmitter, interposes red, blue and green glass "windows" in rapid succession between the eye of the viewer and the screen of an ordinary television C.R.T. The images on the screen of the C.R.T. are in black and white and would convey no impression of colour if viewed direct. Each, however, represents the results of a colour-scan at the transmitter ; they are, in fact, equivalent to the series of black-and-white photographs made through red, blue and green screens for three-colour printing. A red window is in front of the C.R.T. screen when the image resulting from a red transmitter scan is on it ; at this instant the reds of the image are reconstituted. In the same way the

*The Radio Corporation of America has recently provided a system in which scanning is entirely electronic. This system makes use of three separate tubes.

blues are reconstituted by the arrival of a blue window between eye and screen during the scan of the blue image and a green window reconstitutes the greens.

Scanning is rather an elaborate business, triple interlacing being used. The image is built up of 343 lines and each complete image is the product of six scan frames. Here is the complete scan of one image :

No. of Frame	Colour	Lines
1	Red	1—171½
2	Green	171½—343
3	Blue	1—171½
4	Red	171½—343
5	Green	1—171½
6	Blue	171—343

One hundred and twenty frames making 20 complete images are transmitted and received each second. The standard frequency of domestic electric current is 60 c/s in the U.S.A. and as was explained in Chapter VIII, the numbers of frames and images must be multiples or submultiples of this number if undesirable effects are to be avoided. It is stated that there is no noticeable flicker.

All systems of colour television so far evolved suffer from a number of drawbacks, which, though they may not be sufficient to make the picture unacceptable to the eye, must inevitably cause imperfections in the received images. Three of these may be mentioned. First of all three-colour scanning does not reproduce the original colours quite correctly and the slight harshness already mentioned is inevitable. Next, a peculiar difficulty arises when the subject is in rapid motion. Take the case of a single red picture element in line No. 1 of an image at a C.B.S. transmitter. After it has been scanned in red (frame No. 1) $\frac{1}{60}$ second elapses before the blue scan (frame No. 3) reaches it and a further $\frac{1}{60}$ second before the green scan arrives in frame No 5. In those intervals, if the subject is moving rapidly, that particular picture element also moves a little on the transmitter screen. The three scans are therefore not exactly superimposed and on the receiver screen this element is elongated and appears as a red patch with fringes of the other colours. The effect, though not so severe, is like that produced by unskilful colour-printing in which the three blocks are not exactly superimposed.

Thirdly, the fact that three separate scans (red, blue and green) are required to produce every picture element on the receiving screen means that the total available light is only one-third as much as in black-and-white television. You may perhaps find it easier to follow this if you consider the case of a white picture element. The speck of white light which produces such an element is the result of a single scan in black-and-white television. In colour television a white picture element is produced by the mingling of red, blue and green light: three different scans, therefore, are needed in colour television to provide as much light as a single scan of the black-and-white process.

Despite the defects of present systems colour television produces pleasant, realistic effects on the eye. There can be no doubt that rapid progress will be made and that television in colours will one day come into its own. It seems likely, though, that receiving sets for colour must be elaborate and therefore somewhat expensive.

CHAPTER XIX

Big-Screen Television

IF you asked a dozen users or would-be users of television receivers what improvement they most wished to see, the odds are that the majority would plump without hesitation for a bigger viewing screen. It is a little difficult to see why, for the cold, stark fact is that the effect of increasing the size of the screen is that the viewer must sit farther away from it in order to watch comfortably what is going on. Living-rooms in modern homes are limited in their dimensions and the plain truth is that a screen much bigger than 10 inches by 8 inches would be too large for the comfort of viewers in most of them.

A useful rule of thumb for picture size is this : divide the longest side of the image on the C.R.T. screen, measured in inches, by 2 ; the result shows the minimum number of feet at which the image should be viewed. For a 10 × 8 inch picture we have 10 ÷ 2 = 5 feet. That, remember, is the *minimum* distance. If a 10 × 8 inch picture is viewed at under 5 feet the lines become obvious and annoying. The best viewing distance is a little over one and a half times the minimum, say 8 feet.

