BBC

ENGINEERING DIVISION

MONOGRAPH

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Twenty-five years of BBC Television

by

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(Director of Engineering, British Broadcasting Corporation)

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BRITISH BROADCASTING CORPORATION

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FOREWORD

This is one of a series of Engineering Monographs published by the British Broadcasting Corporation. About six are produced every year, each dealing with a technical subject within the field of television and sound broadcasting. Each Monograph describes work that has been done by the Engineering Division of the BBC and includes, where appropriate, a survey of earlier work on the same subject. From time to time the series may include selected reprints of articles by BBC authors that have appeared in technical journals. Papers dealing with general engineering developments in broadcasting may also be included occasionally.

This series should be of interest and value to engineers engaged in the fields of broadcasting and of telecommunications generally.

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TWENTY-FIVE YEARS OF BBC TELEVISION

SUMMARY

After a survey of the events and developments which led to the start of the BBC's high-definition television service, this monograph is a narration of the main engineering developments during the twenty-five years since the service started. Particular attention is paid to those techniques which have been originated by the BBC, or which are utilized in a specially noteworthy manner in the BBC service. There is also a brief review of the BBC's contributions to probable future developments, including colour television and a change of standards.

1. Introduction

The first regular public service of high-definition television in the world was started by the BBC on 2 November 1936. Since then BBC television has grown from a pioneer venture with a small staff of enthusiasts, a handful of viewers, and an uncertain future, to a nation-wide service providing fifty-five hours of programmes each week and reaching $11\frac{1}{2}$ million homes. Yet the basic technical principles on which the service was founded are still valid and have proved capable of development to meet the complex needs of today.

By starting a public television service, using alternative systems that had been developed by the industry, the BBC played a major part in the birth of what has now become a social force in more than sixty countries, an important source of information, education, and entertainment, a generous patron of the arts, and a substantial branch of industry. The BBC itself has initiated, or been associated with, many of the far-reaching developments that have since been adopted all over the world and has carried out a great deal of experimental work on which these and other advances have been based. Its standards of technical quality have been widely followed and acclaimed, and many of its specifications have not only provided exacting standards of performance for British manufacturers, but have also been adopted by manufacturers and television broadcasting organizations in other countries. Other television services coming later into the field have been able to profit by the BBC's experience.

Three factors have provided a setting favourable to progress in this field:

1. The BBC has been able to draw on its long experience of sound broadcasting and on the engineering organization that had been built up over the years before the advent of television. The Engineering Division of the BBC provides engineering services for the whole of the BBC's output and much of the activity of its specialist departments is common to both the television service and the sound broadcasting services.
2. Both the operating departments and the specialist departments, which are responsible for new developments and for new installations, work in close touch with the programme departments, which are themselves constantly striving to extend the scope of television programmes and to improve their methods of production and presentation. Thus the technical developments are closely related to current and future needs and are able to fulfil, and sometimes to anticipate, them.
3. The Engineering Division of the BBC is in close touch with the industry, with the General Post Office, and with the international organizations concerned with the development of television on the technical side.

The purpose of this monograph is to describe some of the advances in television engineering that have been based on experimental work carried out by the BBC over the last twenty-five years and on the extensive operational experience that it has acquired during this period—a period which, except for the war years, has been one of continuous and sometimes spectacular progress. Like the BBC itself, the monograph also looks to the future and examines some of the complex problems that are now in process of solution.

2. Early History

2.1 *The First Real Television Service*

It is important to understand exactly why the BBC high-definition service was unique when it started, as there have been a great many misconceptions. In the first place, the transmissions were of *programmes*, in the broadcasting sense (not merely *tests*), and were in accordance with a published schedule. High-definition pictures had been demonstrated before 1936 but the transmissions had always been on a closed-circuit or experimental basis. Secondly, the picture definition was good enough to enable the viewer to become interested in the programme, without making allowances for the medium. Other countries besides Britain had previously operated regular low-definition services, but it had become clear, well before 1936, that such transmissions could not sustain the viewer's interest after the initial novelty appeal had worn off, no matter how astutely the programmes were planned to keep within the limitations of the low picture detail. Finally, the service coincided with the marketing of receivers at prices which a reasonable proportion of householders could afford. It might seem that this part of the launching of a television service could be taken for granted, but one European country was radiating transmissions of entertainment value before receivers became generally available to the public for use in the home.

The main credit for the development and production of the equipment used in the 1936 BBC transmissions is due to the radio industry. Although television engineering had by that time reached an advanced stage in several other countries besides Britain, it is noteworthy that it was the BBC system of broadcasting which made it possible to launch the first practical television service without having to insist that it should be financially self-supporting* soon after its inception. By introducing experimental transmissions and later a public service at its own expense,† the BBC gave encouragement to the industry to develop complete television systems before any other country had done so.

2.2 *Early BBC Television Transmissions*

Several times during the year 1926 the 2LO 2-kW medium-wave transmitter in Oxford Street radiated pictures experimentally from John Logie Baird's[1] laboratory in Frith Street, Soho. Thirty scanning lines were used, with five picture repetitions per second. In common with all television experiments at this time and for some years later, mechanical scanning systems were used at both the transmitting and receiving ends. Although all the fundamentals of an electronic transmitting and receiving system were put forward by A. A. Campbell-Swinton in his famous letter to *Nature* as far back as June 1908,[2] no practical realization of his proposals was attempted until the early 'thirties.

The first regular BBC transmission started on 30 September 1929, when the 2LO transmitter began radiating pictures from the Baird Company studio in Long Acre. The number of lines was still thirty but the picture repetition frequency was stepped up to twelve and a half. When the Brookmans Park high-power medium-wave Regional transmitter came into service on 21 October 1929, the Baird television transmissions were regularly radiated from this station. Prior to 14 April 1930, there was no sound accompaniment to these transmissions but from this date the newly opened National transmitter at Brookmans Park radiated a sound signal. In 1932 the BBC took over responsibility for the origination of the programmes, and a mechanical flying-spot scanner was installed in Studio BB in the sub-basement of Broadcasting House, while the sound was now radiated from the Midland Regional transmitter. The scanner was later moved to a new studio in 16 Portland Place. Transmissions from this studio continued until 11 September 1935, but in the meantime much progress had been made towards the establishment of a high-definition service.

2.3 *Divergence of Engineering Opinion*

During the late 'twenties, engineers and scientists of considerable standing were hotly debating the fundamental requirements of a practical television system in both the national and technical press. Some writers, including Campbell-Swinton, correctly reasoned that a bandwidth of several megacycles would be needed to transmit a picture of acceptable definition and recurrence frequency. In a most interesting letter to *The Times* of 27 August 1928 C. R. Cosens presupposed a 1-ft square picture with the same definition as a *Times* photograph, repeated sixteen times per second, and showed that this would need a 3·5 Mc/s bandwidth. He pointed out that this would mean a wavelength of 8 or 9 m, and went on to say that such wavelengths were '. . . *at present at any rate*, a job for the expert'. From this he concluded that 'really satisfactory' television was out of the question. This particular writer was one of those who assessed the fundamental problem correctly, even though he did not foresee that domestic reception of very short wavelengths would soon become practicable.

There was, however, another group[1,3] who were misled by the fact that the scanning process takes place line by line rather than dot by dot. They failed to realize that the transmission channel must have sufficient bandwidth to enable the scanning spot to change from black to white in the time taken to scan one picture element, even though the picture is not actually formed, like a half-tone print, from separate dots. This school of thought went on to argue that a high-definition picture could be displayed with a bandwidth only slightly greater than the line-scanning frequency.

Some of the adherents to this line of thought were of high academic standing, and it is understandable that Baird himself, who had no pretensions to any deep scientific knowledge, should have accepted their ideas as justification for his reluctance to break faith with the mechanical systems on which he had already put in so much work. Baird was ahead of others in his ability to foresee the potentialities of television broadcasting, but he failed to develop a practical system, which would have real entertainment value and justify public support.

2.4 *Origins of the High-definition Service*

Although the 30-line transmissions continued until 1935, both the BBC and the industry realized well before

* First Television Licence introduced 1.6.46.

† 1936–39: 10s. 'Wireless Licence' covered the reception of BBC Television without additional charge.
1 June 1946: 'Combined' Licence introduced, £2.
1 June 1954: 'Combined' Licence fee raised to £3.
1 August 1957: 'Combined' Licence fee raised to £4 (by introduction of Treasury Levy of £1).

Financial year ended 31.3.60.		£	£
Gross licence revenue (Television) ..			21,149,216
Less:			
Post Office fees for collection and interference tracing service		1,394,798	
Treasury Retention		1,478,008	
		2,872,806	2,872,806
Income to Television Service from P.M.G.			18,276,410
Other income, publications, interest, etc...			588,920
			18,865,330
Expenditure (Revenue):	£		£
Programmes	8,194,751		
Engineering	5,021,084		
Other	2,600,069		
	15,815,904		
Depreciation	911,535		
Income Tax	720,000		
Total Revenue expenditure	17,447,439		17,447,439
Balance available for Capital Expenditure ..			1,417,891
Net capital expenditure			1,790,147
Amount drawn from reserves to balance ..			372,256

this date that only a high-definition system transmitted on a very short wavelength had any real future.

In 1931 the E.M.I. Research Department, in which Isaac Shoenberg headed a team which included A. D. Blumlein, C. O. Browne, and J.D.McGee, began tests with a 120-line mirror drum scanner, and asked Marconi's Wireless Telegraph Co. Ltd, with their great experience of radio equipment, to develop a 400-W transmitter working on 44 Mc/s, with a 500-kc/s bandwidth. In that year, Shoenberg also initiated the development of high-vacuum viewing tubes suitable for mass production, in place of the gas-focused oscilloscope tubes which were the only types available up to that time.

The transmitter and its aerial were delivered by Marconi's in January 1932. This project and the subsequent development of other wide-band v.h.f. transmitters were handled by N. E. Davis of Marconi's. This firm had taken out a patent for an iconoscope type of television camera in 1930* but had not done any development work directly related to high-definition television prior to 1931. They had, however, done much development of facsimile transmission systems, as a result of which they were able to stress the importance of retaining the d.c. component in the transmitted signal—a realization which has since become universal though not universally observed. A 180-line system was brought into use by E.M.I. in 1932, and was demonstrated to the BBC in December of that year.

During 1933 the Baird Company began the development of a 120-line mechanical system. In August of that year a transmitter working on 37·5 Mc/s, and built by Marconi's, was installed at Broadcasting House, London, and in October the BBC announced in *World Radio*[4] that it would shortly carry out tests of both Baird and E.M.I. equipment with this transmitter. After Sir John Reith (now Lord Reith) and others had seen these tests, the development of high-definition television gained a new impetus.

In 1934, Baird began developing a 240-line system with sequential scanning, while E.M.I. having realized that flicker in a 25-frame sequential system would become increasingly objectionable as viewing-tube brilliance increased, turned their attention to interlaced systems.† In June 1934 they successfully operated a 180-line‡ interlaced system, and by the end of the year they had achieved a 243-line interlaced picture.

Concurrently with these technical developments, the Postmaster General appointed the Television Committee in May 1934, and the Marconi–E.M.I. Television Company was formed in the same month. This company was registered with the object of pooling the resources of Marconi's Wireless Telegraph Co. Ltd and Electric and Musical Industries Ltd in developing a complete television system. M.W.T. was to be responsible for the development and design of the transmitting plant, including aerial arrays, while E.M.I. provided the television modulating and studio equipment.

Other television systems, which were under development at this time, are of interest although they were not ultimately adopted. Bedford and Puckle[5] were working for the Cossor Company on a velocity-modulation system. It was hoped that this would sidestep the difficulty of intensity-modulating a gas-focused tube, but it was found that adequate contrast ratio could be obtained only by the addition of a degree of intensity modulation. Furthermore the scanning of the scene had to be performed with a velocity-modulated flying spot derived from a cathode-ray tube, and this limited the subject-matter.

The system developed by Scophony Ltd[6] was essentially a mechanical/optical receiving system in which a form of light storage was used to display about 200 picture elements simultaneously, with a corresponding gain in brilliance over a scanning spot which could only display one picture element at a time. Ingenious though the system was, it could not compete with the relative simplicity of direct-viewing or projection cathode-ray tubes.

2.5 *Recommendations of the Television Committee*[7]

The report of the Television Committee, which was issued in January 1935, made the following recommendations:

(*a*) that a high-definition public service should be established at an early date and that VHF transmission should be used,

(*b*) that the BBC should be responsible for television as for sound broadcasting,

(*c*) that a standing Advisory Committee approved by the Postmaster General should be formed,

(*d*) that the first station should be in London and that the makers of the two selected systems, Baird and Marconi–E.M.I., should each supply their own apparatus for alternative operation,

(*e*) that the cost should be borne by the revenue obtained from the existing 10s. licence fee.

In February 1935, Shoenberg proposed an all-electronic 405-line interlaced system, using an Emitron type of iconoscope camera. The boldness of this proposal can be appreciated when it is realized that at that time many of the techniques that are now taken for granted were not available; cathode-ray oscilloscopes were rare and no transmitters, feeders, or aerials had been produced with the necessary bandwidth or power-handling capacity, pulse techniques were unknown, and it was uncertain whether a 405-line picture could be produced.

Such a system was nevertheless demonstrated to the Technical Sub-Committee of the Television Advisory Committee on 1 April 1935.

2.6 *Recommendations of the Television Advisory Committee*

The Advisory Committee recommended that the studios and transmitters should be at Alexandra Palace and that Baird Television Ltd and the Marconi–E.M.I. Television Co. Ltd should be invited to tender for the supply

* British patent No. 369,832; 17 July 1930.

† Ballard–Marconi's Wireless Telegraph Co. Ltd. Brit.Pat.Spec. No. 420,391. July 1932.

‡ Although an electronic interlaced scanning system must normally have an odd number of lines, a mechanical interlaced system can quite simply be made to work with an even number of lines.

of apparatus for their respective systems. Transmissions on wavelengths of approximately 6·7 m for vision and 7·2 m for sound (i.e. 45·0 and 41·5 Mc/s) were to be used and the standards of picture transmission proposed by the two companies were accepted, namely:

(*a*) Baird System: 240 lines, 25 pictures per second, sequential scanning.

(*b*) Marconi–E.M.I. System: 405 lines, 25 pictures per second with interlaced scanning giving 50 fields per second.

A VHF sound transmitter manufactured by Marconi's Wireless Telegraph Co. Ltd was provided by the BBC for use with either system.

2.7 *Start of the High-definition Service*

The first programmes from Alexandra Palace on both systems were transmitted during the period of the Radio Exhibition at Olympia, between 26 August and 5 September 1936. A period of 'trial' programmes followed, and the television service was formally opened by the Postmaster General on 2 November.

It was soon found that the use of two standards of definition involved many disadvantages, and that the use of twenty-five frames sequentially scanned produced excessive flicker.

In consequence, the Television Advisory Committee decided that the transmissions should be continued on the 405-line standard alone, and this was put into effect on 6 February 1937.

2.8 *The Coronation Broadcast*

The BBC decided to attempt a broadcast of the Coronation, on 12 May 1937, as its first live television outside broadcast. There had previously been transmissions of outdoor events in the vicinity of Alexandra Palace but these were not outside broadcasts in the true sense, as they relied on a 1,000-ft extension of the camera cable from the Alexandra Palace Control Room.

E.M.I. installed all the apparatus to operate three Emitron cameras and six microphones in a large van, and in the meantime they had developed, and the Post Office had laid down, a balanced-pair cable network to transmit vision signals from various points in Central London to Alexandra Palace. This network is still in use.

The three cameras were set up near Hyde Park Corner, and although the weather was very dull on Coronation Day, they had just enough sensitivity to make the broadcast a success.

2.9 *Transmission of Vision Signals through Telephone Cables*

During 1937, BBC engineers made an important contribution to the development of television. This was the technique for equalizing ordinary telephone cables to enable vision signals to be passed through them over limited distances, in order to link up with the nearest available point on the balanced-pair network. The technique is still used for linking to the much larger permanent network now available. The loss at 3 Mc/s before equalization, when using this system, must not normally exceed 66 dB, and this determines the maximum possible distance, which varies—according to the type of telephone cables in use—from three-quarters of a mile to two miles.

2.10 *O.B. Developments after the Coronation*

Before the war the BBC purchased two mobile radio transmitters for relaying vision signals from outside broadcasts to Alexandra Palace. These worked at about 64 Mc/s with a peak power of 1 kW and had a range of about twenty miles.

Later in the Coronation year, the Super Emitron camera tubes came into use. These were basically image iconoscopes, and as they were four to five times as sensitive as the Emitron, they enabled outside broadcasts to be carried out in more unfavourable conditions. They could be operated with the same control equipment as the Emitron, and were first used publicly at the Armistice Ceremony at the Cenotaph in Whitehall on 11 November 1937.

2.11 *Early Telecine Equipment*

The Baird telecine channels used disk scanners rotating in a vacuum at 6,000 r.p.m.[8] As this was basically a flying-spot system, the picture signals were among the best at that time, but it is doubtful whether this arrangement could have been used for any standard of definition higher than 240 lines.

The original E.M.I. equipment used intermittent-motion film projectors in conjunction with Emitron cameras. The shutter was arranged to expose the mosaic to a stationary image of the film during each field blanking period. Difficulties arose from the fact that the mosaic was not illuminated continuously, and the intermittent projectors were replaced by Mechau projectors, in which continuous projection was achieved by an optical compensator which lap-dissolved the image of each film frame into the image of the next frame.

It was not until after the war, when the twin-lens flying-spot telecine machines were developed, that the quality of 405-line film transmissions became comparable with the best live camera pictures.

2.12 *Closing of the Service*

Although the number of receivers in use by the summer of 1939 was only about 23,000, there is reason to believe that the public response to the new service was on the point of increasing sharply at the very time when transmissions were stopped (on 1 September 1939) because of the imminence of war. Such were the inquiries from both trade and public at the 1939 Radiolympia Exhibition that the number of receivers might well have reached 80,000 by the end of the year if the transmissions could have been continued.

3. The Fundamental Techniques

3.1 *A Universal Prototype*

The original 405-line and 240-line signals were the first to be put to the test of viewing with commercial receivers in unskilled hands. The 240-line system was dropped when its disadvantages had become obvious, but astonishingly few alterations have been made to the 405-line system. If any of the receivers manufactured at that time are still in working order, they should have no difficulty in producing a picture from the present transmissions* in the London area. This is one of many tributes to the genius of Blumlein, Browne, and other engineers who developed the system.

Many of the features of the original 405-line waveform are now an accepted part of every television broadcasting system in the world. Among these are unidirectional constant-velocity scanning, 'infra-black' synchronizing pulses, transmission of the d.c. component of the picture signal, interlaced scanning, and a 70 : 30 picture-to-sync.-pulse ratio. This monograph will refer mainly, however, to those features which were altered as a result of operational experience or which differ in other television systems.

