EBU – TECH 3095

Review of existing systems for the synchronisation between film cameras and audio tape-recorders

Legacy text (February 1973)

Status: Rescanned (OCR) from original.

Geneva
March 2006

Page intentionally left blank. This document is paginated for recto-verso printing

Please note that this text has been scanned and OCR'd from a paper copy. Typos have been corrected and some sentence structures simplified in the original text but the diagrams are scanned, not redrawn.

Contents

Page intentionally left blank. This document is paginated for recto-verso printing

Review of existing systems for the synchronisation between film cameras and audio tape-recorders

EBU Committee	First Issued	Revised	Scanned as legacy text
Working Party G	1973		2006

Keywords: Audio tape-recorder, Film camera, Synchronisation

INTRODUCTION

The coverage of topical events and the production of documentaries constitutes a substantial part of the activities of all television services. To carry out such operations, it is essential that the equipment employed shall be light in weight and easy to operate and for these reasons the 16 mm film camera has for many years been chosen for operations of the type in question.

To provide greater flexibility in editing, the sound component is almost universally recorded on a separate audio tape-recorder and, for reasons of economy, bulk and technical quality, ¼-inch (6.25 mm) magnetic tape is generally adopted. However, this is only an intermediary, because the sound is subsequently transferred to a magnetic film of the same gauge as the picture film. A given length of sound film then corresponds to the same length of picture film, making editing and synchronisation possible.

Nevertheless, there are disadvantages in using separate supports for the initial recording of picture and sound. While it is running, the magnetic tape may slip or stretch and the drive itself may not be constant. In such circumstances, the correspondence referred to above may not be achieved and hence the introduction of synchronising systems designed to provide, at all times, information about the respective positions of the picture and accompanying sound, so that any possible relative shifts occurring during the running may be corrected during the transfer operation.

Several systems have been developed and in use for many years. The present document has been prepared by collaboration of members of Sub-group G3 of EBU Working Party G: it describes commercial systems and those developed within the television services of EBU members.

The most commonly adopted method of synchronisation involves the generation in the camera of a reference signal and the recording of that signal on a special track on a magnetic sound tape. The synchronising signals relate directly to the running speed of the film camera and, as recorded on the magnetic tape, may be considered as “magnetic perforations”. Various methods are used to prevent the synchronising signal from interfering with the recorded sound track. The first part of this document describes some of the solutions and gives details of the positions of the recording heads for the programme and synchronising signals.

However, such systems require a cable between the camera and the audio tape- recorder and this places a restriction on the freedom of movement of the cameraman. In order to avoid that disadvantage, means have been devised of generating synchronising marks separately in the camera and the tape-recorder. Sufficently precise synchronism has been obtained by making use of separate quartz-crystal oscillators for controlling the speed of the camera and the generation of the pilot- tone in the tape-recorder.

Synchronous running may be assured in that manner, but the elimination of the cable between the camera and the tape-recorder makes it impossible to record the start of a camera shot automatically or to operate with more than one camera. A normal development consisted of extending the classical pilot-tone system by transmitting the camera start and stop signals by radio. Systems have been developed in which a radio transmitter mounted on the camera works in conjunction with a receiver incorporated in the tape-recorder; the start, stop and identification signals from several cameras being used together are recorded in the form of coded modulation of the crystal-controlled pilot-tone. These systems are described in the second part of this document.

Nevertheless, none of these systems represent the ultimate solution to the problem. The modern tendency towards simplified operational methods, with neither cables nor auxiliary transmitters, is leading at the present time to the design of a system in which timing reference marks are recorded simultaneously on the sound tape and on the film. The EBU is examining the possibility of standardising a coding system and the tentative requirements for it are described in document Tech. 3096.