The screen of the C.R.T. must always be at least two feet from the wall of a room owing to the depth from front to rear of the cabinet of the television receiving set. Hence the chairs of viewers of a 10 × 8 inch picture should be 8 + 2 = 10 feet from the wall against which the set stands. We can further simplify the simple rule of thumb by making it read :—the best viewing distance from the wall against which the set stands is two more feet than there are inches in the shorter sides of the image.

The 10 × 8 inch, or possibly 12½ × 10 inch image is thus about the largest that can comfortably be used in the average living-room, for in comparatively few can viewers conveniently sit more than 10 to 12 feet from the wall against which the set stands. A 20 × 16 inch picture would as a rule be much too large ; the *minimum* viewing distance then becomes 12 feet and the best viewing distance 18 feet from the wall. It is often no easy task to convince people about these things, but they are none the less true !

There is certainly a demand and a big one for television on the grand scale for use in large living-rooms, entertainment halls and cinematograph theatres. Inventors innumerable have attempted to find solutions of the problem ; but it cannot be said with truth that any of them has yet been completely successful. There are two main stumbling blocks, which may be summed up in the words " light " and " lines." Let us consider light first.

The image on the screen of the receiver C.R.T. is painted by a single minute moving spot of light. Were the eye not deceived owing to the phenomenon of persistence of vision, it would see on the screen at any one instant nothing but a single tiny luminous spot. Since persistence of vision exists the brilliance of the whole image depends upon the amount of light produced by the spot at those instants when it is reproducing a pure white picture element and its relative brilliance in reproducing the innumerable shades of grey that compose the whole gamut between dead black and pure white.

What all this comes to is that if we wish to increase the brilliance of the television image, we must increase the brilliance of the C.R.T. spot. The size of the C.R.T. screen is limited, not only by the art of the glass-blower, but also by the fact that within the tube there is a high vacuum. The pressure of the atmosphere on an evacuated glass tube tends to crush its walls inwards. The walls must be strong enough to resist the pressure of the atmosphere and the larger the tube, the more difficult does the problem of making it sufficiently strong become.

At the time of writing the largest C.R.T. suitable for general use has a screen diameter of 15 inches, which means that it can be used for a television image some 12½ inches by 10. It is important to realise that the cost of a C.R.T. goes up by leaps and bounds as its size becomes very large. A small tube with a 3-inch screen is not expensive, since it is quite easily made; but as the screen diameter is increased to 6, 8, 10, 12 or 15 inches the cost of manufacture becomes progressively very much greater. That is one of the reasons why a television receiver providing a small image can be produced so much more cheaply than one giving a larger picture.

From what has been said it will be realised that the largest image that can be produced directly on the screen of a receiving C.R.T. is about 12½ × 10 inches. What means can be found of increasing its size? Why not regard the C.R.T. image as the equivalent of a magic lantern slide and use a lens system which will project it in much enlarged form on to a screen? The answer is that the illumination of the projected image falls off in inverse proportion to its surface area.

Suppose, for instance, that we magnify a 10 × 8 inch image on the C.R.T. screen to 100 × 80 inches by means of lenses. The original picture area is 10 × 8 = 80 square inches; the magnified image has an area of 100 × 80 = 8,000 square inches. The area of the magnified image is 100 times that of the original and the total illumination is 100 times less. The only solution here is to increase the brilliance of the spot on the C.R.T. screen. This can be done by increasing the voltage on the anodes of the tube and so speeding up the bombarding electrons of the beam. But very high voltages are undesirable in receivers designed for domestic use and they have certain unwanted effects, one of which is to shorten the working life of the C.R.T.

Can we find some means of obtaining adequate illumination in the projected and enlarged image, without using a C.R.T. operating with an undesirably high anode voltage? A good many systems providing possible answers to this question have been suggested. Amongst them is the Scophony system, which makes no use at all of the cathode-ray tube. I am not going to describe it in detail, largely because it employs a form of mechanical scanning and, rightly or wrongly, I regard mechanical scanning as belonging to the past rather than to the future of television. At the same time, however, it must be admitted that the Scophony process has obtained results in the matter of big-screen television which are probably superior to those of any other method now in use. I have seen whole programmes from the Alexandra Palace reproduced on a screen measuring some 10 feet by 8 and clearly visible to every member of an audience of several hundred people in a large hall. I freely admit, therefore, that I may be wrong in holding such views about mechanical systems. Still, as the mythical Scots ghillie said to the phenomenally successful Southron fisherman, "Ah agree ye've catchit sahmon when nae ither body could; but Ah'm nae juist conveencit that yer preenciples are sound!"