3.2 *Contrast Law Correction*

Blumlein[9] originally assumed that a television picture should have the same tonal gradation as that of the cinema, in which black-and-white prints are produced to an overall gamma value of about 2·5. He realized that the non-linearity in the voltage-to-brightness characteristic of most picture tubes gives an approximation to this gamma value, and he assumed that the camera had a linear light-to-voltage characteristic, from which it followed that the rest of the transmission channel, including both transmitter and receiver, should be linear. Later experience has shown, however, that it is preferable to aim at an overall gamma of unity. This may be due to the different picture size, peak brilliance, and ambient lighting conditions of television viewing, as compared with the cinema. If the overall characteristic is to be linear, the transmitted signal should have a gamma of about 0·4. In practice, it proved necessary to work the original iconoscope cameras well into the 'top bends' of their characteristics, which gave an approximation to the required gamma without any additional correction. Later cameras, which had a linear characteristic, needed external contrast law correction.

3.3 *Double-sideband Modulation*

When the system was being planned in 1935, it was decided that no system of single-sideband modulation would be practicable. Vestigial-sideband working was not considered. As the whole of the band 40·5 to 52·5 Mc/s had been allocated for television, there was no immediate prospect of any other station, and as the range of the transmitter was expected to be about thirty miles only, this decision to avoid the extra complication of any form of sideband suppression seems to have been justified at that time.

3.4 *Positive Picture Modulation*

The present-day practice in most countries is to use negative picture modulation, but the arguments in favour of either polarity remain fairly evenly balanced to this day. Tests conducted by E.M.I. at an early stage showed that positive modulation offered greater freedom from synchronizing troubles in the presence of interference, and this has been confirmed in the course of the recent UHF field trials.[10] Blumlein recognized that the constant amplitude of the tips of the synchronizing pulses, in a negative-modulation system, allowed for a simpler form of a.g.c. but he pointed out that a.g.c. could be readily enough obtained, with positive modulation, by gating the black-level signal which follows the trailing edge of the line-synchronizing pulse. He did not envisage any system so crude as mean-level a.g.c. which is at present widely used, and which completely abolishes the d.c. component in the received picture.

Another argument in favour of starting the service with positive modulation was that the synchronizing pulses would occupy the curved bottom bend of the transmitter modulation characteristic. This simplified the preliminary correction in so far as the curvature would affect the amplitude, but not the shape, of the transmitted synchronizing pulses, and therefore fitted in with the policy of avoiding unnecessary complications.

For colour television, the relative advantages of positive or negative modulation depend on complex factors, to which a considerable amount of study is being devoted.

3.5 *Choice of* 405 *Lines*

At one stage in the development period a 180-line system, sequentially scanned at twenty-five frames per second, was used by E.M.I. As brighter viewing tubes became available, this gave excessive flicker, and during 1934 a change was made to a 243-line system with twenty-five frame interlaced scanning. However, when the Television Advisory Committee was set up in 1935, a 405-line interlaced system was recommended to the committee. It was thought that this would remain stable for a reasonable length of time, and it was stated that 'It is a considered opinion that the present transmitted and received pictures can be considerably improved in detail without exhausting the possibilities of the present system.'[9] The foresight of these early planners is emphasized when one remembers that a 3·5-Mc/s spacing between sound and vision carriers was decided on although the video bandwidth was then thought to be 2·0–2·5 Mc/s.

It may not be generally realized that the maximum horizontal resolutions of a 405-line system with a 3-Mc/s bandwidth, a 525-line (60-field) system with a 4·2-Mc/s bandwidth, and a 625-line system with a 5-Mc/s bandwidth are almost exactly equal. Few, if any, of the live camera tubes now in use can consistently maintain a resolution greater than 405 lines in all parts of the image, and many picture signal sources used in television broadcasting are not even capable of reaching this resolution. In the recent Field Trials[10] the *overall* assessment of a 21-in. 625-line picture with a 5-Mc/s video bandwidth was not significantly different from the overall assessment of a 405-line picture of the same size, although there can be no doubt that the scanning lines are substantially less noticeable in

* This might not, of course, apply to 'upper-sideband-only' sets but it is doubtful whether any of the original commercial receivers were of this type.

the 625-line picture. Again, many television services have no means of handling any film material other than 16-mm, and 16-mm film has a lower maximum resolution than that of a 405-line television image. These are among the facts which justify the original choice of the 405-line system, especially as no standard giving appreciably higher definition had been developed when the BBC Television Service was resumed after the war.

Nevertheless, an increase in the number of lines, with a corresponding increase in video bandwidth, would give an improvement in picture quality, and it is the BBC's view that the 625-line system will, with further improvements in equipment, show a marked superiority over the present 405-line system, especially when viewed on the larger screens.

3.6 *Duration of Blanking Intervals*

A line-blanking period of slightly under 20 per cent of the total line-scanning time was settled soon after Alexandra Palace had come into operation, and a similar percentage has since been adopted by all other television services. This is remarkable in view of the limited practical experience of magnetic scanning circuits at that time.

The field-blanking interval was then fixed at the equivalent of twenty lines. This was largely to suit the telecine machines then in use, in which each picture was projected on to the camera mosaic during the field-blanking interval only. The interval has since been reduced to fourteen lines.

It was originally argued that the field-synchronizing signal should occur more or less in the middle of the field-blanking interval, as receivers did not have shift controls, and this arrangement would tend to keep the picture vertically centred on the viewing tube. Most magnetically deflected receivers were, however, provided with centring adjustments on the scanning yoke, and it was found preferable to make the field blanking and synchronizing start simultaneously, thus allowing the maximum possible time for flyback after the synchronizing signal. This is another feature of the 405-line waveform which differs from other systems, but which is now generally accepted.

3.7 *Choice of Frequencies*[8]

The video bandwidth of the 405-line signal in its original form was assumed to be 2·0 Mc/s. It was thought that the carrier should be at least twenty times the maximum modulation frequency, which implied a vision carrier of not less than 40 Mc/s.

There were no internationally agreed waveband allocations above 30 Mc/s at that time, and the Post Office allocated the band between 40·5 and 52·5 Mc/s (subsequently amended to 41–68 Mc/s by the Atlantic City Convention) for television in the United Kingdom. The newly appointed Television Advisory Committee decided that the London station should radiate vision on 45 Mc/s. In theory, the accompanying sound could have been transmitted on any frequency in the existing long, medium, or short wavebands but these bands were very overcrowded even at that date. Furthermore, the use of a frequency near the vision carrier would simplify the receiving installation, as a single aerial could serve for both sound and vision, and a single local oscillator would serve for both signals. The frequency actually chosen was 41·5 Mc/s, and the resulting separation of 3·5 Mc/s left room for a 3 Mc/s video bandwidth giving a resolution which is barely exceeded by the best of the camera tubes in use at the present time.

3.8 *Type of Sound Modulation*

The prevailing practice in most countries at present is to use frequency modulation for the sound signal, but this method was not out of the experimental stage when the Alexandra Palace station began transmitting. As with positive or negative picture modulation, the relative advantages of amplitude or frequency modulation for television sound are still fairly evenly balanced. The main practical advantage of frequency modulation is that it enables receiver design to be simplified by the use of intercarrier sound, in which the sound signal is extracted from the difference frequency between the sound and vision carriers. Although frequency modulation offers greater resistance to certain types of impulsive interference, this advantage is not as important for television as it is for 'sound-only' broadcasting. In a receiver for the British system, with limiters of average efficiency in both sound and vision circuits, it is almost always the picture which sets the limit to the degree of interference that can be tolerated.

A possible advantage of amplitude modulation, when operating an N.T.S.C.-type colour system, has recently been pointed out. A colour receiver is peculiarly susceptible to pattern interference caused by spurious C.W. signals in the region of the chrominance subcarrier, and a fruitful cause of such interference is the beat (which occurs at about 840 kc/s in the 405-line system) between the sound and chrominance carriers. If the sound is amplitude-modulated, the visibility of the beat may be substantially reduced by arranging that its frequency bears a suitable exact relationship to the line-scanning frequency. This cannot be done with frequency-modulated sound.

Form of the Field-synchronizing Signal

The original specification allowed the field synchronizing signal to have any duration between 3 and 6 line periods, interrupted in such a way as to maintain line synchronization. The BBC fixed the duration at 4 line periods (i.e. eight broad pulses) and this standard is still in use.

The absence of any form of equalizing pulses to facilitate interlace was defended at the start of the service on the ground that this only caused lack of interlace with field synchronizing separators of the integrator type, and that there were, even at that time, numerous other circuits which gave completely accurate interlace without equalizing pulses. This question has been raised again from time to time, but a series of tests, conducted during 1952 in co-operation with the British Radio Equipment Manufacturers' Association, confirmed that there is no general need for equalizing pulses.

3.9 *Development of Cameras*

3.9.1 *Baird 30-line and 240-line Scanners*

BBC engineers and programme staff operated the 30-line studio from August 1932 to September 1935. Crude though the results were, it was during this period that they learned many of the fundamental rules of operational television engineering which still apply today.[11] Among these were the importance of keeping the microphone out of shot, and the effects of camera and lighting angles, although the positions of the 'camera' and 'lights' were represented by the flying-spot scanner and photocells respectively.

Apart from two disk-scanned telecine channels, the only picture sources used in the 240-line Baird system were a flying-spot scanner, a fixed camera with an 'intermediate-film' scanner, and a camera using a non-storage Farnsworth image dissector. The limitations of all these pieces of equipment were among the reasons why the Baird system was not adopted, but it may be noted that the time of sixty-four seconds—required to produce a wet but developed, fixed, and washed negative—was less than the time needed by the BBC's present-day high-speed processing machines even if the drying time is deducted.*

3.9.2 *The Emitron*

The availability of a storage-type live camera was an essential factor in the success of the Marconi–E.M.I. system. This was made possible by the iconoscope tube, which was first described by Zworykin[12] in 1933. A tube embodying the same fundamental principles was developed independently by McGee and others in the E.M.I. Laboratories, and was first made to generate picture signals in 1932.[13, 14]

The Emitron cameras which used these tubes made it possible to derive a video signal instantaneously from a normal camera image of an indoor or outdoor scene. They were insensitive and demanded extremely skilled operation of the electronic controls, but given adequate lighting (200 ft-candles or more) and sufficiently skilled operation of the camera control units, they produced pictures not far short of the best which present-day cameras can offer.

The original Emitrons had no viewfinder at all—only a peephole which gave a view of the image on the mosaic. It soon became clear that some form of viewfinder was essential for studio working, and a combined viewfinder and rangefinder—similar to the type used on many 'still' cameras—was provided. This 'worked' but caused the cameraman intolerable eyestrain when used over long periods. Finally, a twin-lens arrangement, with a parallax-corrected image on a ground-glass screen, was adopted. It was at first thought that an optical viewfinder was preferable, as it could be given a wider angle of view than the television image and help the cameraman to anticipate what was coming into shot. In 1952 the BBC Designs Department developed a camera with a single-lens optical viewfinder which gave an erect image. Electronic viewfinders, however, are now universal in Britain, except in such applications as the Radio Camera[15] where the overriding considerations are lightness and compactness.

* It is only fair to add that the quality and permanence of the output of the present-day machines is immeasurably better.

3.9.3 *C.P.S. and Image Orthicon Cameras*

In November 1947 the BBC used cameras with cathode potential stabilized (c.p.s.) tubes for the first time at the outside broadcast of the wedding of H.R.H. Princess Elizabeth and H.R.H. the Duke of Edinburgh. By 1949 the image orthicon tube, which has a basic sensitivity about a thousand times that of the original Emitron, had become accepted as the preferred tube for outside broadcast use. In 1954 the BBC was the first to transmit programmes with the 4½-in. image orthicon tube made by the English Electric Valve Co., which gives a picture quality considerably better than that given by the earlier 3-in. tubes.

3.10 *One-man Vision Control*

With these low-velocity tubes, operated about half a stop over the 'knee' of the transfer characteristic, redistribution is negligible and the black level is stable.[16] The original iconoscope, by contrast, generated shading signals which had an amplitude of the same order as the picture signals themselves, and which varied with picture content. The stability of the 4½-in. image orthicon tube has been exploited by the BBC in a system of one-man vision control by which the technical picture quality of all the cameras in a studio (up to six) can be controlled by a single operator.

It was found that the number of operational controls could be reduced to two, i.e. light input (variation of lens iris) and lift (picture black level), if the remaining controls, numbering about thirty, could be preset in advance. This degree of stability was stipulated in the BBC specifications for camera equipment and was attained by the manufacturers. Each camera is controlled by a quadrant type of control which alters light input when it is moved to and from the operator and lift when it is rotated.

Besides economy of staff, this system, together with new techniques for measuring picture quality, consistently produces pictures of higher quality than were previously achieved.

3.11 *Production Control Room Equipment*

In the original production control rooms at Alexandra Palace, the producer and vision mixer did not have a continuous display of the pictures from all the working studio cameras and ancillary picture sources. They had only a 'transmission' and a 'preview' monitor, and were completely dependent on the camera control operators for the supply of the correct picture signals at the appropriate moments in a production.

As each of the Lime Grove studios was brought into use, the vision control rooms were equipped with enough picture monitors to cover all the working studio cameras, and also to preview any telecine or outside-broadcast inserts which might be required.

In the early days of the service, the only receiving-type valves available were octal-, five-pin-, or seven-pin-based types. These had higher inter-electrode capacities than the miniature valves now in general use, and the usual method of obtaining level wide-band amplification was to incorporate π-section filters in the intervalve couplings, with the valve output and input capacities forming elements in the filters. The amplifiers now used at the Television Centre (which have been developed by the BBC) all use a three-stage negative feed-back triple, with the output taken from the cathode of the last valve. The long-term gain stability is high enough to make it possible to operate the amplifiers with a fixed gain of exactly 15 dB. The attenuation in the various programme routes does not exceed 13 dB in any case, and additional fixed attenuation is added to make the overall gain of the circuit and amplifier exactly zero. Pulse and bar techniques[31] are used in setting up the circuits.

Mixing circuits originally used variable-mu valves working into a common anode load. This allowed for remote control by a line carrying d.c. only, but it was subject to variation due to valve ageing and differences between individual valves, and was unsuitable for 'cutting'. In the mixers now used at the Television Centre, which have been developed by the BBC, the grid and cathode of each mixer valve are connected across one diagonal of a resistance bridge, and the signal is applied across the other diagonal. When the bridge is balanced, equal signals are fed to both grid and cathode, and there is no output, but when the resistance of one arm of the bridge is varied the bridge goes out of balance and an output is obtained.

Clamping was originally applied only at the input to the sub-modulator at the transmitter, with leaky-grid d.c. restoration elsewhere in the video chain. Nowadays every mixer is associated with a stabilizing amplifier which incorporates feedback clamping, and can yield a synchronizing waveform substantially free from distortion even when the input pulses are distorted or have added noise to the extent of 50 per cent of their amplitude.

3.12 *Waveform Generators*

In the earliest E.M.I. waveform generators, the master oscillator was a multivibrator, and mains-hold was maintained by comparing the phase of the mains with the 50-c/s output of the divider chain, and deriving a bias voltage which controlled the multivibrator frequency. This circuit responded rapidly to sudden changes in the phase of the mains supply, and mechanical receivers, which were still under development at that time, could not always follow these changes on account of the inertia of their scanning systems. Attempts were made to slow down the response to these phase changes by interposing a long time constant in the bias control circuit, but with the limited knowledge of servo systems available at that time, these were unsuccessful. A mechanical master-frequency generator was therefore devised, in which a motor driven synchronously from the mains at 3,000 r.p.m. drove two rotors, one with 405 poles and the other with one pole. This provided both the twice-line master frequency and the field frequency, without using divider chains. In later years, the use of all-electronic master oscillator and mains hold systems has become universal.

The first transistorized waveform generator was an astonishingly compact unit which formed part of the Radio Camera.[10] A rack-mounted unit, also transistorized, which provides genlocking and all the other facilities required in a studio waveform generator, will shortly go into service at the Television Centre.

3.13 *The Pre-war London Station*

The basis of the design of a high-power television transmitting station is to provide a field strength high enough to give adequate signal-to-noise ratio at the maximum range compatible with reasonable freedom from fading and from co-channel interference under average reception conditions. With the limited knowledge of VHF propagation available when the London television station was planned in 1935, it was thought that the fading-free range would be about thirty miles, and on this assumption the Alexandra Palace site appeared to give the best population coverage.

The Alexandra Palace station was designed with a peak-white vision transmitter power of 17 kW, and an e.r.p. of 34 kW, which was thought to meet the requirements just mentioned. This power was very high and for many years Alexandra Palace was by far the world's most powerful VHF transmitter. There were separate single-tier aerials, each with a separate feeder, for sound and vision. High-level modulation was used in the vision transmitter. Although peak output was sometimes limited in the early days by the swing available from the modulator, this form of modulation has now become the preferred practice after experience with both high-level and low-level modulated transmitters in other parts of the country.[17]

3.14 *Post-war Resumption and Extension of the Service*

In September 1943, the Government appointed a Committee, under the chairmanship of Lord Hankey,[18] to prepare plans for the reinstatement of the television service after the war. This Committee recommended that the service should be restarted in London on the same standards as those in operation before the war, and that television should be extended, as soon as possible, to the most populous provincial centres on the same basis. The Government accepted these recommendations, and the service was accordingly reopened on 6 June 1946 with the Alexandra Palace transmitters and studios. The question of standards was reviewed during the ensuing two years, and it was decided by the Government that no change should be made.

The Committee also recommended that 'The aim should be to produce an improved television system having a standard of definition approaching that of the cinema, and possibly incorporating colour and stereoscopic effects. Vigorous research on such a system should begin immediately staff can be made available . . .' and that 'The considerable amount of research which will be necessary before a radically improved television service can be produced calls for the closest co-operation between all the interests concerned. Research should be co-ordinated under Government auspices, great care being taken to avoid stifling or hampering initiative and competition: the task should be entrusted to the Advisory Committee.'

In 1947 the band of frequencies 41–68 Mc/s, which was known as Band I, was allocated to television broadcasting by the Atlantic City Conference of the International Telecommunications Union.

Once the question of standards had been settled, a plan for nation-wide coverage was prepared by the BBC and approved by the Postmaster General. This envisaged as a first step five high-power stations, covering about 80 per cent of the population of Britain, and serving respectively the London area and South-east England, the Midlands, the industrial North of England, central Scotland, and South Wales with part of the West of England.

The new high-power stations had transmitter powers of 50 kW, and a national coverage of over 60 per cent was reached in 1951, at which date few European countries had any television service, and those which did were using much lower-power transmitters. The main centres of population between the areas covered by these five stations were to be served by seven medium-power stations, which would bring the coverage to 97 per cent.