The essence of the Scophony system is a most ingenious method of making the light of a single picture element endure many times as long as it does when produced on the screen of a C.R.T. The result is that the illumination of the received image can be far more brilliant by the Scophony method than by the use of a cathode-ray tube. Owing to the greater amount of illumination available the image can be projected with full brilliance on to a large screen.

Another suggested method makes use of a special form of C.R.T., known as the Skiatron. The Skiatron looks very much like the normal C.R.T., and its screen is scanned and painted by the spot in the normal way. But the image on the screen has very little illumination of its own. The screen is coated with a substance which, when it fluoresces under the bombardment of the electron beam, does not produce much direct light, but becomes capable of reflecting strongly light thrown upon it from an outside source. Fig. 97 indicates the way in which the Skiatron

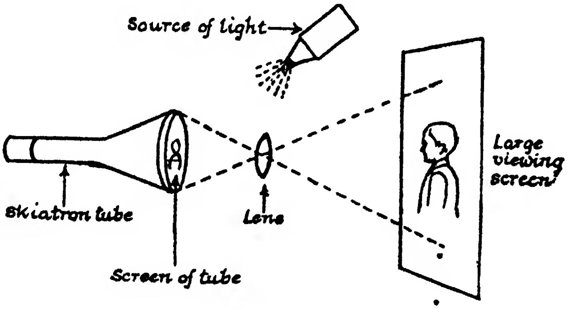


FIG. 97.—Diagrammatic representation of the skiatron principle.

can be used for providing a large image. Light from a powerful source is centred on the screen and is reflected in various degrees, according to the whites, blacks and greys of the picture elements, by the image formed there. The reflected light is focused by a lens system and projects a much enlarged image on to a screen. The point to note about this system is that the amount of light available depends not on the brilliance of the C.R.T. image, but on the intensity of the outside lighting source.

The Skiatron was developed during the war for enlarging the images on the P.P.I. (Plan Position Indicator) tubes of radar sets, for which purpose it was most useful. In its present form it does not provide a complete answer to the problem of obtaining big-screen television images. The principle, however, opens a wide field for research and may lead to important developments.

Another possible method of overcoming the light difficulty may be described as the converse of the intermediate film method, outlined in Chapter V. Here, the image on the screen of the receiver C.R.T. is photographed by a ciné camera. The film is developed and fixed by the same ultra-rapid methods and then passes whilst still wet through a ciné projector. The delay is 30 seconds or less and the illumination depends only upon the amount of light available in the projector.

So far we have discussed only the light problem ; there remains that of lines. Suppose that a perfect means is found of projecting the received picture on to a screen measuring, say, 10 feet by 8. There are 120 inches in 10 feet and by our first rule of thumb the *minimum* viewing distance for such an image is 60 feet. The most desirable distance is one and a half times that, or 90 feet. In other words, only those in the back seats of the largest ciné theatres would see such an image really well. What would mar the enjoyment of those sitting farther forward ?

Each image, you will recall, is built up of 377 active horizontal scanning lines. The depth of the picture on the screen is 8 feet, or 96 inches. It follows that each line of the scan is about a quarter of an inch wide on the screen. At a viewing distance of less than 60 feet the lines in this case are obvious and annoying.

Clearly, if we want images from television large enough to be thrown on the ciné screen in such a way as to be pleasing to the entire audience, the width of the lines must be reduced. And that means using more lines to build up the image.

Realising that in the future television will have a big part to play in the ciné theatre, the Television Commission wisely decided that the next goal of intensive research and development must be the realisation of 1,000-line transmission and reception. This will be achieved without a doubt, though there is many a Beecher's Brook confronting starters in the Grand National Television Research Stakes !

To mention but one or two of the difficulties that have to be overcome, there is first of all the problem of the size of the scanning spot. We saw in an earlier chapter that if definition is to be good, the diameter of the spot on the C.R.T. screen must not exceed the width of one scanning line. To effect the necessary reduction in the size of the spot is a difficult business technically, though doubtless success will be achieved in this direction.

Imagine the problem of spot-size solved ; is the finishing straight in sight? It is not, for there are many more stiff fences to be tackled. A 1,000-line scan means that there are $1{,}000 \times 1{,}000 \times \frac{5}{4} = 1{,}250{,}000$ picture elements per image. At 25 complete images a second that means modulation frequencies ranging up to over 30 Mc/s and such enormous frequencies present some pretty problems to the designers of transmitting and receiving sets.

All such difficulties will certainly be solved in time and big-screen television with high-quality images will become a reality. But much water may pass beneath the bridges before this happens.

CHAPTER XX

Looking Ahead

VERY wisely, the Television Commission decided to standardise the present British system of 405-line, 50 frames per second, interlaced television transmissions. The Alexandra Palace station, using this system and serving an area containing nearly one-third of our population, is at work again after its wartime eclipse. Thousands of people own television receivers suitable for dealing with these transmissions. It would have been unfair to these to make any radical change, unless such a change could bring about immediate outstanding improvements in the home reception of the television broadcasts and the evidence given before the commission showed that nothing of the kind could be expected.

Admittedly, 405-line images did not represent the highest possible attainment of television, even in the state of development reached when the war was over ; but a 405-line transmitter was in being, others could be erected with no great delay and manufacturers were ready to produce a reasonable supply of 405-line receivers in a comparatively short time. It was therefore decided that the 405-line service from the Alexandra Palace should be restarted at the earliest possible moment and that a chain of transmitters should be erected so as to extend the service to the greater part of this country. At the same time the existence of a demand for higher-definition television, suitable for big-screen reproduction, and the desirability of satisfying it were recognised. It was therefore laid down that intensive research should be directed to the development of a 1,000-line system and that in due course such a system should come into being. But (and this is important) it was decided that the 405-line system should continue to be used side by side with the 1,000-line system for some years after the latter had become a reality.

Those who now buy television receivers are thus completely protected ; not for many years will their apparatus be rendered obsolete by the closing down of the 405-line transmissions.

There are some who feel that if 1,000-line television is in the offing, it may be no bad thing to wait for it. The answer to them is twofold : in the first place it will be some little time before any such system can come into action, for, as we saw in the previous chapter, there are many thorny problems to be solved ; secondly it can be said emphatically that if the receiver does them full justice, the present 405-line transmissions give images with all the detail that can usefully be employed in home reproduction.

Not a few of the lower-priced receivers on the market in pre-war days left a great deal to be desired. The definition of some of them, in fact, was barely up to 200-line standards. It is hardly fair to judge the possibilities of 405-line television with the aid of a receiver which is only about 50 per cent efficient in reproducing on its screen what is sent out from the studio ! The difference between the images given from the same transmission by good and indifferent receivers can be quite startling.

For some time to come, then, our main television service is certain to be provided by transmissions of the same kind as those now in use. Technical improvements in these transmissions will undoubtedly be made as time goes on ; but they will usually be of such kinds that the good receiver will respond to them either without any alteration at all, or after minor and inexpensive modifications.

What are we to expect of television in the future? Within ten years we should have a country-wide 405-line service and before that time a start may well have been made with the 1,000-line transmitters. Developments cannot be very rapid, for, even if all outstanding problems were solved tomorrow, the necessary transmitting gear cannot be designed, made and erected in a moment. Big-screen television, colour television and stereoscopic television, with images in relief, will all certainly come; but some years must inevitably elapse before we see the results in our homes.

It is interesting to speculate whether after all the years that have passed since Nipkow devised the first scanning disc, we are now on the right road in television. Some of man's great inventions are born so complete that they stand the test of time. Improvements are made in them, but they are improvements of details and the basic principle endures. The electric lamp of today, with its filament glowing in an evacuated glass bulb, is fundamentally the same as the original electric lamp of Edison and Swan; the telephones we use now differ only in detail from the instruments first produced by Bell; the modern camera works on the same principle as the camera of Daguerre.

Is television using the iconoscope and the cathode-ray tube another such discovery? Or shall we find one day that these no more provide the right road than did the mechanical scanning disc! It is impossible to say. I cannot, though, help feeling that the fundamental imperfections of television methods involving any kind of scanning will one day inspire some genius to work out something on entirely different lines.