This coverage, which was actually reached in November 1956, might seem a very high one, and it was indeed greater than any other broadcasting organization had achieved at that time; but in terms of actual numbers it meant that about one and a half million people were still out of range of the BBC television service. Many of them, moreover, would be living in areas where other forms of entertainment, such as the theatre and the cinema, were not readily available. The BBC has therefore continued to press towards the goal of 100 per cent coverage, which may never be reached, but must be approached asymptotically. The present coverage of 98·8 per cent is still the highest in the world.

The staffing of all these stations has presented a major problem, and the solution was helped by the integration of the BBC's sound and television services. Automatic and semi-automatic methods were developed for operating sound transmitters[19] and monitoring their outputs.[20, 21] This enabled staff, who were already trained in broadcasting engineering, to be released from the sound service.

3.15 *Frequency Planning*

The Alexandra Palace station, which transmitted both vision sidebands, occupied the band 41·5–48 Mc/s with its sound channel, and the remainder of the band could accommodate only three further double-sideband channels. By partially suppressing one vision sideband, however, a further four channels could be accommodated. The receiver-attenuation (r.a.) system of vestigial-sideband working was chosen, as this simplifies the practical problems at both transmitter and receiver. The total band (1·5 Mc/s) occupied by the 'Nyquist flank' in the receiver characteristic is a larger fraction of the video bandwidth than in any of the other television systems now in use, and the distortion due to vestigial-sideband working is therefore lower. It was decided that the Alexandra Palace transmitter should continue to radiate both sidebands for the time being, in view of the large number of double-sideband and upper-sideband-only receivers in use at that time.

The European Broadcasting Conference, held at Stockholm in 1952, produced plans for the use of the VHF Bands I, II, and III, for broadcasting. In planning national coverage for the BBC television service, it was anticipated that frequencies in Band III (174–216 Mc/s) would be made available to the Corporation. These frequencies have not, however, yet been allocated to the BBC and it has therefore been necessary to accommodate the twenty-five existing stations and the twenty-three 'satellites' already planned in the five channels of Band I.

This has required much planning effort in order to reduce as far as possible co-channel interference between existing and proposed stations. The choice of channel is in some cases difficult, but once it has been made, co-channel interference can be minimized by the following means:

(*a*) The use of vertical polarization at certain stations and horizontal polarization at others, resulting in a reduction of at least 10 dB in mutual interference between a pair of stations.

(*b*) Shaping the horizontal radiation patterns of the transmitting aerials where appropriate. (This has also to be done in the case of certain stations which operate on frequencies close to those of nearby continental stations, to reduce the power radiated in the direction of the continental station below a specified level.)

(*c*) Offsetting the nominal carrier frequency of one of a pair of co-channel stations, usually by two-thirds of the nominal line-scanning frequency (i.e. 6·75 Mc/s) in the case of the vision carriers, and 20 kc/s for the sound carriers.

It has been found possible to keep co-channel interference within reasonable bounds but its occurrence in certain areas for a proportion of the time and particularly at certain seasons of the year is inevitable due to seasonal variations in propagation conditions; this gives rise to some complaints from the public.

An experiment recently concluded by the BBC has shown that a further reduction in co-channel interference of at least 6 dB can be achieved by the use of precision-frequency offset of the vision carriers, that is a frequency offset maintained to within a very few c/s of two-thirds of the line-scanning frequency, however this varies owing to variations in the frequency of the mains supply. In this experiment, carried out in Channel 2, the frequency of the vision carrier of the high-power transmitter at Holme Moss was maintained to within very close limits by a highly stable crystal drive which itself was manually corrected when necessary by reference to the standard frequency transmissions from Droitwich on 200 kc/s. At North Hessary Tor—a medium-power station also operating on Channel 2—a vision carrier was generated differing from that of Holme Moss by two-thirds of the instantaneous line frequency to within the close limits of + or −2 c/s. A receiver sited approximately midway between the two stations in an area where co-channel interference effects were marked showed a significant reduction in the beat patterns when North Hessary Tor was switched to precision offset conditions.

3.16 *Post-war Transmitting Stations*

The transmitters for the BBC Television Service have been constructed by the industry to BBC specifications. Many of the aerials have, however, been designed by the BBC. These include the two-tier arrays for the regional high-power stations, aerials with shaped horizontal radiation patterns for certain of the medium- and low-power stations, and the eight-tier aerial, giving an 8-dB gain,[22] for the Crystal Palace station.

The majority of the television transmitting stations are also serving as high-power or medium-power VHF/f.m. broadcasting stations, to radiate three, or in two cases four, sound programmes. The sound transmitters are installed in the same buildings as the television equipment and operate on a joint-attended basis, with automatic alarm devices to give an indication in the adjoining television control room—where engineers are on duty—if anything is amiss. This is another example of the advantages resulting from the operation of sound and television broadcasting by a single organization. A cylindrical slot aerial, radiating horizontally polarized signals, is mounted on the mast immediately below the television radiator, to carry the sound programmes.

In all the transmitters commissioned since the Alexandra Palace, a common aerial has been used for vision and sound. This has made it necessary to provide combining filters, which at the first station had to be mounted at the top of the mast, but later designs were installed in the transmitter buildings.

The 'split-aerial' system, which was originated by the BBC, enables a service to be maintained uninterrupted during a breakdown, with less loss of radiated power than that which occurs when it is necessary to switch over to a low-power standby transmitter and or a small reserve aerial. In the basic version of this system, the aerial is split into two sections which are fed separately, but in phase, through two separate feeders. Each feeder is in turn fed from the combined output of one of two identical pairs of sound and vision transmitters. There are thus two vision transmitters of equal power, and two sound transmitters of equal power. If one transmitter breaks down, the service continues with a 6-dB drop in radiation—3 dB due to reduced power and 3 dB due to reduced aerial gain. If the breakdown appears likely to be prolonged, the combined output of the unaffected pair of transmitters can be switched to both sections of the aerial, or two transmitters can be fed into half an aerial, thus limiting the drop in radiation to 3 dB.

This system has so far been applied at the Crystal Palace and certain of the BBC low-power stations. It has become generally accepted as the best method of maintaining continuity of service with the minimum deterioration during breakdowns.

The BBC has also developed a version of the small satellite stations—known as translators—suitable for the British standards. These unattended low-power stations receive sound and vision signals by radio from another BBC station and retransmit them on a different channel. Both signals are retransmitted without demodulation, which simplifies the installation and increases its reliability.

A similar idea has been widely used on the Continent for serving small areas screened by high ground from the main transmitters, but the British use of amplitude-modulated sound makes the design of such equipment more difficult.

4. Growth and Progress

4.1 *The Scope of Post-war Development*

By 1939 the BBC Television Service had already reached a state of technical development that comprised all the essentials of a practical and economic television service. In reaching this stage the BBC relied, for the most part, on equipment and techniques which had been developed by the radio industry.

After the war, however, the BBC played a major part in the engineering developments. Among these were increased national coverage, more numerous and widely distributed studios, and a wider range of potential sources of programme material. It has always been the aim of the BBC Television Service to ensure that the technical quality of all major broadcasts shall exploit the transmission standards as fully as the current state of engineering development permits. All equipment throughout the transmission chain is designed and maintained with this criterion in view. The BBC has always recognized its obligation to provide television coverage over the whole of the United Kingdom including, as far as is practicable, the remote rural areas, and to reflect in its programmes the interests of all parts of the United Kingdom. Much attention has been paid to developing means of taking live material from all parts of the country and from abroad and to extending the scope of outside broadcasts to the widest variety of sources, including submarines and helicopters.

4.2 *Propagation Studies*

The new transmitting stations, which were instrumental in extending the national coverage beyond the London area, have been mentioned in the preceding sections. An essential part of this development was an increased knowledge of the propagation of the television broadcasting frequencies. The experiences of the relatively small number of pre-war viewers, and measurements by the Research Department, had shown that under interference-free conditions an acceptable quality of reception was possible with field strengths even as low as 100 μV/m. If viewers became more critical, or interference in Band I increased, it might become desirable to provide some 250 μV/m at the limit of the fading-free zone. This would require an e.r.p. as high as 500 kW, and international agreement to use this power for each of the high-power Band I stations was accordingly sought and obtained at the Stockholm Conference in 1952.

Field strength measurements were also made during the years between 1936 and 1939 to investigate, in a preliminary way, the possibility of the signals from the Alexandra Palace station being propagated to considerably greater distances than had been expected. By 1937 the possibility of the extension of the Television Service to provincial centres other than London was being considered and it was at first thought that a second transmitter might be set up in the Birmingham area using the same frequency as Alexandra Palace.

One interesting experiment which was carried out in 1937 involved making a series of field strength measurements approximately in a straight line between London and the extreme north of Scotland. These measurements revealed the somewhat surprising result at that time that weak though fading signals could be received at many places along the route, even at the most distant points. Very little was known at the time about the effects of tropospheric refraction on propagation in the VHF band and the inaccurate conclusion was drawn that although signals could be picked up at distances exceeding 100 miles from the transmitter, they would be so weak that there would be no objection to working a second transmitter on the same channel as the Alexandra Palace transmitter in the Midland area. Further measurements on long distance propagation showed that the level of interference from Alexandra Palace was still much too high in the Midlands to permit co-channel working without an unacceptable level of mutual interference.

Experimental work of this kind by the BBC was suspended during the war but through the use of VHF and UHF for radar and other purposes there was a very considerable advance in knowledge of tropospheric propagation effects by the immediate post-war period. It had been found that the field strength at long distances from a transmitter at VHF and UHF depended on the climatic conditions. It was therefore very necessary to acquire a knowledge of the statistical distribution of these field strength values over a sufficiently long period of time to be sure that all possible effects of climate had been included.

With the re-introduction of the Television Service in 1946 consideration was immediately given to the possibility of extending the service to other parts of the British Isles and it was thus of great importance that a full knowledge of the variability of field strength at long distances should be obtained.

An extensive series of measurements with the above aim in view has been made by the Research Department of the BBC. Initially, long-term recordings for a period of many months were made on the Alexandra Palace and Sutton Coldfield transmitters at places as widely separated as Leeds, Largoward in Fife, Redmoss near Aberdeen, and Redruth in Cornwall. These measurements were later supplemented by a further series of tests from special experimental transmitters working in the television Band III, and more recently by investigation in the UHF Bands IV and V. The latter was the most comprehensive investigation of its kind yet undertaken.[10] A mobile laboratory, which was specially equipped for this survey, also enabled 405- and 625-line systems to be critically compared.[40] More recently also, attention has been turned to the problem of the enhanced propagation where a large part of the path between the transmitter and the receiver is over sea, and as an example it has been found that in the Bands IV and V the over-sea propagation is so good at certain periods of time that interference effects may occur between transmitters in the United Kingdom and on the continent of Europe.

The data collected by the early post-war experiments soon showed that if a frequency channel were to be shared between two transmitters, the required minimum separation distance between the sites to avoid an unacceptable level of mutual interference would have to be considerably greater than the 100 miles or so envisaged before the war. In fact, if the same polarization is used at both transmitters sharing a frequency channel, the separation distance should be at least 250–300 miles in the case of 100-kW transmitters.

The work carried out by the BBC in connection with the long distance propagation of radio waves on frequencies used for television has, of course, been co-ordinated with that of other countries through the International Radio Consultative Committee (C.C.I.R.).

4.3 *The Television Centre*

Although the service was restarted in 1946 with the same two studios at Alexandra Palace which had been used before the war, the need for expansion had been apparent well before the wartime closing of the service. A search was begun after the war for a site which would be near to the centre of London and large enough to accommodate a permanent television headquarters as well as the main London Studio Centre. In 1949 the BBC acquired thirteen acres of the site of the Franco-British Exhibition of 1908 at White City: this was barely adequate in area but otherwise eminently suitable.

The planning of the Television Centre, already started when the site was acquired in 1949, was an unparalleled act of faith in the future of television. When completed the project will have cost over £15 million. Many innovations in the layout and equipment of the studios were adopted as a result of study or experience and of an assessment of future needs. Studio equipment of the most modern design is being installed and new ideas have been incorporated in the finishing of the studio floors and in the acoustic treatment. Remote control of equipment has been effected where practicable and operational techniques have been streamlined.

The Centre will be capable of producing 1,500 hours per annum of programme material for television; in terms of quantity this is the equivalent of 1,000 full-length feature films. With its central control room and four studios now in operation, the Centre has already become the hub of the whole BBC television network.

The architectural and technical aspects of the Television Centre have been described in detail elsewhere,[16,23] and it will suffice to mention here that the plan of the architect, Mr Graham Dawbarn, F.R.I.B.A., was an imaginative answer to the problem of making the best use of the oddly shaped triangular site, while at the same time realizing the circular layout of studios originally suggested by the late Peter Bax of the BBC Television Design Department in about 1942. In this arrangement, the scenery is designed and produced in a building adjoining the studios, and fed into the studios through a wide corridor running round the outer periphery of the studio building, while artists and staff obtain access from the inner ring which contains dressing rooms and control rooms, as well as engineering and production offices. In the Television Centre as planned and now largely completed, seven of the studios are directly grouped around the inner ring, and additional studios will be built in the 'spur' extension which will occupy the northern corner of the site. These studios will be fed with scenery by an extension of the peripheral corridor along the west side of the spur, while artists and staff will reach the studios from an extension of the inner ring, running along the other side of the spur. In this way, the studios in the spur will be incorporated in the main access plan.

The wedge-shaped spaces, between the studios surrounding the inner ring, fit into the scheme admirably by providing spaces for essential ancillary facilities, such as the Presentation Suite (which includes the Central Control Room and Presentation Studios), the Telecine Suite, the production lighting control equipment, and transformers and switchgear for the power supply.

The whole project has been planned to provide for the eventual introduction of a second and possibly a third BBC television programme, and also for the introduction of colour.

When the White City site was acquired in 1949, it was realized that some years must elapse before programmes could be transmitted from the site, and in the meantime existing buildings were acquired and converted for use as television studios. These included the Rank Film Studios at Lime Grove, Shepherds Bush, the Shepherds Bush Empire Theatre, and the Riverside Studios of the Alliance Film Company, near Hammersmith Bridge. Much of the planning of the Television Centre is based on experience gained in these buildings. Some of this experience, such as the optimum shape and size of production studios, was gained while making the best use of the buildings as they stood. Other lessons were learnt by deliberately including alternative technical arrangements in the conversions of different studios. These included the best positions of control rooms relative to the studio, the best control room layout, and the most suitable system of lighting control.

4.4 *Film Transmission Equipment*

Apart from the early 240-line disk-scanned apparatus, all methods of televising film up to 1949 involved the use of a camera tube, and the pictures therefore had much the same shortcomings as the live transmissions of those days. In that year, the BBC was the first to use twin-lens flying-spot machines, and from that time the picture quality on 35-mm film transmissions fully exploited the system standards.

The modern equipment used for transmitting films has been developed from the 1949 prototype. The film passes through the machine in continuous motion at a speed corresponding to 25 film frames per second. It is exposed in the picture gate to a television raster compressed to half the normal height built up on the scanning cathode-ray tube. Due to the relative motion of the film frame and the scanning beam the complete frame is scanned by one field scan in the time taken by the frame to move a distance corresponding to half its height. At this point the shutter changes over the lens system and the frame is rescanned by the second field scan in a similar time interval. Thus each film frame is completely scanned by the odd and even field scanning beams as it passes the picture gate of the telecine machine. The modulated light output, i.e. the light from the raster as modified by the picture information on the film, is collected by a photo-electric cell and the output of this cell forms the basic video signal output of the telecine machine.

If a comopt (or 'married') print, having an optical sound track, is being used the variable area or variable density sound information is dealt with in the same way as in cinematograph practice. Provision is made, however, for a magnetic sound track, recorded on sprocketed magnetic film, to be run synchronously with the picture film if required.

Recently, a new technical problem has entered the field —that of transmitting the various wide-format cinematograph films. Notably, of course, those demanding special handling are Cinemascope, and the 'squeezed' version of Technirama. Electronic anamorphosis is practicable, on the basis that if this film is scanned at the transmitting end in an aspect ratio equivalent to 2 × 3 instead of 4 × 3, the domestic receiver will continue to reproduce the horizontal coverage as four units, creating a horizontal stretch in the ratio of 2 : 1. However, having obtained a potentially wide picture with an aspect ratio approximating to 7 × 3, a decision has still to be taken as to the best way of accommodating it on a 4 × 3 television screen.

If the potential wide picture is fitted to the height of the screen, there will be lost areas at either side; on the other hand, if the width of the picture is equated to that of the screen the latter will exhibit large blank areas above and below the picture, a type of display which tends to be viewed with some distaste. In practice, the two methods used are (*a*) to provide facilities for 'panning' across the wide picture, to transmit the section bearing the most significant action, or (*b*) to gang the line and frame scanning amplitude controls to provide a kind of electronic 'zoom'. This latter arrangement assumes that the two controls ganged have been made to exhibit some known and linear relationship of effect, but has the advantage over the alternative panning system, that significant action can be accommodated when it is either simultaneously at both sides of the picture, or alternating rapidly between them.

4.5 *Film-making in the BBC*

The BBC has continued to use the 35-mm gauge for the major part of its own film-making. Many television broadcasters would consider this extravagent, and would support this view by pointing to the indifferent resolution of many receivers. In practice, however, the situation is generally the other way round, and an imperfect transmission is more noticeable on a poor receiver than on a good one. Distortions in different parts of the transmission and reception chain rarely mask one another: on the contrary, they generally add up to produce increased deterioration of the final picture. When filmed inserts are included in live studio plays it is clearly important that the quality should match, especially if the same artists, sets, or properties appear in both the filmed and live sequences. Experience has shown that this can only be satisfactorily achieved with 35-mm film.

Nevertheless, 16-mm film is widely used in the BBC for news items where the small size of the camera is an advantage. The work done by the BBC in developing 16-mm film processing is referred to in Section 4.6. Facilities for reproducing sound from a magnetic track (either on the same film as the picture or on separated sprocketed film) are being added to all telecine equipment. This offers a higher standard of quality than an optical sound track can achieve after the several dubbings which it must usually undergo before reaching the final positive film.

The difficulties of filming in television studios became increasingly obvious as the service expanded, and in 1956 the Ealing Film Studios[24] were purchased by the BBC and have since been used for the making of documentary films, film inserts into studio programmes, and other films apart from those needed by the News and Newsreel Service. Films produced for television are generally on a less lavish scale than feature films produced for the cinema but the greater volume of film has meant that the reviewing, cutting, dubbing, and sound-recording facilities have had to be substantially modified and extended since the BBC took over the Ealing premises.

No separate film studios have been provided outside London, but equipment for the shooting and editing of film and to a limited extent its processing, has been provided in the main regional centres—as well as equipment for the transmission of films.

The BBC is believed to be the biggest single user of film in the world, and the film department produces, in terms of footage, the equivalent of some 140 full-length feature films each year.

4.6 *News and Newsreel Service*

In view of the need for speedy production of television news programmes, the BBC News and Newsreel Service, which is based at Alexandra Palace, has its own independent television studio, film unit, film processing, reviewing, and editing facilities, as well as telecine, film telerecording, and video tape recording equipment. The service also operates single-camera interview studios near Broadcasting House, London, at London Airport, and near the Houses of Parliament. The latter studio is operated on an 'unattended' basis, the camera channel and lighting being switched on at Alexandra Palace. The studio near Broadcasting House was equipped experimentally with a remotely controlled camera developed by BBC engineers. The camera controls (pan, tilt, focus, zoom, and iris) could be operated from a control panel at Alexandra Palace some six miles away. More recently five remotely controlled vidicon cameras have been installed in the Alexandra Palace studio itself, and enable one operator to control four operational cameras—the fifth being a reserve.

As mentioned in the last section, the film used in the Newsreel Service is mainly 16 mm, on account of the greater compactness of the cameras. While the Television Film Studios rely on commercial processing facilities, the importance of speed in newsreel production has led to film processing equipment being provided at the Alexandra Palace and at the major regional centres. For this purpose, a commercially produced film-processing machine has been redesigned by the BBC.[25] The original roller drive was replaced by slip-free sprockets, and the constancy of speed, as well as the stability of the temperature and solution strength in the developing and fixing tanks, were greatly improved. A new technique of sensitometric control[26] was also developed, and the overall result was a quality and consistency of film processing comparable with the best of the commercial film laboratories.

4.7 *Recording of Television Signals*

Telerecording was not available before the war, but as soon as the service had been resumed, the BBC strove to find a satisfactory way of doing this. All the early systems used photographic film, and even with the availability of video tape, the Corporation still has a very large requirement for film telerecording.

The basic method of making telerecordings on film is to make a film of the television picture with a cinematograph camera. Just as sound films shot at 24 pictures per second can be run at 25 pictures per second without any serious adverse effects, the television picture frequency of 25 per second enables telerecordings made at this frequency to be projected optically at 24 pictures per second or televised at 25 frames per second. The film can also be run through a telecine channel with a line standard other than 405 lines. These are among the reasons why the BBC continues to make large scale use of film telerecordings.

In filming a television picture, there is, however, a fundamental difficulty which must always be circumvented in one way or another. A normal intermittent-motion film camera must interrupt its exposure for at least 10 ms during each film pull-down. This interruption must not be allowed to overlap the active scanning period of the television signal, and it should therefore be completed during the field blanking period. This period, however, only lasts about 1·4 ms in a system with 50 field/sec. The BBC has been more actively concerned in methods of overcoming this difficulty than any other organization.

The first occasion on which a recording of a television programme was broadcast was in November 1947, when a film was made of the broadcast of the Armistice Ceremony in Whitehall. A camera with a 180° pull-down was synchronized with the television picture frequency, and the lens was shuttered during the whole of each alternate field in order to leave time for the pull-down. This meant that only alternate fields were exposed, and the resulting spaces between the lines were filled in by defocusing the spot in the picture tube. The definition obtainable with this system was, of course, limited.

The BBC began to make regular use of film telerecordings in November 1949.* The method used at that time was to display the picture on a high-quality monitor and make a film of it by using a Mechau continuous-motion projector adapted as a film camera. The optical compensator in this machine caused an image of the displayed picture to keep pace with the continuously moving film for the duration of a full frame, without interruption for pull-down. A complete picture (odd and even fields) could therefore be recorded, but the action of the optical compensator was imperfect and caused some deterioration of the recorded image.

There was an urgent need to have at least one improved telerecording system available in time for the Coronation in June 1953. To meet this need, the performance of the Mechau system was improved by both optical and electronic modification, and the so-called suppressed-frame system was also developed.[27] In this latter system an intermittent film camera was used, and the displayed picture was blacked out electronically on each alternate field to allow time for film pull-down. By this means, only half the active lines were recorded but the full horizontal resolution was retained. In spite of the halving of vertical resolution, this system gave very acceptable results and remained in use until 1957, when the equipment was modified to work on the stored field system, in which both fields are scanned and recorded.[28] Since part of each alternate field must be scanned while the film camera is shuttered for pull-down, this system relies on the afterglow of the display-tube phosphor to store this field until the shutter reopens. During the scanning of the stored field, the output of the video amplifier is automatically increased to compensate for the decay during storage, and this ensures that both fields have equal brilliance when exposed together.

Another approach to the problem of recording all the active lines in both fields is to develop an intermittent film traction mechanism which can complete the pull-down during the field blanking period, or so nearly complete it that very few active lines are lost. This requires very rapid acceleration of the moving parts of the mechanism; the principal difficulty is not, as might be supposed, the tearing of the film, but the avoidance of excessively rapid wear in the mechanism itself. A commercial 16-mm 'fast-pull-down' channel has been in use since 1957, and gives picture quality as high as is likely to be obtainable from 16-mm film, and with an unimportant loss of picture area.

With a view to using the fast-pull-down system for 35-mm telerecording, the BBC also ordered a 35-mm camera which it was hoped would have a pull-down angle of $17\frac{1}{2}°$, equivalent to 1·9 ms. This proved unattainable, and the best that could be achieved was a 40° pull-down angle, which would have meant a loss of some sixty active lines. However, in devising means for recording all the active lines with this camera, BBC engineers have produced the best film telerecording system so far developed.* The basis of their method is to shutter the lens, for a period equal to the pull-down time, at the end of each field, and to depend on the afterglow of the display tube only during the relatively short time-interval between the end of field blanking and the end of the shuttering period. In this way, no line is stored for longer than 3 ms before being exposed, and most of the lines in both fields are exposed as soon as they are scanned. The relatively small decay in brilliance during storage is corrected by placing a neutral density filter, whose density varies in the vertical direction, in front of the display tube. This filter will, of course, affect both 'odd' and 'even' fields equally, while pull-down occurs only at the end of alternate fields. Since, however, the lens is shuttered for the same period at the end of both fields, the exposure cycle is exactly the same on both fields. A single-bladed shutter, rotating at field rate, is used.

The space between the filter and the picture tube face-plate is sealed and filled with glycerine, so that the face-plate, the glycerine, and the filter form a layer of approximately constant refractive index.

The main advantages of this system are as follows:

1. The neutral density filter reduces the flare effects which are usually caused by spurious internal reflections within the tube face-plate.
2. Standard electronics can be used, since no amplifier gain modulation is necessary, as in the case of the stored field system.
3. Because the storage time is relatively short, the light output available from the tube is greater and a slow, high-resolution film stock can be used.
4. Since all fields are treated alike, any errors in adjustment, or changes in amplifier or cathode-ray tube characteristics, do not lead to a $202\frac{1}{2}$-line structure in the recorded image, with a consequent problem of moiré pattern during rescanning.

Yet another method of recording television signals has come into use recently which records the entire picture and sound information on magnetic tape. The equipment uses tape which is 2 in. wide and runs at a speed of 15 in./sec. The actual recording is performed by four magnetic heads equidistantly spaced around the periphery of a disk rotating at right angles to the tape and revolving at a speed of 24 r.p.sec. The diameter of the disk and the width of the tape are so proportioned that the picture information is recorded across the tape in a series of diagonal magnetic tracks. The equipment is capable of reproducing excellent pictures but suffers from the following disadvantages:

1. There is no visible record.
2. A recording can only be reproduced on a television

* British Patent No. 648,924.

* British Patent Specification No. 859,030.

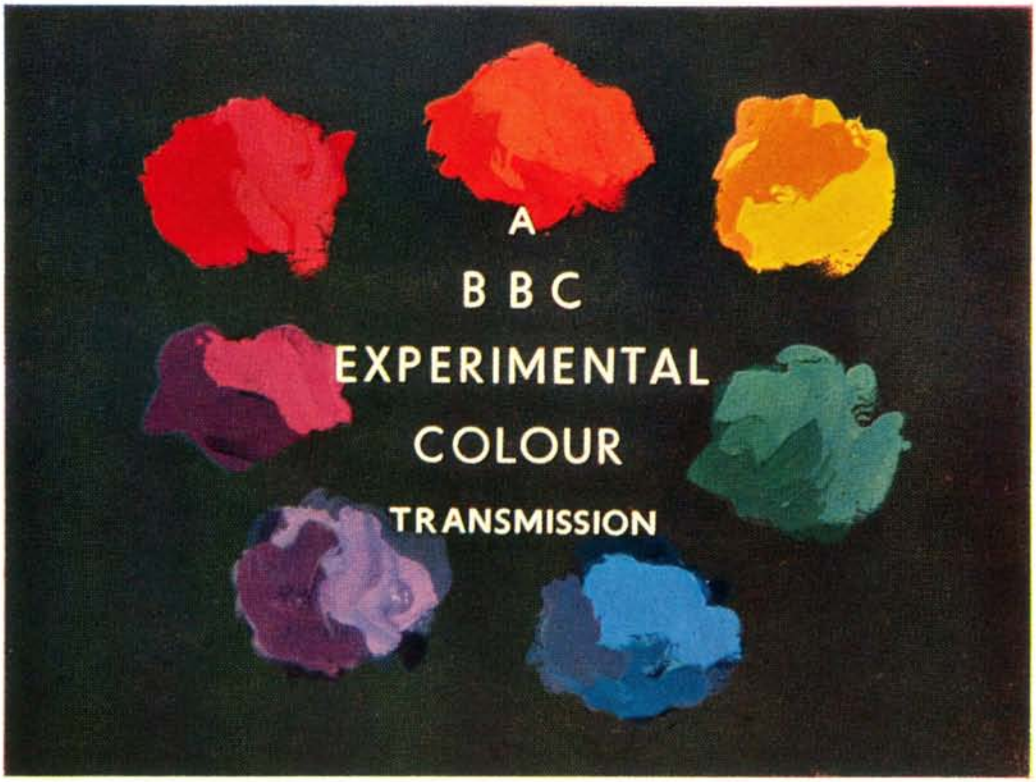


Plate 1 — Caption card used in the experimental colour transmissions

Plate 2 — Test transparency used in the experimental colour transmissions

Plates 3 *and* 4 — *Studio productions in the experimental colour transmissions*

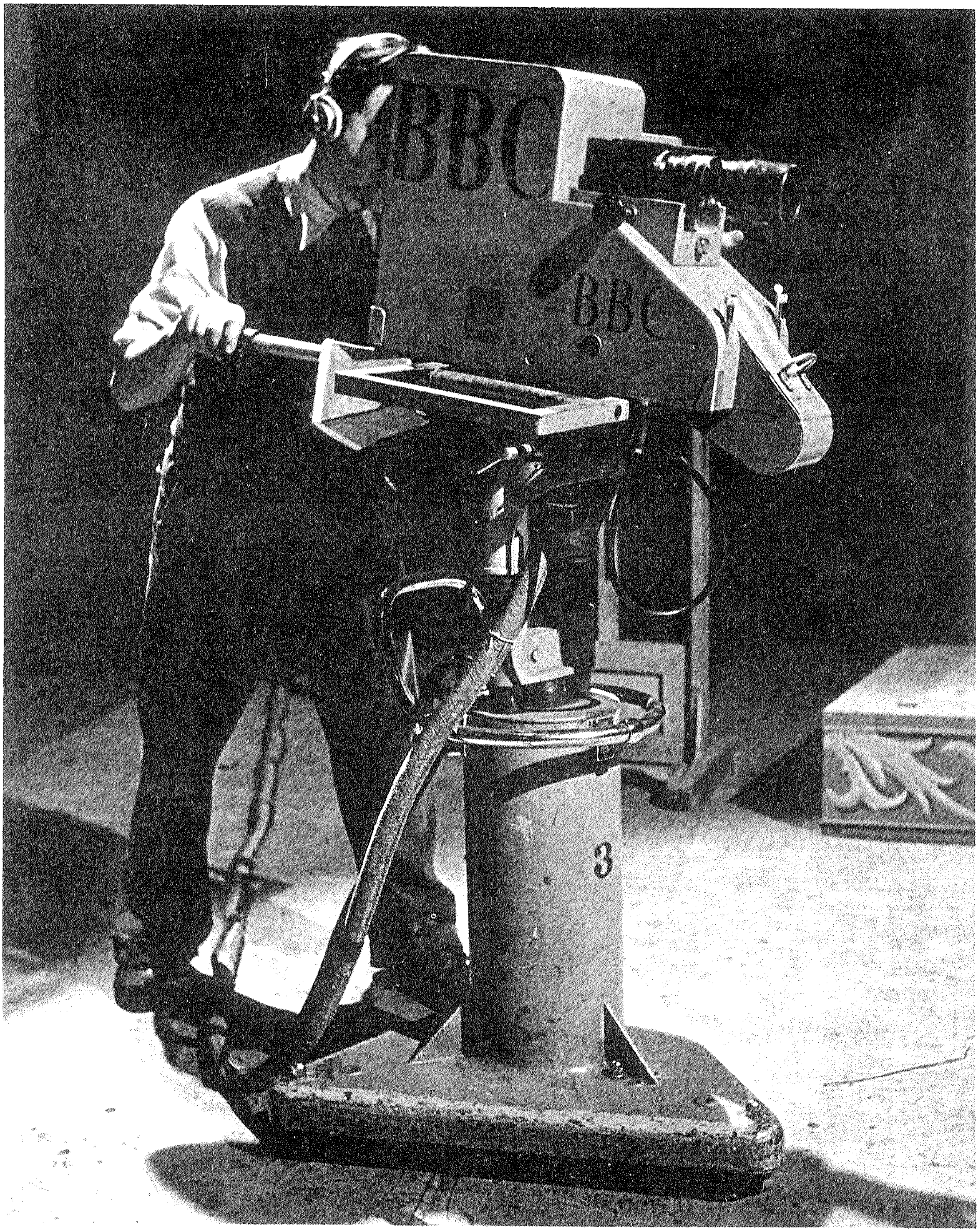


Plate 5 — The Emitron Camera

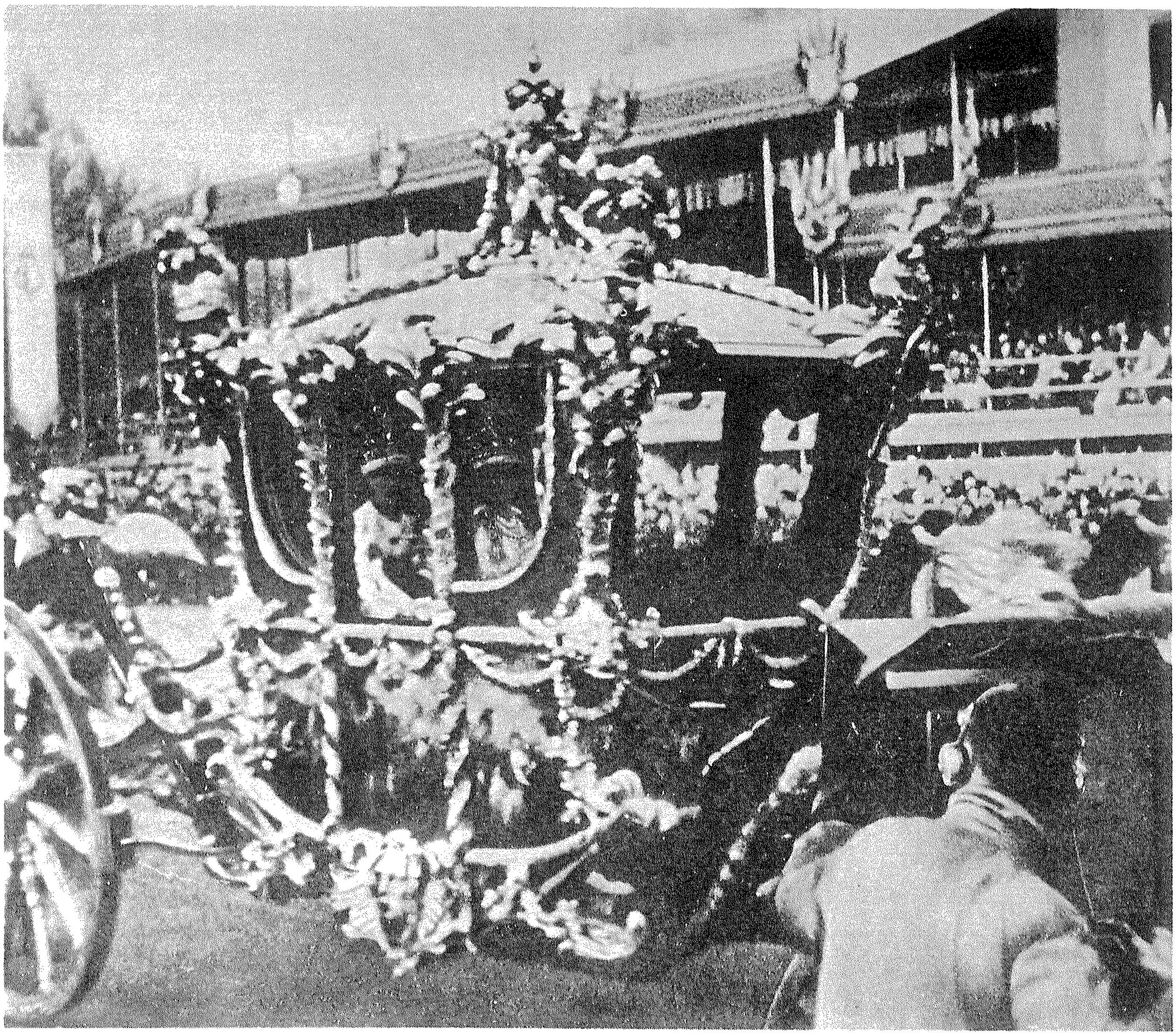


Plate 6 — The first outside broadcast in May 1937. The Royal Coach is passing the cameraman at Apsley Gate