Good as the results are that we achieve by scanning methods, one cannot feel satisfied that it should take $\frac{1}{25}$ second (40,000 microseconds!) to reconstitute on the C.R.T. screen an image whose every part comes in reality into existence at the same instant. We have seen how this must lead to " fringes " in colour television ; even in black-and-white television a fast-moving subject may make an appreciable change of position between the moment when the scanning spot starts the first line of the C.R.T. image and that when it finished the four hundred and fifth. The television engineer plays up to persistence of vision for all he is worth—but the eye is not always completely deceived.

The problem of inventing a method of transmitting instantaneous images without scanning appears to present insuperable difficulties ; but genius has in the past found ways of making the impossible possible and it will no doubt continue to do so in the future.

Index

(*a*)
(*b*)
(*c*)
(*d*)

How the cinematograph deceives the eye.

(*See page* 34.)

PLATE I.

An original photograph (*a*) as transmitted from London and (*b*) reproduction received in Bombay at a distance of 5,000 miles by radio (*See page* 57)

PLATE II.

(1)

80 screen

(2)

100 screen

(3)

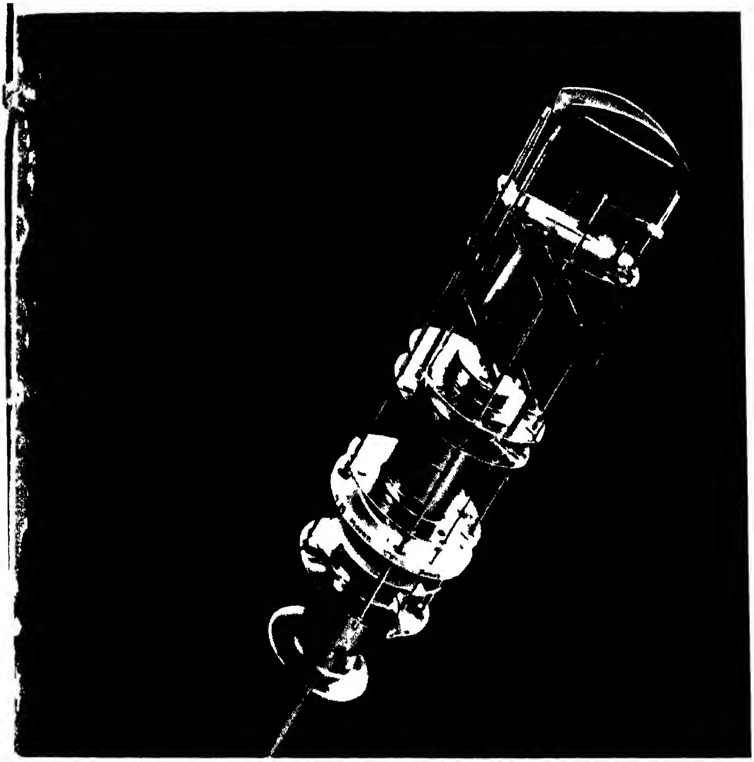
200 screen.

The definition of a printed illustration depends upon the fineness of the screen employed (*See page* 66.)

PLATE III.

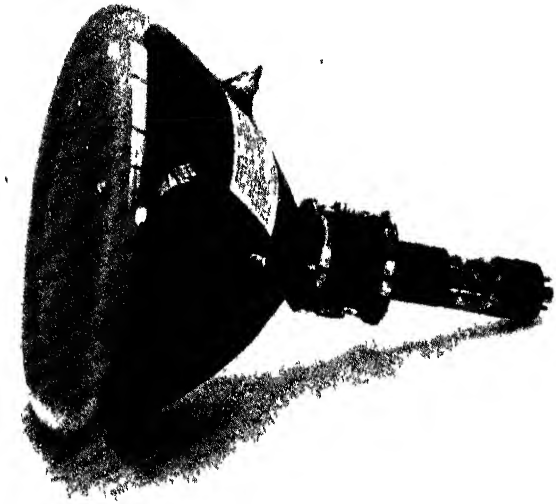
The largest cathode-ray tube made, 17 in screen (*Photo: Electronic Tubes, Ltd*)

PLATE IV



Inner construction of electrostatically controlled C.R.T.
(*Photo : Electronic Tubes, Ltd.*)