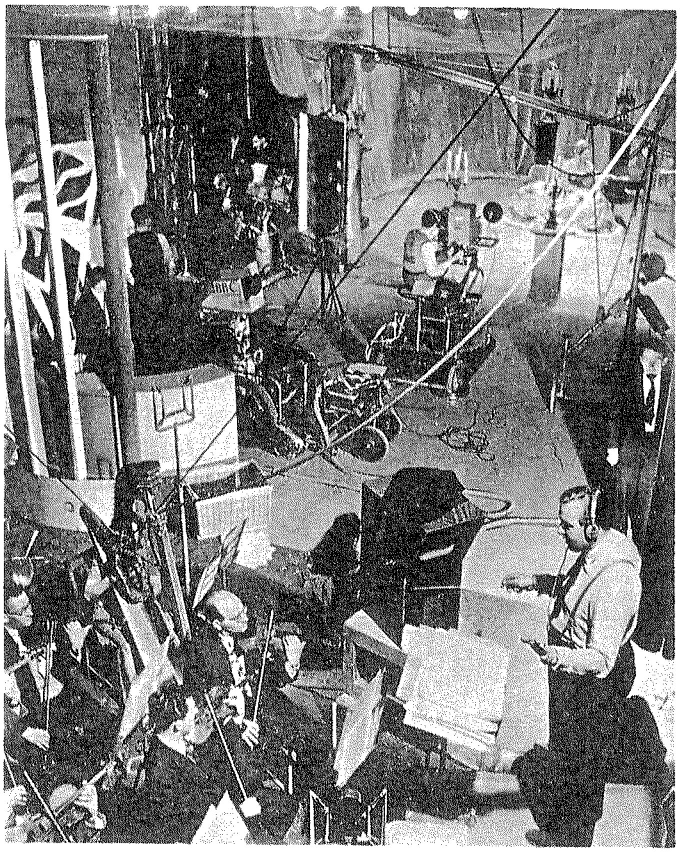
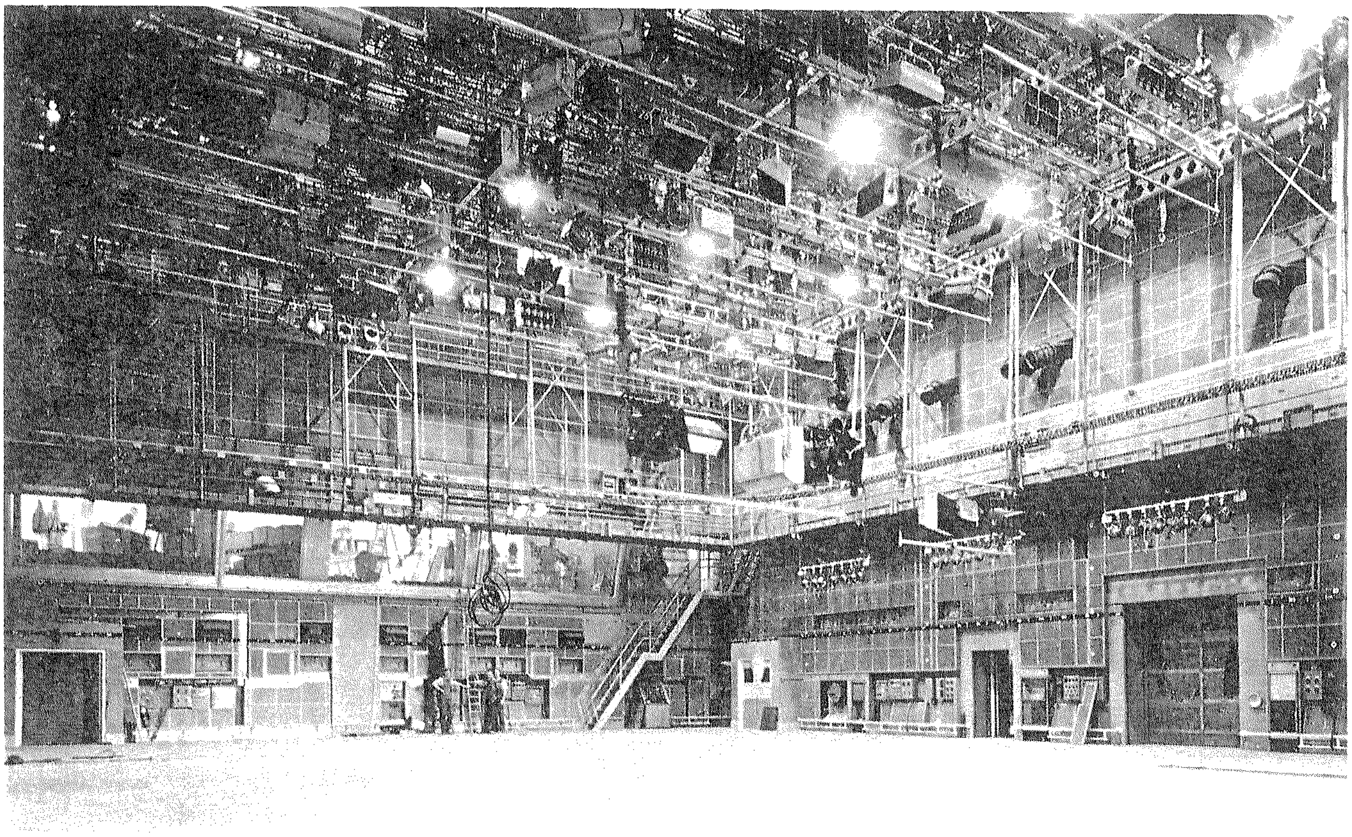


Plate 7 — A rehearsal in one of the original Alexandra Palace studios

Plate 8 — Studio 3 at the London Television Centre. Contrast the spaciousness with the cramped conditions at Alexandra Palace shown in Plate 7



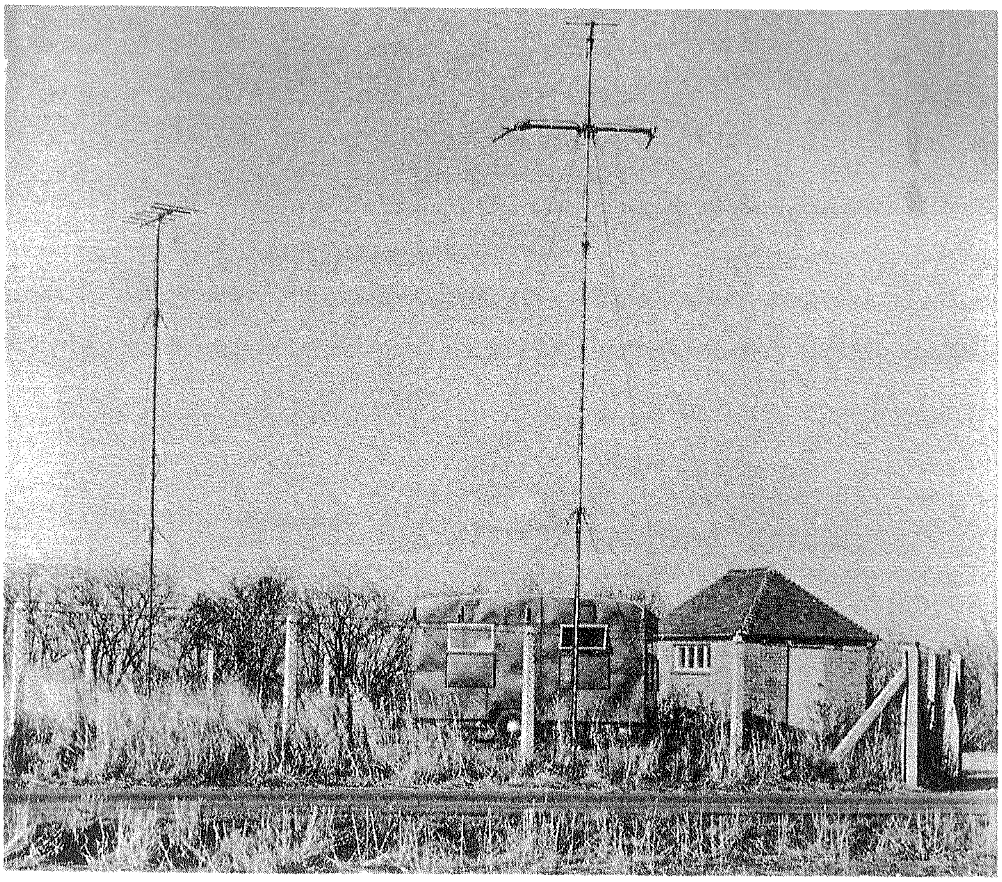
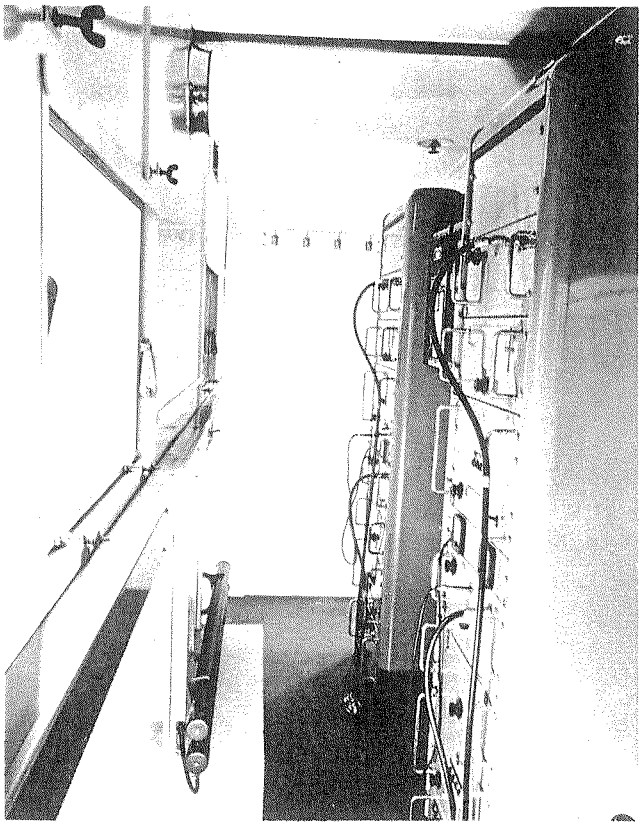


Plate 9 — Exterior and interior views of a caravan for long-distance propagation measurements



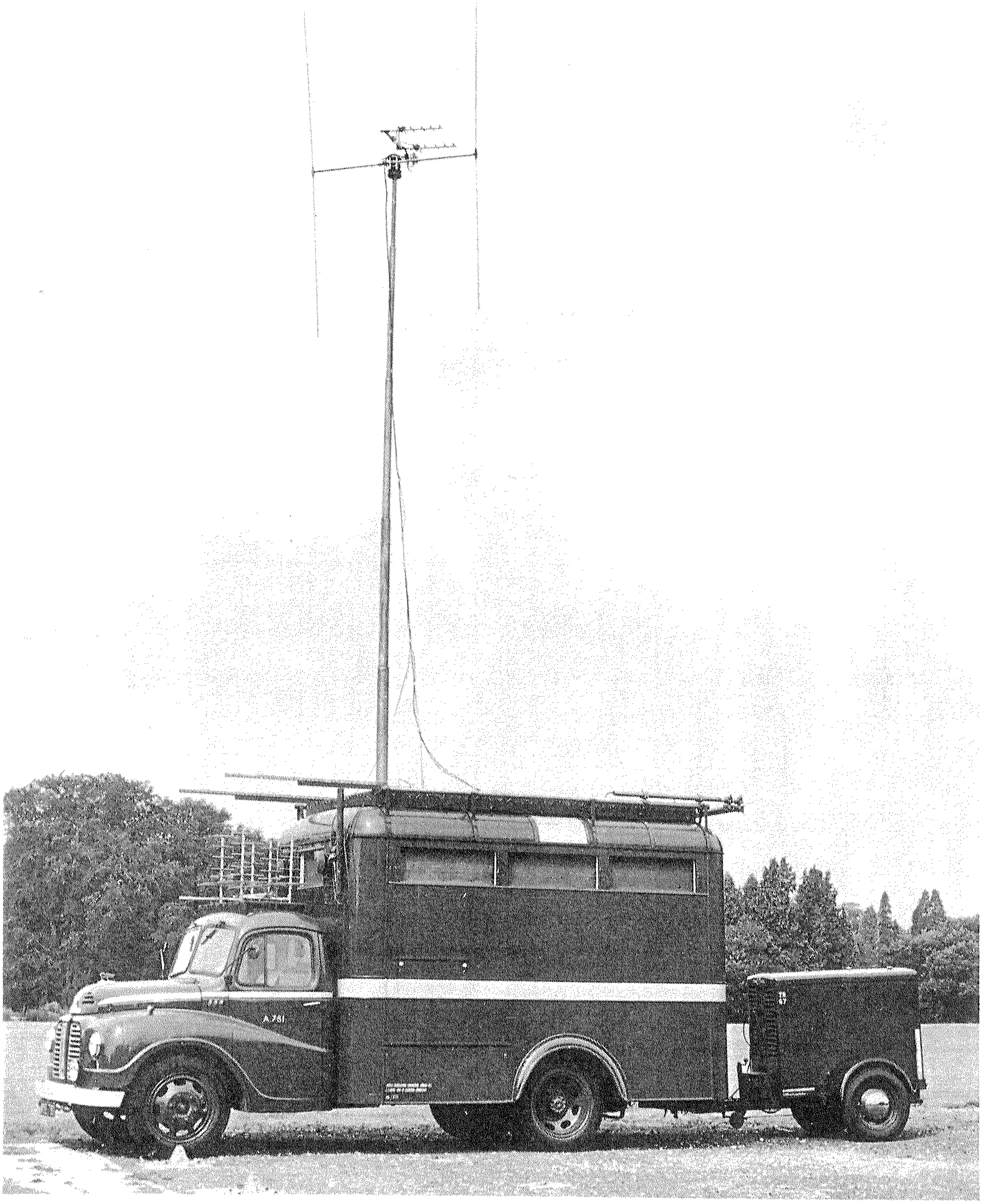


Plate 10 — The mobile VHF and UHF measuring laboratory

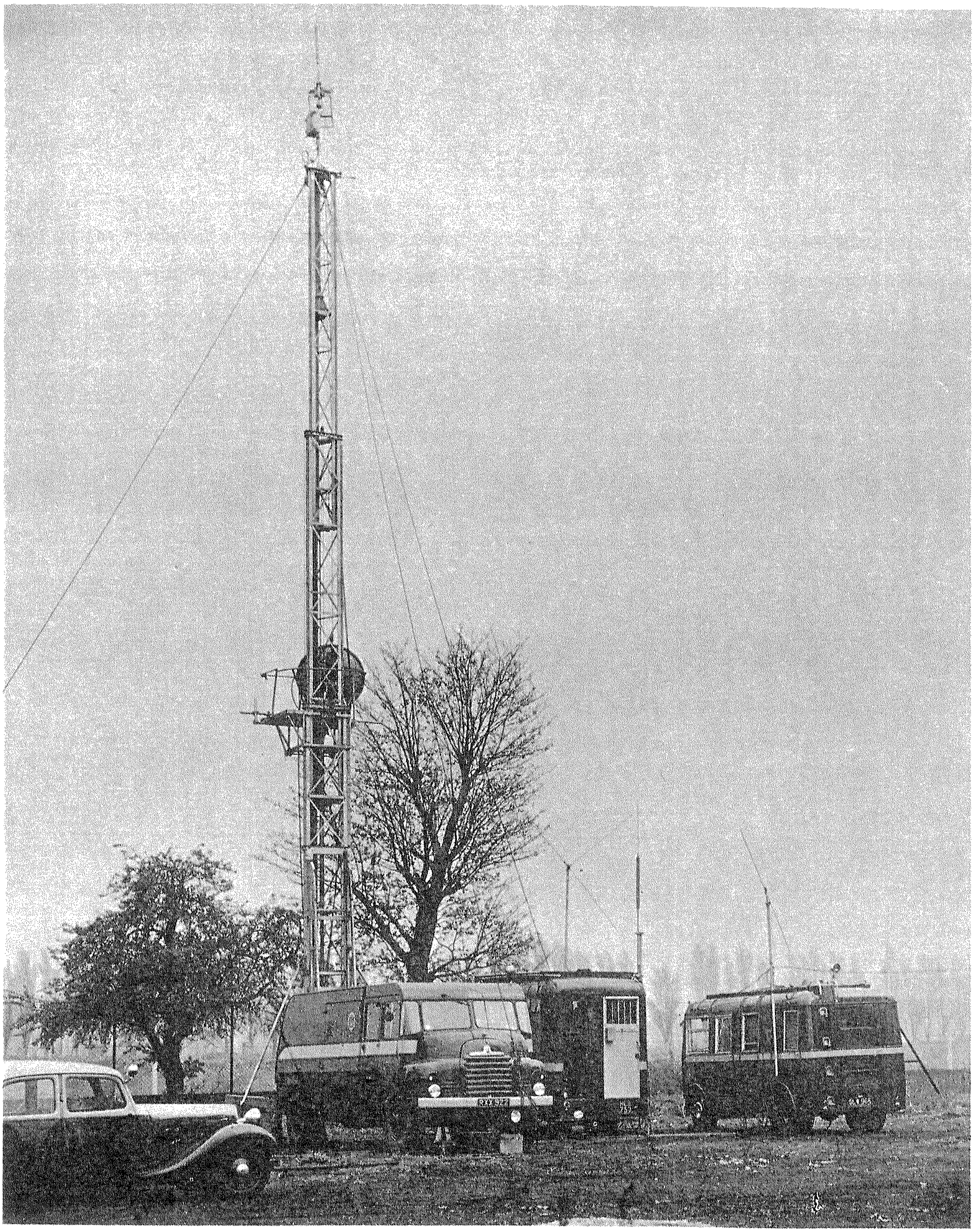


Plate 11 — *Radio link tower and vehicles used in an outside broadcast*

Plate 12 — *A photograph of the received picture of Major Gagarin during the first live transmissions from Russia on* 14 *April* 1961

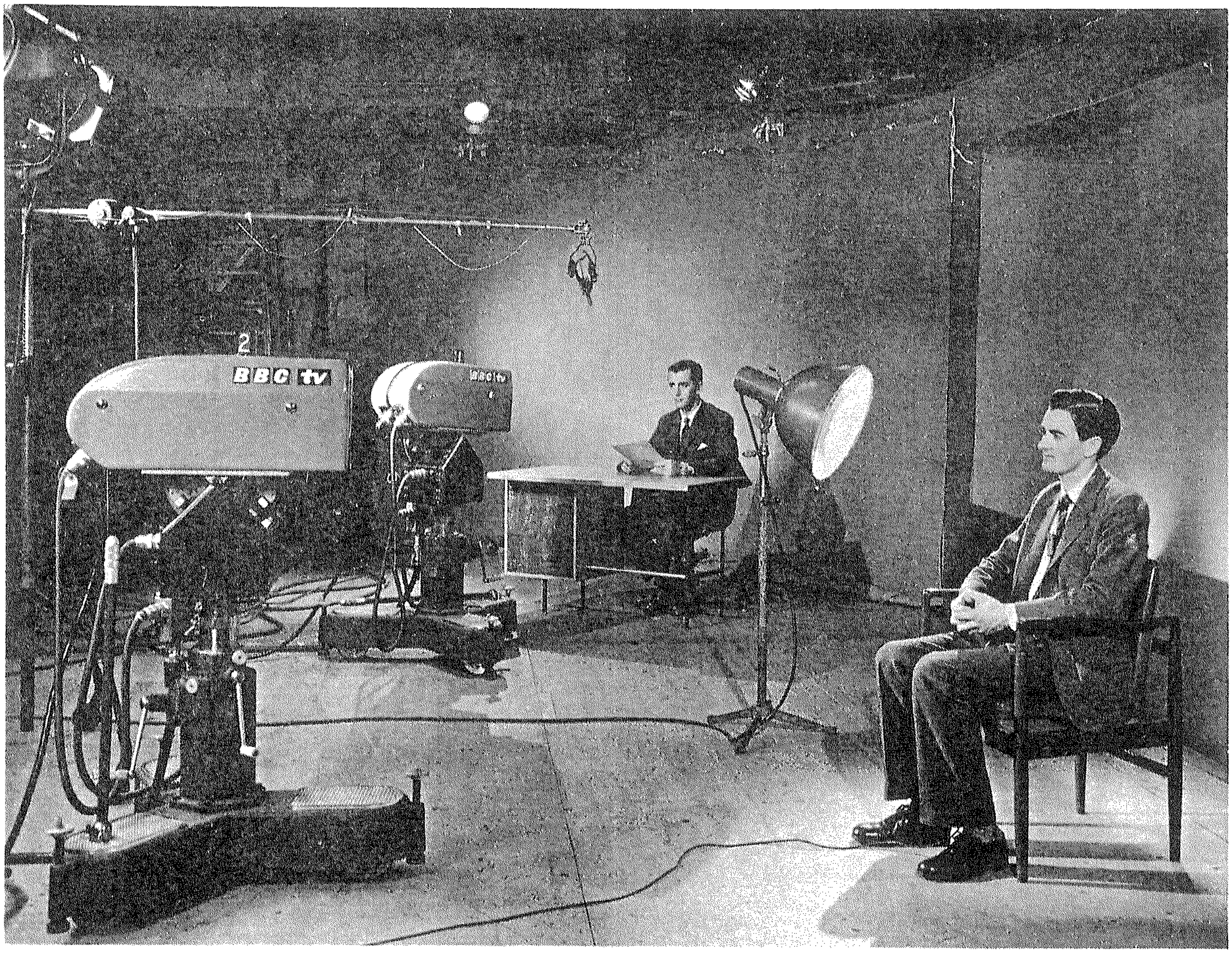


Plate 13 — *Remotely controlled vidicon cameras in the News Studios at Alexandra Palace*

Plate 14 — The lighting supervisor (left) and the vision control operator (right) using a common set of picture and waveform monitors in the Vision and Lighting Control Room at Studio 4 in the Television Centre

system operating on the same standards as those on which it was recorded (unless standards conversion equipment is interposed).

3. Editing is made more difficult.

Against these must be set the almost instant availability of reproduction—merely the time taken to rewind the tape (although in practice an operational safety margin is introduced to allow checking of machine alignment); no processing necessary as in film telerecording techniques; the facility of erasing unwanted programme material and re-using the tape.

4.8 *Outside Broadcasts*

Outside broadcasts—in the sense of live broadcasts of events outside the studios—play a more important part in the BBC's television programmes than in those of any other broadcasting organization. While some types of programme can be broadcast from recordings without losing any of their interest, others gain enormously in their appeal to viewers if it is known that the events televised are actually happening as they appear on the screen. The major national events come into this category, as well as sporting events, whose results are not known to anybody until they are seen to happen. The BBC has devoted a great deal of effort to the production of outside broadcasts of the highest possible standard, and from the widest range of sources.

Pre-war outside broadcasts have been referred to in Section 2. The mobile control rooms (known as m.c.r.s) which have come into use since the war have three working camera channels, each with its own picture monitor incorporated in the camera control unit. The interior layout provides control desks for the producer (who operates the vision mixing controls himself) and for the sound control engineer. The camera control units are placed so that their picture monitors can be seen by the producer and sound control engineer as well as by the c.c.u. operators. The first m.c.r.s to be brought into service after the war used c.p.s. or image iconoscope cameras. However, as soon as image orthicon cameras, using 3-in tubes, came into use it became clear that the much greater sensitivity of this type made it the best camera for outside broadcasts, and it has since become the only type of camera used for this purpose, except in special applications where the need for extreme compactness or lightness makes it essential to use vidicon cameras. Several of the three-camera outside-broadcast units now in service use the new cameras with $4\frac{1}{2}$-in. image orthicon tubes; it is felt that the advantages of higher signal/noise ratio and better tonal graduation more than outweigh the disadvantages of greater bulk and weight compared with the earlier 3-in. tube cameras.

It is mentioned in Section 4.12, dealing with programme distribution, that most of the vision links in the simultaneous broadcast network are two-way. These return circuits, together with the BBC's mobile radio links, enable outside broadcasts to be relayed from almost any point in the British Isles. Where suitable Post Office cable circuits do not exist, BBC mobile point-to-point radio links are employed to send the vision signals from outside-broadcast sites to the nearest convenient injection point on the permanent network. As far back as 1950, the BBC was sufficiently well equipped with s.h.f. links to relay an outside broadcast from Calais, using four links in tandem, and as many as five links have been used for exceptionally difficult sites.

For obvious reasons, the use of Band I, and later of Band III, for outside broadcast links has had to be largely abandoned. The micro-wave links are generally used for the longer hops, but there is often a need for some form of short-range link between the m.c.r. and the first microwave link. The mobile Band V f.m. links, which are used for this purpose, have been developed by the BBC.[20]

4.8.1 *Roving Eye*

Two successive versions of a vehicle known as the Roving Eye have been developed by the BBC, and each has proved an important addition to the ouside broadcast facilities. The later version is a medium-sized van carrying two image orthicon cameras and vision mixing equipment, together with a petrol-electric generator, transmitters, and aerials for sending picture, sound, and control signals to a fixed receiving point, and also a commentator's microphone. With such an installation, live pictures and a commentary can be broadcast from the van while it is moving, but operational experience soon showed that its roving capabilities were of secondary importance compared with its ability to provide, at short notice, a complete two-camera outside broadcast unit with its own radio link equipment.

4.9 *Planning of Studio Installations*

It was not until the first studio at the Television Centre was opened in June 1960 that the BBC had the opportunity of producing television programmes in a studio designed and built expressly for this purpose. Nevertheless, at the time when the building of the Main Block at the Television Centre—which includes the studios—was started in 1955, much valuable experience in the layout and equipment of studios had already been accumulated. The execution of the original master plan of April 1951 had been delayed by Government restrictions on capital expenditure; in the meantime, experience at Lime Grove had indicated that studios should be more nearly square in shape, and the plan was modified accordingly.

Experience had also indicated that the production, sound, lighting, and vision control areas should be adjacent to one another on a common floor level, and that all should have a direct view of the studio floor. Alternative arrangements meeting most of these requirements were provided in the two Riverside studios, and alternative internal layouts of the control rooms were also tried out in these studios. In Riverside Studio No. 1, the production desk faces the studio floor directly through a sloping observation window, with the picture monitors mounted in a single row at the top of the observation window. While this was an excellent arrangement in many ways, it could not be used with 21-in. picture monitors, and later tests with a full-scale mock-up of a complete control suite showed a universal preference for monitors of this size.

In the layout adopted at the Television Centre, the production desk is placed sideways to the observation window and diagonally inclined to face it. The use of a curved desk improves the visual contact between the operational staff, who sit at its convex edge, and the nine 21-in. picture monitors are mounted in two rows.

The adjacent control area, which also has a studio observation window, provides operational control positions for the Lighting Supervisor and the Vision Control operator. These technical operations are closely interrelated and the two control positions share a common group of picture and waveform monitors. The one-man vision control system has already been referred to in Section 3.10.

On the opposite side of the production control room, again provided with a studio observation window, is the sound control room. As a result of experience gained at Riverside, quadrant faders (similar to those used for vision control) are used for sound control in place of the traditional type of sound control knobs.

In the Riverside Studio No. 1, the dimming of the lights is carried out by an electro-mechanical system using variable resistances and a few auto-transformers, operated by electomagnetic clutches through servo-control circuits. In Riverside Studio No. 2, the light output of the liminaires is controlled electronically by xenon-filled thyratrons.[30] Experience with the two systems has shown that the electro-mechanical system is preferable for television use, and this system has been chosen for the Television Centre, with auto-transformers throughout in place of the mixture of resistances and auto-transformers.

4.10 *Distortion and Noise Measurement*

Until comparatively recently, the means of measuring the distortions which are present in practical television transmission systems were imperfect. The object of all measurements is to make objective assessment which relates closely to the subjective appreciation of the defect measured. For example, the transmission of a television signal over a long circuit results in distortion, and it is desirable to measure that distortion in precise terms which are related to the degree of subjective appreciation in the viewed signal. In the early days, the performance of transmission equipment was specified in terms of steady-state measurement of amplitude and delay distortion in a given frequency band. Although experience enabled broad limits to be set, it could not be said with any degree of certainty that these limits were necessary.

The problem was tackled by a number of organizations —particularly the General Post Office[31]—and the majority of television testing is now carried out by means of transmitting a waveform which has many characteristics in common with the television signal. The test waveform must have the property that it can be produced with reasonable ease in a precise form so that the deformation in that waveform can be accurately measured. These deformations can be related to an important degree to the subjective depreciation in the picture. Under these circumstances it is no longer necessary to carry out the complex measurement of television distortion as the preservation of the waveform is the key requirement.

The test signal which meets these requirements is a sine-squared pulse, i.e. the square of one half-cycle of a sine-wave. It is generated by passing a pulse of very short duration through an easily-reproducible low-pass filter network, and is combined in practice with a square-wave test signal and synchronizing pulses to form what is known as the 'pulse-and-bar' test waveform.

The output of the transmission system under test—which may be anything from a single video amplifier to a long series of links in tandem—is assessed by superimposing a special graticule on an oscilloscope display with an expanded time scale.

Having obtained a suitable method of measuring waveform distortion, it is desirable to deal with the distortion on a waveform basis rather than to refer back to steady-state measurements. Although in the present state of the art this is not always possible, correctors have been devised which enable two types of distortion to be corrected on a video-to-video basis. One of these is exponential distortion, so named because it is produced in networks where the current changes exponentially with time when a voltage step is applied; i.e. in various combinations of resistance and capacitance, or resistance and inductance.

This distortion can be corrected by a passive network. The other type is echo distortion, which is produced when a signal arrives at its destination over two different paths having different time delays, and sometimes opposite polarities. In this case, correction involves a tapped delay line, with amplifiers having their inputs connected to the tappings, and feeding to a common output.

Linearity has for many years been estimated by inspection of a linear sawtooth waveform, or by measuring the received amplitudes of a synchronizing pulse waveform with varying amounts of a full-line signal in the picture period. Considerable discussion on the measurement of linearity has taken place on an international level without full agreement being reached, but the BBC is now bringing into use the internationally recognized staircase waveform with five steps from black to white level.

The BBC has pressed for the general adoption of test signals incorporating a sine-squared pulse since this type of signal was first proposed, and the pulse-and-bar signal will soon supplant the older method entirely in testing vision links.

For a time, a test-line signal, consisting of the pulse-and-bar waveform together with the five-step staircase, was radiated during programme transmissions in the eleventh 'line' of each field blanking period. This enabled the radiated signal to be checked during transmissions, using line-selecting waveform monitors, and did not cause any visible interference in the vast majority of properly designed receivers. There were, however, a few complaints from viewers using receivers with very slow field flybacks and for the time being the use of the test-line signal during programme periods has been dropped.

Noise has for many years been measured as the quasi peak-to-peak noise amplitude displayed on an oscilloscope. This method gives very inconsistent results owing to such variable factors as trace brightness and ambient illumination, and it has been felt for some time that a meter display method, based on an r.m.s. noise measurement, would be much superior. Such methods are now being used for measuring random continuous noise in the presence of the television signal and are giving much better reliability.[32, 33] It is, of course, still necessary to use oscilloscope methods for measuring impulsive noise.

4.11 *Testing Methods and Laboratory Equipment*

Reference has already been made to the BBC performance specifications which have in some cases been adopted by manufacturers and broadcasting organizations in other countries.

A number of these performance specifications are based on new methods of testing, and some of the more significant of these methods are summarized below.

4.11.1 *Testing of Television Lenses*

It was shown by the BBC's Research Department in 1953[34] that the limiting resolution of a lens—which is usually quoted for optical purposes—is not the most realistic criterion of its quality when working in the finite bandwidth of a television system.

A lens whose spatial frequency response covers the television passband without loss of contrast is better for television purposes than a lens in which the limiting resolution may be much greater than that of the television picture, but in which the contrast falls off within the television band. The subjective impression of sharpness has been shown to be linearly related to the area under a frequency response curve, if the curve ends at the pattern frequency corresponding to the maximum television picture detail.

The method of obtaining the frequency response formerly involved Fourier transforms and was somewhat laborious, but it was replaced in 1958 by another method[35] which enabled the frequency response to be read directly from the output of a photocell.

4.11.2 *Testing of $4\frac{1}{2}$-in. Image Orthicon Camera Tubes*

The satisfactory operation of the one-man vision control demands camera tubes conforming to the specified performance within close limits, and the BBC has developed a series of objective tests[36] relating specifically to the $4\frac{1}{2}$-in. image orthicon tube operated with external contrast-law correction. Such tests would only be practicable with a tube having a stable black level and negligible redistribution effects, and with stable control potentials. These conditions are met by the $4\frac{1}{2}$-in. image orthicon working half a stop above the 'knee' in a channel meeting the specification devised for the Television Centre.

The principal parameters which are tested are:

Sensitivity
Contrast Law
Signal-to-noise ratio
Sharpness of picture
Geometrical distortion
Microphony
Uniformity of picture background (both white and black)
Freedom from spurious effects
Lag, sticking, movement blur, etc.
Colour response
Ease of adjustment
Freedom from drift

Space does not permit a detailed account of all these tests, which are fully described in the reference just indicated, but a few of the more interesting techniques may be briefly mentioned.

(*a*) *Sensitivity and Contrast Law*

The camera is exposed to a small square window in the middle of a dark surround, and the brightness of the window as well as the lens aperture is set to produce a known highlight brightness on the tube photocathode.

The resulting pulse in the output of the camera channel is viewed with a line-selecting oscilloscope, and is mixed differentially with a line 'spike' test waveform having a known amplitude and a duration of approximately 2μs. The camera is panned until the pulse and the spike waveform are overlapping, and the amplitude of the spike is adjusted with an attenuator until the camera pulse is seen to be just balanced out in the waveform display.

A neutral grey strip wedge is then placed in front of the window, and the balancing-out procedure is repeated with steps of increasing density. The two sets of readings enable signal output to be plotted against photocathode illumination, from which both the contrast law and the basic sensitivity for any given operating point can be derived.

(*b*) *Picture Sharpness*

As with television lenses, the criterion of sharpness is a high depth of modulation at the upper limit of the passband, rather than a very high limiting resolution.

Horizontal resolution is measured by observing the response to vertical test gratings—which should have a sinusoidal distribution of transmission—at various frequencies up to the limit of the passband, and expressing the peak-to-peak amplitude as a percentage of the black-to-white amplitude for large areas. It is of interest to note that the centre resolution of the best tubes at 3 Mc/s does not exceed 75 per cent. Vertical resolution is measured by a method due to Theile and Pilz known as 'field strobe'. A short pulse of about 4μs is generated at the same point on each line and applied as a brightening pulse to an oscilloscope scanning at field rate. With the camera channel output connected to the vertical deflection, the display gives a vertical 'slice' through the picture in the form of a series of small dots. If this display is used to observe the signal produced by a sharp horizontal step from black to white, the vertical resolution can be measured in terms of the time of rise or fall (measured in lines or fractions thereof). The field strobe can also be used to measure edge effect, which is most pronounced in this direction, while at the same time the measurement in the field direction is insensitive to the amplifier frequency and phase response.

(c) Colour Response

The method now used[37] gives an oscilloscope display of the spectral response of the tube to a tungsten lamp, together with calibration lines from a helium lamp.

A diffraction grating slit spectroscope is adjusted to produce a spectrum of a tungsten lamp of known colour temperature on the tube photocathode, and a displaced display of the spectrum of the helium calibrating lamp is also produced on the photocathode. If the lines of both spectra are parallel to the direction of field scan, a line selecting oscilloscope can display both the spectral response of the tube and the calibration lines.

(d) Time Required for Testing

The total time required to test a tube is approximately one hour, which is no longer than the time taken to perform some of the much less objective tests which the new procedure supersedes.

4.12 *Programme Distribution and Source Synchronization*

In planning the national simultaneous-broadcast network, it was insisted that as many of the permanent links as possible should be 2-way, and at present 900 route miles of the vision circuits which the BBC rents from the Post Office are 2-way links (i.e. 1,800 channel-miles), and 300 route miles are 1-way, making a total of 2,100 channel-miles. The 2-way links are more costly but they enormously widen the scope for relaying regional and outside broadcasts to the whole of the national network.

By 1955, the gradual improvement in the performance of the permanent simultaneous broadcast links and their associated return circuits had reached the stage where it became possible to reap the full benefit of the 2-way links and adopt continuity working, which had already been standard practice in sound broadcasting for some years. In this system all vision signals are routed through one central control room—whatever the point in the United Kingdom from which they originate—and afterwards distributed to the national transmitter network. This meant that an outside broadcast from, say, a place near Kirk O'Shotts was relayed a total distance of some 900 miles before being radiated by the Kirk O'Shotts transmitter. The procedure was nevertheless justified, because any alternative arrangement involved simultaneous mixing operations in different parts of the kingdom. This was very cumbersome and would have become progressively more so as the number of transmitters and potential programme sources continued to increase.

Since 1953, central synchronizing pulse generation has been used at the main London studio centre (Lime Grove and latterly the Television Centre). This makes it necessary to distribute the pulses from the central point to all the studios, telecine, telerecording, and similar areas from which picture signals originate, but it is the most satisfactory way of ensuring that pictures from all sources within the building are synchronized line-by-line at the final combining mixer in the Central Control Room. It is not possible to mix or superimpose two picture sources unless they are synchronized with a very close timing accuracy. The tolerance at the Television Centre has been fixed at 50 ns.

When picture signals are coming into the studio centre from an external programme source, e.g. a regional studio or an outside broadcast, it is not practicable to synchronize them from the central pulse generator, and the method of Genlock is used, whereby the central pulse generator is controlled by synchronizing pulses derived from the incoming asynchronous source. This cannot, of course, be done with more than one incoming signal at a time but if the Television Centre should ever be producing two programmes both might require Genlock at the same time. It would be excessively complex to provide two sets of synchronizing pulses, and the solution may be to use standards conversion to provide a synchronous signal from an asynchronous source, when Genlock is already in use on another asynchronous source.

4.13 *Television Standards Conversion*

Television standards conversion is a major factor in the post-war widening of the range of potential sources of programme material. The first practical conversion system, and most of the advances in conversion technique, have originated in the BBC Engineering Division.

As soon as regular television services had begun to appear in continental countries, both engineers and programme planners wished for a means of exchanging live programmes with these countries. Before this could be done, however, some instantaneous means of converting the transmission standards had to be found, as none of the new services had the same standards as the BBC.

In 1950 the BBC mounted a live outside broadcast from Calais, using four radio links in tandem, including one across the Channel. This was a considerable technical achievement but it was not a true international programme exchange, as the pictures were not immediately available to French or any other viewers outside Britain.