PLATE



Magnetically controlled cathode-ray tube showing deflector coils.
(Photo Ferranti, Ltd)

PLATE VI

The B B C Emitron camera in use
(*Photo* *B B C*)

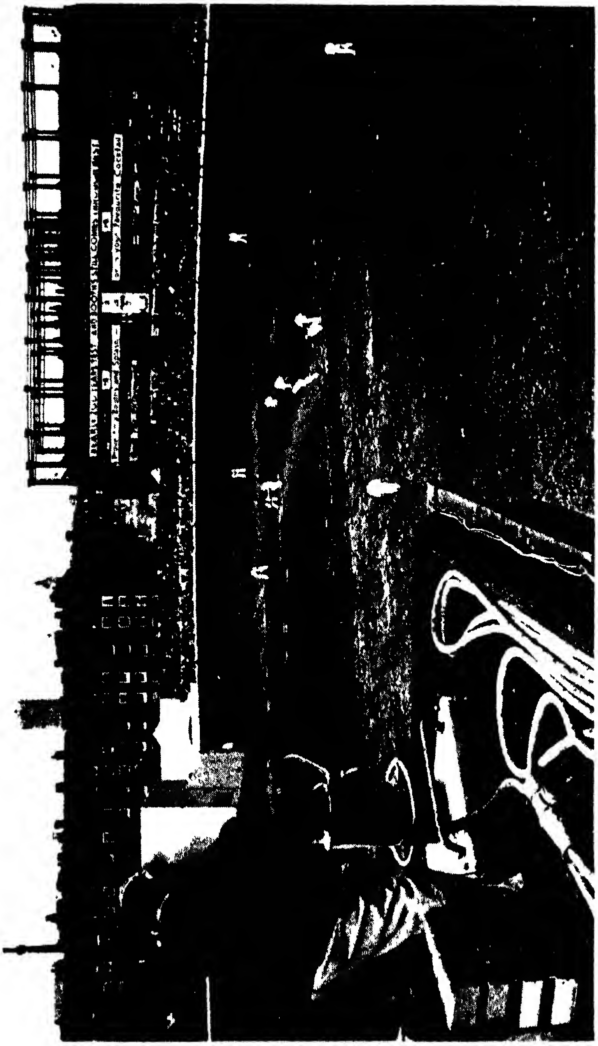
PLATI

Outside broadcast television van with " fire-escape " aerial ladder.
(*Photo : B.B.C.*)

PLATE VIII.

An unretouched photograph of the image on the screen of a television receiver
(*Photo B B C*

PLATE IX



Televising a cricket match with an emitron camera.

PLATE X.

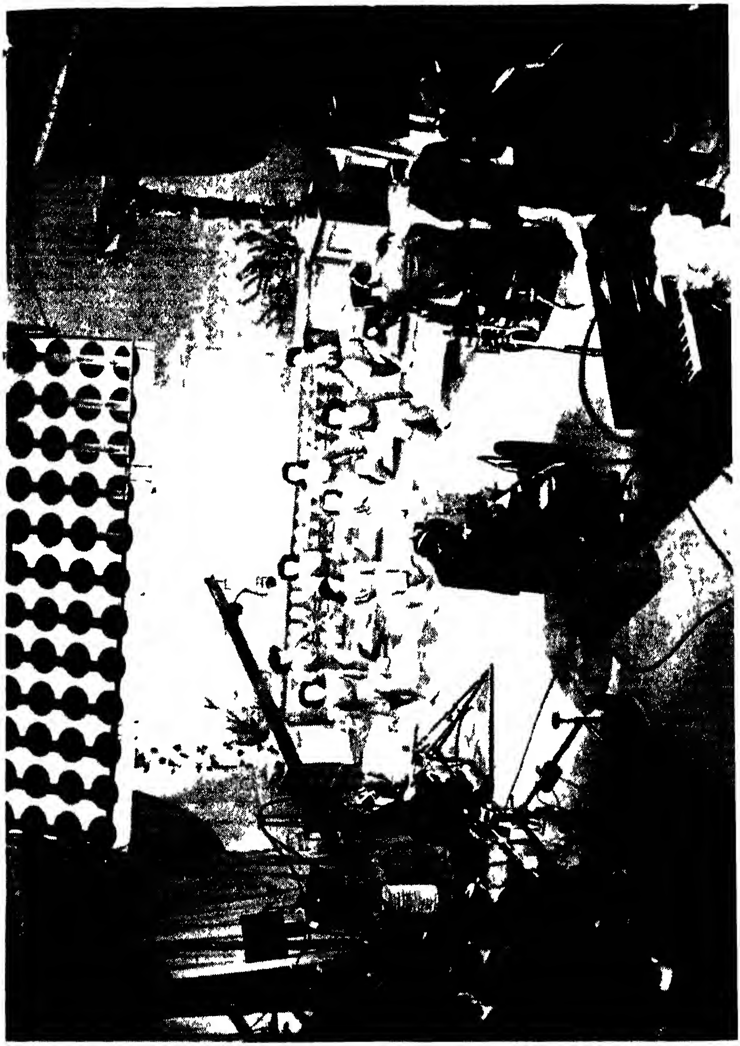
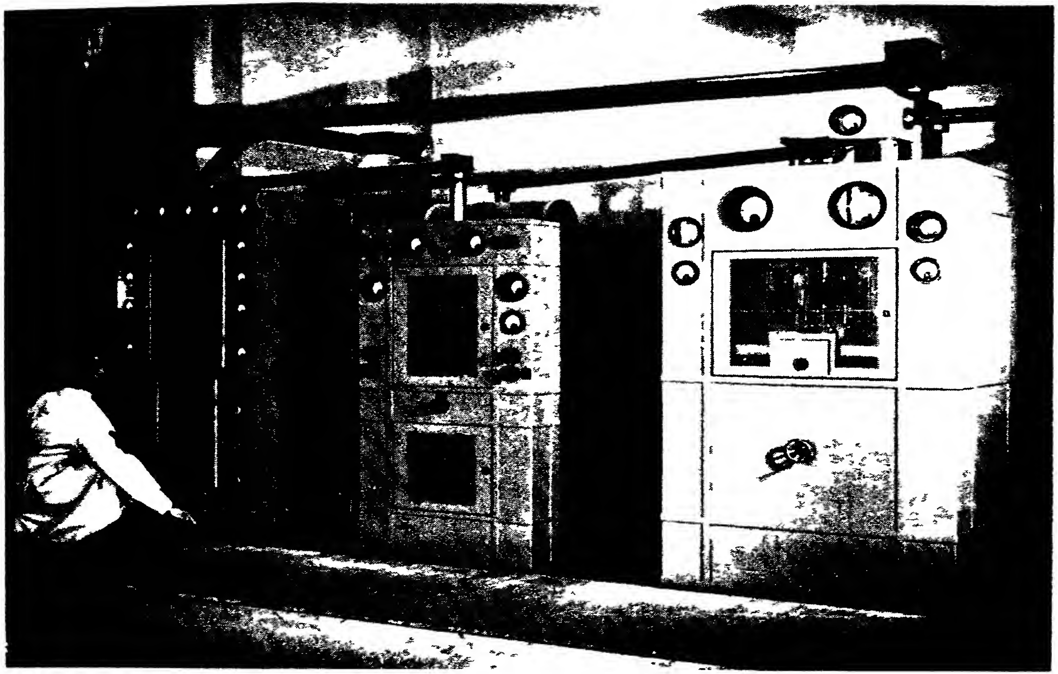


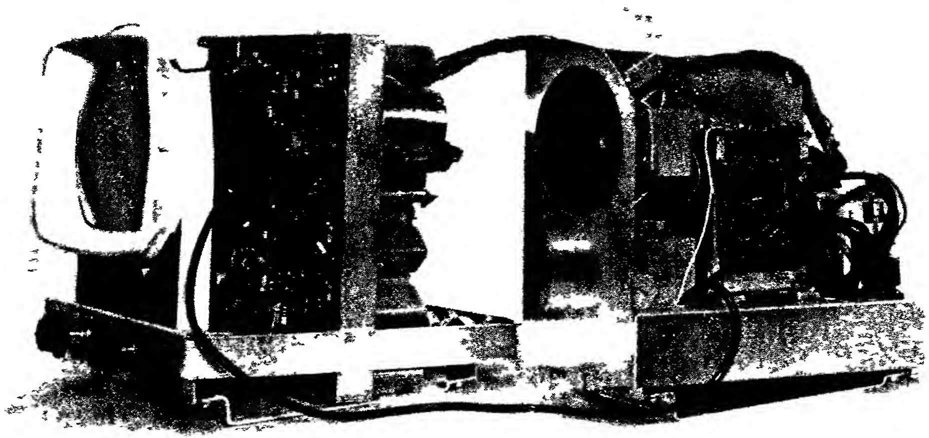
PLATE XI

LATE XII.