Various writers had proposed solutions involving the use of some form of storage tube, in which a charge pattern would be built up by a scanning beam working on the original standard, and would then be 'read' by a second scanning beam working on the converted standard, but no practical realization of this arrangement had been produced. The obvious method was to televise a picture on the original standard with a camera working on the new standard but experiments on these lines—using the picture tubes and camera tubes in genral use at the time—had given very unpromising results. Early in 1952, however, the BBC Research Department showed that this basic method was perfectly feasible if certain precautions were taken.[38]

Experiments on such a convertor have revealed that three main problems required solution before satisfactory results could be obtained. The first of these arises because the primary picture as displayed on the cathode-ray screen may be regarded as an intensity-modulated light spot rather than a continuous image. If the camera used in the apparatus can behave as a simple photo-electric cell, a signal will appear at the convertor output which corresponds to the brightness variations of the cathode-ray tube spot. In this manner an unconverted component of the input signal will appear at the convertor output.

A second difficulty encountered when a camera is arranged to view a television image arises from the interference or strobing patterns produced when the scanning beam of the camera tube explores the line structure of the image to be converted.

The third fundamental problem is associated with any difference of field frequency which may exist between the two standards. Such a frequency difference may result in a cyclic variation of the vertical distance on the target of the camera tube separating the image of the cathode-ray tube spot and the camera scanning beam. The properties of both the cathode-ray tube phosphor and the camera tube are very important in this respect.

In the BBC convertor the difficulties were overcome by the combined effect of (*a*) using a picture tube with an afterglow of about one-third of a field period, and (*b*) using a camera in which the output signal does not carry a superimposed signal representing the total amount of light, i.e. the image orthicon. The inter-line spaces in the picture to be converted must be filled in by line broadening or spot-wobble, in order to avoid a beat pattern caused by the difference in the two line-scanning frequencies.

Using experimental convertors of this type, 819-line pictures from Paris were converted to 405-lines and broadcast by the BBC in July 1952. A similar type of convertor developed by French engineers was used to feed the 441-line service in Paris, which was then running side by side with the 819-line service. When the original pictures were satisfactory and the links were working properly, the method was quite successful.

Standards Convertors for 50/60 *c/s*

The exchange of live programmes with the American continent has yet to be achieved. The American television systems have a field frequency of 60 c/s, and the conversion system just described produces considerable flicker when the field frequencies differ by as much as 10 c/s. Means have been devised, however, for cancelling out this flicker,* and these have already been used for reproducing telerecordings on magnetic tape taken on the American standard and reproduced on the British standard, and vice versa.[39] This system will be equally suitable for converting live picture signals if a transatlantic vision link should ever become available.

The method used is to insert a reference pulse at the end of each line before the signal is applied to the cathode-ray display tube, so as to produce a bright stripe on one side of the displayed picture. A pulse corresponding to this stripe appears in the output of the camera, and this, like the picture information, is modulated at the difference between the field frequencies. This pulse is then selected by a gate and used to control the gain of an amplifier, so as to cancel out the flicker automatically.

* British Patent Application No. 3875, 1960.
British Patent No. 801140.

The camera tube used in this convertor is a c.p.s. Emitron, in which the mechanism of signal generation is basically similar to the orthicon.[40] This tube has the important advantages of a linear transfer characteristic, stable black level, no shading signals, and negligible 'sticking'.

The c.p.s. tube is one of the types displaying the photocell effect which has already been mentioned, but this is corrected by providing a separate photocell which views the whole area of the display screen. The output of this photocell is proportional to the total light emitted by the screen, and can therefore be used to cancel out the unwanted signal in the output of the camera tube.

The BBC has granted a permit to an American company permitting it to manufacture, or have manufactured, standards conversion equipment in accordance with the BBC design: the equipment is made by a British firm, which is also permitted by the BBC to make and sell equipment.

4.13.1 *Eurovision*

In June 1953, pictures of the Coronation were relayed by France, the Netherlands, and Western Germany. The main development of Eurovision started in 1954, by which time television services had begun in Denmark, Belgium, Switzerland, and Italy. In the June of that year, the television services of these four countries, together with those of Great Britain, France, the Netherlands, and Western Germany, were connected for a period of a month, during which each of the various services contributed, in turn, programmes for the benefit of all the other seven. Shortly after this, the European Broadcasting Union started to undertake the co-ordination of programme exchanges in both technical and programme spheres, and co-operation between the broadcasting authorities and the national P.T.T. administrations, already effective, was further strengthened. An International Technical Co-ordination Centre was established by the E.B.U. in Brussels.

In November 1957, the BBC began using $4\frac{1}{2}$-in. image orthicon cameras (with their very high signal/noise ratio) in its convertors, and at the same time restricted the contrast range of the unconverted picture to about 5 : 1 in order to keep the voltage/light transfer characteristic almost linear. The net result has been a conversion of such high quality that it adds very little distortion to the final picture. Besides converting incoming 625- or 819-line pictures to 405 lines, the BBC is now undertaking the conversion of outgoing signals from 405 to 625 lines. The horizontal definition of the 625-line picture need not be appreciably degraded by its being derived from a picture of a lower standard (as might be thought), since the horizontal resolutions of a 625-line 5·5-Mc/s picture and a 405-line 3-Mc/s picture are almost equal.

In September 1955, the BBC radio links between the cross-Channel terminal near Dover and London were replaced by a coaxial-cable circuit installed by the Post Office. The BBC and R.T.F. continued jointly to operate the cross-Channel radio links until July 1959, when a permanent Post Office radio link was brought into service.

The BBC standards convertors are now installed in the Post Office terminal station at Tolsford Hill, near Dover.

Both the technical and the administrative co-ordination of these exchanges is undertaken by the E.B.U. During the past year, additional equipment has been installed at the E.B.U. technical co-ordination centre in Brussels to enable direct executive action to be taken there in switching certain Eurovision circuits. This has become necessary because of the increasing complexity of the vision network and of the lines that carry the accompanying sound. Members of the BBC engineering staff are seconded to the E.B.U. for this work and others are lent for short periods from time to time.

The number of television programme exchanges in which the BBC was involved during 1960 was:

Incoming 259
Outgoing 117

By 1960, twenty television services in sixteen countries had been linked together by the Eurovision network.

The first live television relay from Russia took place on 14 April 1961 when BBC viewers saw the arrival of Major Gagarin in Moscow. For this broadcast, it was arranged at very short notice that a receiver in Helsinki should pick up the Russian broadcast transmission from Tallinn—a distance of sixy miles—and relay it on the Eurovision network. A permanent s.h.f. link between Tallinn and Helsinki, which was installed in time for the May Day celebrations, had intermediate relay points on the Russian island of Naissaar and the Finnish island of Porkkala.

4.14 *Test Cards and Transparencies*

There was a need for a test card which would give a comprehensive range of checks of as many aspects of the performance of a television chain as possible, and the BBC test card C, which was devised in 1949, fulfils this need well enough for it to have been adopted by a number of other television services. This card provides simple checks of the following fundamental ingredients of a good television picture:[41]

Aspect Ratio
Resolution and Bandwidth
Contrast Law
Scanning Linearity
Separation of Picture and Sync. Signals
Low-frequency Response
Reflections
Uniformity of Focus.

This card is still widely used, both in the form of a card and of a transparency. It is included in the daily Trade Test Transmissions, and is used for general-purpose checks within the transmission network, but it has recently been supplemented by other transparencies for more specialized checks. Among the more interesting of these is the BBC Test Transparency No. 51[42] for testing camera channels. This uses a specially selected picture with a density wedge and resolution gratings superimposed. The density wedge has eleven steps, each of 0·15 density change, and the gratings have a sinusoidal distribution of transmission, instead of the normal square wave produced by alternate black-and-white strips of equal width. This is important for accurate measurement of the response at any frequency whose third harmonic lies outside the passband of the system, as the subtraction of the harmonics by the system produces an artificially high response at the fundamental. If the grating is a perfect square wave and the system responds to the pure fundamental only, the reading will be $4/\pi$ times too large.

4.15 *Cable Film*

The use of the transatlantic telephone cable for the two-way transmission of news films for television between Europe and America began in June 1959, using a system and equipment developed by BBC engineers.[43] In this system, known as Cablefilm,* the film is run at low speed through a film scanner and the vision signals so obtained are made to modulate a carrier of 5 kc/s which is transmitted over the cable. At the receiving end the film is reconstituted by a telerecording apparatus and shown at the normal speed.

Consideration of the phase characteristics of the cable, using two 3-kc/s speech circuits, indicated that a maximum video frequency of 4·5 kc/s could be used. It was therefore necessary to effect as many economies in the bandwidth of the video signal as are compatible with acceptable picture quality. These economies are as follows:

Restriction of the horizontal definition to that corresponding to a bandwidth of 1·75 Mc/s in the 405-line television system.

A reduction to 200 lines using sequential scanning.

The scanning at the transmitting end of only alternate film frames with each frame-scan reproduced on two adjacent film frames at the receiving terminal.

These measures result in reducing the 3-Mc/s bandwidth of the British television system to approximately 450 kc/s, the remainder of the bandwidth reduction being obtained by a decrease in the scanning speed until the maximum video frequency corresponds to the available 4·5-kc/s upper limit. The time required to scan the film is approximately 100 times normal and thus a half-minute news flash takes approximately fifty min. to transmit.

Complete television programmes recorded as film are freely exchanged internationally; this presents no major technical problem.

Programmes are also exchanged on magnetic tape, although, as stated in Section 4.4., unless the television standards of the exchanging organizations are the same, standards conversion equipment must be employed.

The BBC has made recordings, via such a converter, direct on to magnetic tape using the American 525-line 60 field/sec. standards so that the tapes could be reproduced immediately on arrival in the United States. These recordings included such items as the 'Little Summit' in Paris in December 1959 and H.R.H. Princess Margaret's wedding in May 1960.

* British Patent Application Nos. 16,323, 18,277, and 18,853, 1959.

4.16 *Training of Staff*

The rapid development of television, coupled with the national shortage of trained engineers, technical assistants, and technical operators, and the competition from Independent Television, created a major problem in the recruitment and training of technical staff. The BBC's Engineering Training Department provides regular courses for recruits and for staff seeking promotion to the higher grades, as well as refresher courses for established staff and special courses in particular techniques such as colour television and video tape recording. Selected engineers from Commonwealth countries have been accepted both for formal courses and for training attachments to the various departments of the Engineering Division, and information and assistance have been freely given to such countries to help them in developing their own television services.

5. Present State of Development

5.1 *London and Regional Studio Centres*

In its Television Centre in London, opened in June 1960, the BBC already has one presentation suite and four main production studios in full operational service, whilst three further production studios and a second presentation suite are to be equipped. Five telecine channels are installed and working together with three video tape channels. A new International Control Room to handle all incoming and outgoing television programmes to the Continent was brought into service in August. Further studios and their associated technical areas are planned for inclusion in the 'spur' extension on which construction is expected to begin about 1965.

Construction of a new Television Centre for Scotland has already started in Glasgow and similar centres are planned for Cardiff, Manchester, and Birmingham.

More detailed information on the studio facilities in London and the Regions is given in the following sections.

5.2 *Existing Studio Facilities in London*

Studio	*Area in sq. ft*	*Number of Cameras*	*Studio Service Date*
Television Centre			
2*	3,500	3	10.5.61
3*	8,000	4	29.6.60
4*	8,000	4	8.1.61
5*	3,500	3	29.8.61
Presentation A	800	2	13.9.60

NOTE: Six cameras can be made available in Studios 3 and 4 and four in Studio 2.

Studio	*Area in sq. ft*	*Number of Cameras*	*Studio Service Date*
Lime Grove			
D*	5,400	4	21.5.50
E*	4,800	4	21.8.53 (withdrawn for re-equipment 13.5.61)
		4	10.7.61
G*	6,000	4	23.12.50
Riverside			
1*	6,000	4	25.9.56
2	4,480	3	4.6.56
Television Theatre			
*	2,000	4	15.10.53
Alexandra Palace			
B	2,100	3	2.11.36 Re-equipped for News 27.6.55
		2	Remotely controlled cameras, 10.6.61
London Airport (M.C.A.)			
		1	26.10.56

This studio is manned as required by staff based at Alexandra Palace.

Studio	*Area in sq. ft*	*Number of Cameras*	*Studio Service Date*
All Souls' Hall	600	1	8.5.56

Camera remotely controlled from All Soul's control room.

Studio	*Area in sq. ft*	*Number of Cameras*	*Studio Service Date*
St Stephen's Hall	100	1	29.10.57

This is an 'unattended' studio. The sound equipment is switched on by the commentator and the camera channel, monitor, and lighting equipment mains supply is remotely switched from Alexandra Palace.

* Inlay facilities available in these studios.

5.3 *Existing Studio Facilities in the Regions*

Studio	*Area in sq. ft*	*Number of Cameras*	*Studio Service Date*
Birmingham			
Gosta Green	5,000	3	30.3.58 (drive in basis 29.12.55)
Broad Street	380	1	24.11.58
Bristol			
B.H. Studio A	2,500	3	26.10.53

(St Katherine's Hall has temporarily replaced Studio A from 1.4.61. The enlarged Studio A is expected to be in service by mid-1962.)

Studio	*Area in sq. ft*	*Number of Cameras*	*Studio Service Date*
Interview Studio	480	1	14.5.58
Cardiff			
Broadway Television Studio A	3,300	3	22.12.59 (drive in basis 1.12.57)
Broadway Interview Studio B	1,200	1	15.8.59
Glasgow			
Springfield Road	3,800	3	16.8.57
B.H. Studio 3	820	1	1.5.55

* Inlay facilities available in these studios.

Studio	*Area in sq. ft*	*Number of Cameras*	*Studio Service Date*
Manchester			
Dickenson Road	3,300	3	3.4.56
B.H. Interview Studio	960	1	16.12.59
Belfast			
Studio 8	1,300	2	20.2.59
Newcastle			
Studio 1 B.H.	400 for television (1,000 overall)	1	5.1.59
Norwich			
Interview Studio St Catherine's Close	400	1	5.10.59
Southampton			
Interview Studio South Western House	400	1	30.7.58
Plymouth			
Interview Studio	400	1	20.4.61

5.4 *Outside Broadcast Facilities*

London

3 Mobile control rooms (m.c.r.s 14, 15, and 16)
7 Radio link vehicles
2 Eagle tower vehicles
2 P.T.A. fire-escape aerial vehicles
1 Roving Eye II and receiving tender
1 Land Rover (single camera channel)
2 Foreign commentary vehicles
1 Land Rover starting price unit
2 Radio camera vehicles
1 Mobile video tape recorder (multistandard)

Midland

1 Mobile control room (m.c.r. 10)
6 Radio link vehicles
1 Eagle tower vehicle

North

1 Mobile control room (m.c.r. 13)
6 Radio link vehicles
1 Eagle tower vehicle
1 Land Rover (single camera channel or radio link equipment)
1 Humber Snipe (high-speed experimental single-channel Roving Eye)

West

1 Mobile control room (m.c.r. 12)
5 Radio link vehicles
1 Eagle tower vehicle
1 Mobile video tape recorder

Scotland

1 Mobile control room (m.c.r. 11)
6 Radio link vehicles
2 Eagle tower vehicles
1 Mobile video tape recorder

Wales

1 Mobile control room (m.c.r. 9)
6 Radio link vehicles
2 Eagle tower vehicles

Northern Ireland

1 Mobile control room (m.c.r. 18)
1 Radio link vehicle
1 Eagle tower vehicle
1 Mobile video tape recorder

All m.c.r.s except m.c.r.s 13 and 18 are equipped with three camera channels. No. 10 has Marconi Mk 1B 3-in. image orthicon cameras, Nos. 11 and 12 have Pye 3-in. image orthicon cameras, and all others have Marconi Mk III $4\frac{1}{2}$-in. image orthicon cameras. m.c.r. 13 is equipped with four and m.c.r. 18 with two Marconi Mk IV $4\frac{1}{2}$-in. image orthicon camera channels.

Roving Eye II is equipped with 2×3-in. Marconi Mk 1B image orthicon cameras.

The Land Rover single camera units and the Humber Snipe high-speed experimental Roving Eye are each equipped with a $4\frac{1}{2}$-in. image orthicon camera channel from one of the m.c.r.s as required.

5.5 *BBC Transmitting Stations*

Station	Channel	Frequency		Effective radiated vision power	Polarization	Opening date
		Sound	Vision			
		Mc/s	Mc/s	kW		
Crystal Palace	1	41·50	45·00	200	V	28.3.56
Divis				12	H	12.7.55
Sheffield				0·05	H	19.12.60
Thrumster				0·25–7	V	15.12.58
Holme Moss	2	48·25	51·75	100	V	12.10.51
Dover				0·05–1·4*	V	21.4.58
North Hessary Tor				1–15*	V	17.12.54
Whitehawk Hill (Brighton)				0·4 max.*	V	5.8.59
Rosemarkie				1·5 max.*	H	16.8.57
Londonderry				1·5 max.*	H	18.12.57
Kirk o'Shotts	3	53·25	56·75	100	V	14.3.52
Rowridge				1–32*	V	12.11.54
Talconeston (Norwich)				1·3–15*	H	1.2.55
Blaen-Plwyf				1–3*	H	29.4.57
Sutton Coldfield	4	58·25	61·75	100	V	17.12.49
Sandale				10–28*	H	5.11.56
Folkestone				0·007 max.*	H	14.7.58
Les Platons				1	H	3.10.55
Meldrum				4–17*	H	12.10.55
Hastings				0·002	H	14.12.60
Wenvoe	5	63·25	66·75	100	V	15.8.52
Pontop Pike				12	H	1.5.53
Douglas, Isle of Man				0·18–2·8*	V	20.12.53
Orkney				4–14*	V	22.12.58
Peterborough				1	H	5.10.59

* Directional aerial.

The population coverage of the above stations is 98·8 per cent of the population* of the United Kingdom (100 μV/m contour). It should be noted that there are a number of 'pockets' situated within the 100 μV/m contour where reception may be poor because of local screening; in some areas, reception may also be unsatisfactory at times because of co-channel or foreign interference.