The high-frequency stages of the Marconi E M I transmitter at the Alexandria Palace Television Station
(Photo B B C

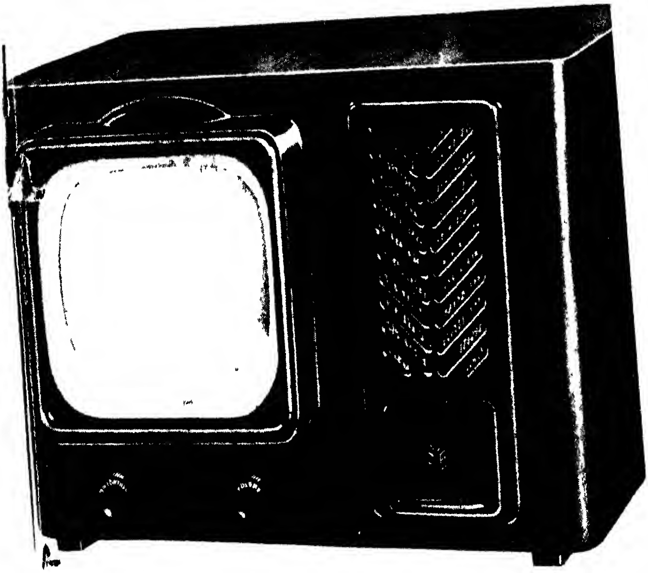
PLATE XIII



Chassis of complete television receiver

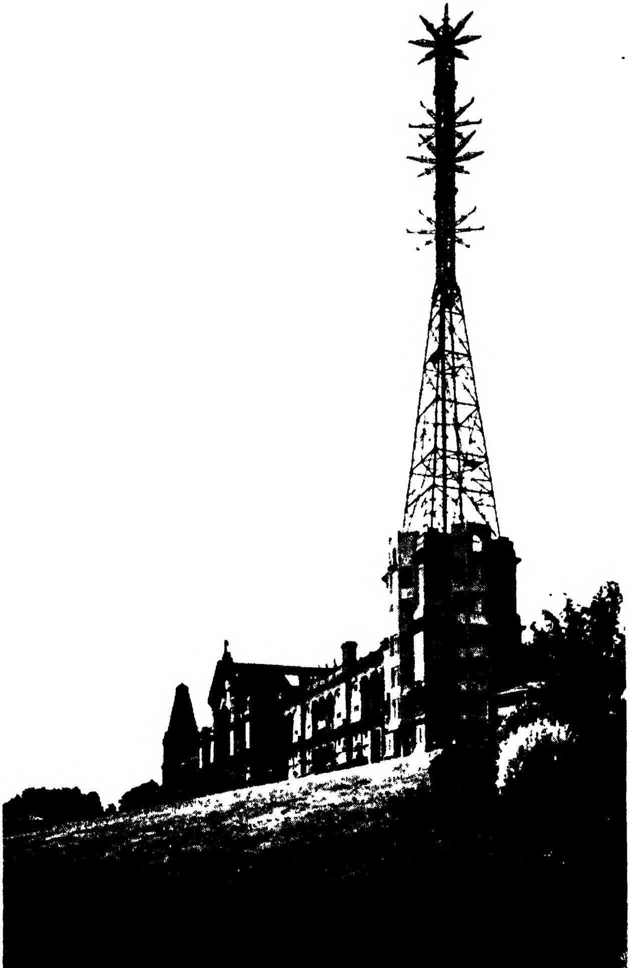
Television receiver. Console model.
(*Photo : Pye Radio, Ltd.*)

PLATE XIV.



Television receiver. Table model.
(Photo: Pye Radio, Ltd.)

PLATE X



Vision and sound aerials, Alexandra Palace.
(*Photo : B.B.C.*)

PLATE XVI