5.5.1 *Proposed BBC Television Satellite Transmitting Stations*

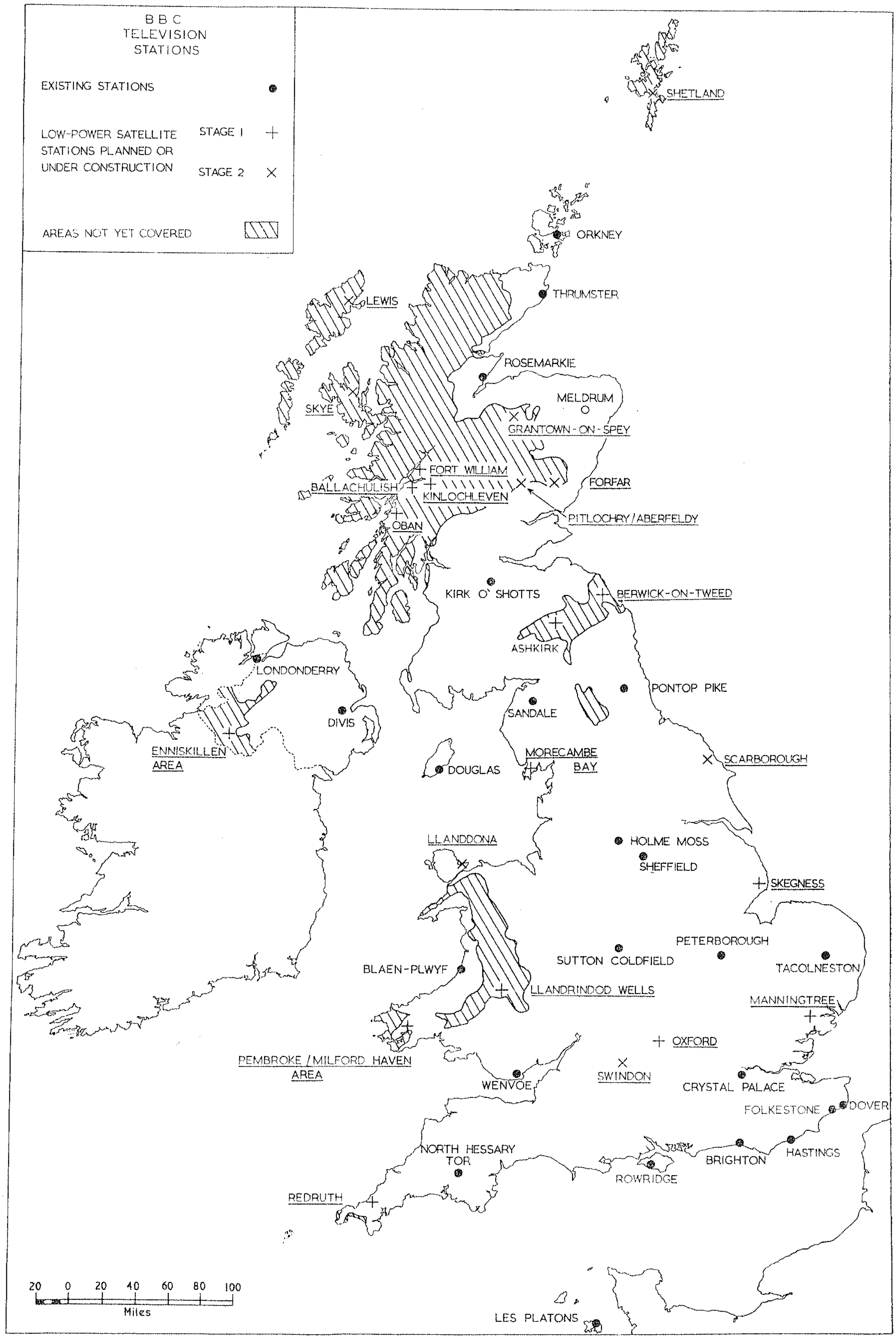
Until sites have been chosen and technical operating conditions agreed, it is not possible to predict exactly the improvements in coverage which the above stations will achieve. It is estimated, however, that the twenty-three stations will increase the coverage by some 300,000 (0·6 per cent) and give improved service for a further 1,400,000 people.

* The total population (1951 Census) was 50,369,000.

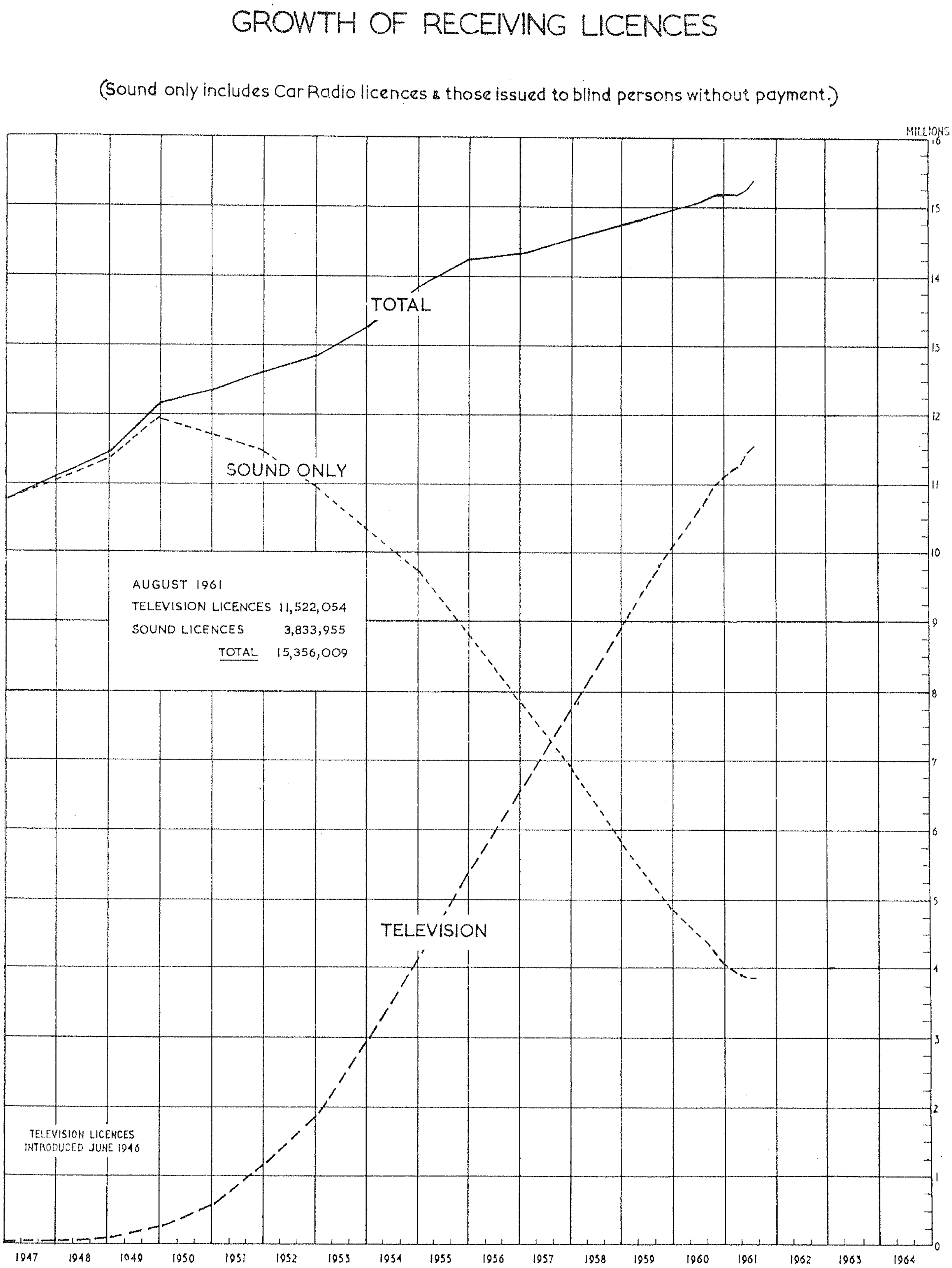
Stage I	*Stage II*
Fort William	Forfar, Angus
Ashkirk (Galashiels)	Grantown-on-Spey
Berwick-on-Tweed	Lewis
Llandrindod Wells	Pitlochry/Aberfeldy
Kinlochleven (Loch Leven)	Shetland
Oban	Skye
Beckley (Oxford)	Llanddona
Redruth	
Morecambe Bay	Scarborough
Eniskillen area	Swindon
Manningtree	
Pembroke	
Skegness	
Ballachulish	

Stage I is due to be completed during 1961 and 1962; construction of the stations in Stage II is proceeding concurrently and it is expected that most will be completed by the end of 1963 and the remainder in the spring of 1964.

5.6 *BBC Television Coverage*



5.7 *Growth of Broadcast Receiving Licences*



5.8 *Picture Sizes and Prices of Receivers*

The cost of television receivers over the twenty-five years has been substantially reduced and the screen size increased as the following table shows.

Table of Average Price and Screen Size for Direct Viewing Television Sets

Year	*Screen Size in inches*	*Typical Price (including purchase tax where applicable)*
1936	9	£80
1938	7 or 9	£75
1939	5	£24
1950	9	£46
	12	£69
	14	£156
1960	14	£56
	17	£65
	19	£68
	21	£82
	23	£97

The foregoing figures apply only to direct viewing models. The projection type of receiver, popular at one time by virtue of its large screen, has now been almost entirely superseded by direct viewing types with the exception of large screen projection equipment developed for special purposes, such as the Eidophor projector. This equipment, which has been used by the BBC—notably in the *Insight* series of programmes—front-projects a picture derived from a standard television video signal on to a cinema size screen for viewing by an audience.

6. Current and Future Development

6.1 *Situation in* 1961

In September 1960, the Postmaster General appointed a committee under the chairmanship of Sir Harry Pilkington to inquire into the future of sound and television broadcasting. Future engineering developments will depend on the recommendations of this committee and on such governmental action as may result.

The work done by the BBC on the appraisal of picture quality and the measurement of noise has provided important data for consideration in the choice of a television standard, and the BBC's view on the 625-line standard has already been stated. In the following pages, the BBC's contributions to other probable lines of future development are reviewed.

6.2 *Colour Television*

The BBC has been carrying out research and development on colour television since the resumption of the television service after the war. In the early post-war years an experimental sequential system with mechanical colour separation was developed, and a considerable amount of research was carried out on the fundamentals of trichromatic colorimetry as applied to television.[44,45]

By 1953, the consensus of opinion was (as it still is) that no public colour television service could be contemplated unless it were compatible, i.e. the transmissions were of a form which would enable existing monochrome receivers to produce black-and-white pictures. It seemed unlikely that compatibility would be achieved with any system which was not effectively simultaneous, and the first report of the Television Advisory Committee[46] pointed out that the impossibility of increasing the channel spacing in Band I (41–68 Mc/s) would necessitate a fully compatible system if colour transmissions were made in this band. Towards the end of 1953 the BBC Research Department began the development of an adaptation of the American N.T.S.C. fully compatible simultaneous colour television system to the British 405-line standard.

On 7 October 1954, the first 'compatible' type of colour television picture was radiated from the medium-power transmitter at Alexandra Palace. The pictures included slides and 16-mm motion pictures, and the details of the standards employed on this occasion differed little from those employed regularly from 1955 until the present time. On this historic occasion only one colour television receiver, so far as is known, displayed the pictures, but there was a fair-sized audience viewing the compatible black-and-white pictures in their homes on normal domestic television receivers. Although many hundreds of tests were subsequently necessary to prove the point, it seemed to the observers of this first transmission, which was a co-operative effort of the Research Department of Marconi's Wireless Telegraph Co. Ltd and the BBC Engineering Division, that in this adapted N.T.S.C. system there existed a standard capable of providing excellent colour pictures and compatible ones of good quality.

During the winter of 1955–6 a regular series of transmissions was radiated from the medium-power transmitter at Alexandra Palace, with the primary purpose of testing the compatibility of the pictures on a comparatively large sample of domestic receivers. Again, only slides and pictures from 16-mm motion film were used, this time the equipment being of BBC design and manufacture. In the meantime, Studio A at Alexandra Palace had been equipped with a single three-tube colour camera of Marconi design, and the first occasions on which colour pictures including scenes from the studio were broadcast occurred on 3, 4, and 5 April 1956 during a special demonstration for delegates of Study Group IX of the C.C.I.R.* who were visiting this country as part of a world-wide assessment of the state of development of colour television. The programme of this demonstration was probably the most comprehensive which has yet been given, and was as follows:

Colour pictures were first shown using three separate full-bandwidth links to convey the R, G, and B signals, in order to show the performance of the R.C.A. 21-in. shadow mask tube independently of the N.T.S.C.-type coding and decoding system. Pictures were then shown after passing the signals through the coding and decoding circuits in the following alternative forms:

* Comité Consultatif International des Radiocommunications.

1. Composite video signal over a single cable link (to estimate the effectiveness of the Band-sharing system).
2. Chrominance and luminance over separate cable links (to estimate whether the transmission of luminance in a separate channel might improve picture quality).
3. Sound and composite vision signals transmitted by radio on the Band I, Channel 1 frequencies. (To observe whether any deterioration of picture quality or mutual interference between sound and vision were noticeable.)

The effects of varying the bandwidth of the 'I' or in-phase component of the chrominance signal, of impulsive and random noise interference and of varying errors in subcarrier phase, were also demonstrated.

In all cases where a 'Y' or luminance signal was available the picture was also presented on a black-and-white receiver having the same picture size.

By the autumn of 1956, Studio A at Alexandra Palace had been equipped with a second experimental colour camera and, a little later, a 35-mm Cintel film scanner was installed to supplement the slide and 16-mm film scanner. With this equipment and with the enthusiastic help of a small group of programme staff, an ambitious and comprehensive series of programmes was broadcast, this time from the Crystal Palace transmitter, in the winter of 1956–7 and was observed in people's homes on specially developed experimental colour receivers and also, of course, on a large number of black-and-white domestic sets. The details of this series of tests and the results obtained therefrom have been fully described in Monograph No. 18.[47] On 30 and 31 January 1957, a special programme was broadcast and shown to a large audience of Members of both Houses of Parliament on six receivers installed in a room in the House of Lords.

During the winter of 1957–8 a further series of experimental programmes was broadcast from the studio at Alexandra Palace and was seen by a rather bigger audience on colour receivers than in the previous year.[48] At the conclusion of these tests in 1958 the studio at Alexandra Palace was dismantled and the cameras installed temporarily in a van which carried out two outside broadcasts. The slide- and film-scanning equipment was moved to the Lime Grove Studios whence a regular series of transmissions outside normal programme time has been given, beginning in the autumn of 1958 and continuing with only short breaks to the present time.

The BBC demonstrated colour television to the public for the first time at the National Radio Show at Earls Court in 1961. Live transmissions from a glass-sided studio as well as film transmissions were demonstrated on six 21-in. monitors. Each colour monitor had a 21-in. black-and-white monitor alongside it to demonstrate compatibility. Only a small minority of the public or of dealers had seen any colour television previously, and both groups were favourably impressed.

6.3 *Television Broadcasting on UHF*

In 1956 the Television Advisory Committee recommended that transmissions should be carried out in the ultra-high frequency bands (Nos. IV and V) to assess the potentialities of these bands for television broadcasting, and experimental transmitters for both bands were installed at the Crystal Palace television station. The Band IV tests were carried out with a low-power transmitter radiating square-wave-modulated signals at 495 Mc/s, but the Band V installation included transmitters for both vision and sound, with a vision transmitter power of about 10 kW and an e.r.p. of 125 kW from a helical aerial at a height of 690 ft. The transmitters could be modified to work either on a 405-line system (with a.m. sound) or a C.C.I.R. 625-line system (with f.m. sound), the vision carrier frequency being 654·25 Mc/s in both cases. In addition to the BBC a number of other organizations participated in these field trials, which were the most comprehensive series of UHF television propagation tests yet conducted in any country. The trials are fully described in another BBC publication,[10] and the mobile field-strength measuring laboratory developed by the BBC is described in an earlier BBC Engineering Monograph.[49]

The main conclusions of the trials—which applied equally to a 405-line or a 625-line service—were that over a terrain such as south-east England, the first-class service area of a Band V transmitter with an e.r.p. of 1,000 kW would be comparable in size to, but more irregular in shape than, that given by the present Band I transmitter with an e.r.p. of 170 kW at 45 Mc/s.

The second-class service area obtained would also be of approximately the same actual size as that given by the Band I station but, on the higher frequencies, the topography would materially modify the shape of the area with respect to the present Band I coverage, with consequent changes in the numbers of viewers served.

Owing to the greater dependence of the Band V signal on topography, the contours of both the first- and second-class service areas would be more irregular in the case of Band V, and this would increase the number of transmitters needed to give national coverage.

6.4 *Television Bandwidth Compression*

The performance of long-distance television links in the continent of Europe has by now been so improved that there is no urgent need for a system of channel reduction, indeed the sound and control lines associated with the vision circuits often present more operational complications because the commentary in sound may have to be carried in several languages simultaneously, whereas the picture is usually common to all the receiving countries. The problems involved in the transmission of television over long sea paths would, however, be considerably alleviated by an efficient and practical system of bandwidth compression.

The BBC Research Department recently carried out an investigation[50] of three proposed systems of bandwidth compression. All three methods are variants of the idea of quantizing the essential brightness changes in the picture waveform into relatively few discrete amplitude levels: these are then redistributed to occur at a uniform rate for transmission. A second signal must be transmitted in order to allow correct repositioning of the brightness changes in the final picture. Full instrumentation of any of the systems would be complex.

Subjective tests were arranged, in which each of the systems was made to reproduce a 405-line picture (which normally requires a 3-Mc/s bandwidth) in a 1-Mc/s channel. The results were not encouraging. None of the systems showed any marked superiority over the pictures produced by a much simpler 'crispener'[51] circuit, in which the signal was passed through a 1-Mc/s low-pass filter, and the 'edges' were then sharpened by a circuit which steepened any positive-going or negative-going steps exceeding a predetermined amplitude. The crispener circuit does not, of course, restore details removed by the low-pass filter but the sharpening of the edges produces a subjective impression of increased bandwidth.

None of the systems seemed likely to offer enough bandwidth-saving to enable a television signal to be sent over a long-distance telephone cable or radio link.

7. Conclusion

This paper describes the major developments which have been landmarks in building up the BBC Television Service in the past twenty-five years. In retrospect it is clear how a small number of decisions by the Government, by the Television Advisory Committee, and by the BBC itself has made a major contribution towards the successful technical development of television in this country, which has led the world in this field.

A world-wide service of news and entertainment by television, colour, improved picture quality, more programmes, all will become available in the next few years. Continued progress in the field of electronics will make these developments possible and research will be as important and its range as fundamental as the initial work which preceded the start of a public service of television twenty-five years ago.

Prospects for television are exciting and full of interest. The BBC looks forward to being authorized to provide at least two and perhaps three programmes with many of the items in colour. For transmitting these new programmes, new transmitters giving nation-wide service will be needed in the UHF bands, as yet unused for television in this country. The BBC believes that the extension of television to these new bands should provide the opportunity for changing the line standard from the present 405 lines to 625 lines, which is the standard already used in all other European countries, except France (where this new standard will be adopted for the second television programme and possibly later on for the present programme as well). In the past ten years improved cameras, improved receiving sets, and improved methods of testing have brought about a noticeable improvement in picture quality.

The BBC pays tribute to the many engineers in the United Kingdom and in other countries who have contributed to the knowledge and progress of the art. It looks forward to maintaining the fruitful association with engineers of the General Post Office and of the radio industry which has marked the first twenty-five years of the world's first high-definition television service.

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