PART ONE

RECORDING SYSTEMS USING CABLES FOR THE SYNCHRONISATION

1. Introduction

The simplest and most reliable method of ensuring the synchronous working of a film camera and an audio tape-recorder consists of connecting them together by a cable which feeds to the tape-recorder signals representing the movement of the film in the camera. That system obviously has a considerable disadvantage from the operators' point of view, that is to say, the lack of relative mobility. The sound recordist is tied physically to the cameraman, and the coverage of events in crowdad locations, for example, involves almost gymnastic performances on their part to prevent the members of the public from getting caught up in their cables. Nevertheless, that is the method that has been used for very many years and which, still today, is the most commonly employed. A cable is a reliable linking element. Even when it was a question of developing a system suitable for working with several cameras at the same time, Danmarks Radio retained the principle of connection by cable.

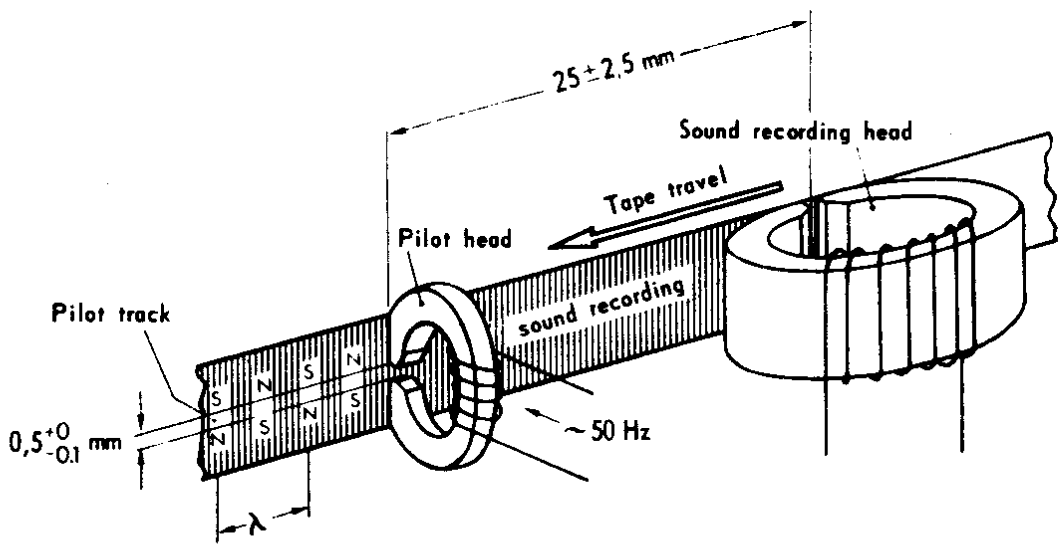
However, the simultaneous use of several cameras imposes additional restrictions: if they are supplied from a battery, only the camera linked to the tape-machine can supply synchronous pictures. If it is required that they can all be used synchronously, they must be powered synchronously by a common A.C. supply.

In any case, the evolution of film operations advances inevitably toward increased mobility, and at present technical design is being orientated in the direction of the development of self-contained units. We shall discuss their principles in Part Two of this document.

Note: In the drawings showing the position of the heads on the sound tape, the synchronising heads are identified by broken shading, and the programme heads by continuous shading.

2. Synchronisation of an audio tape-recorder with a single camera

2.1 The pilot-tone method

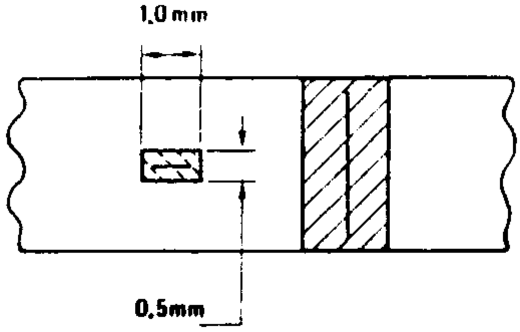


The principle of the method consists in recording on the sound magnetic tape a signal representing at any time the movement of the film in the camera.

The film advances, in the camera, at a speed of 25 frames per second. In order to obtain a signal representing that frequency, a small alternator is mounted on the shaft of the motor in the camera, generating, at that speed, a sinusoidal output of frequency 50 Hz. That signal is transmitted over the "pilot" cable to the tape-recorder. It constitutes the "pilot" signal, which is recorded on a "pilot" track on the tape. Any fluctuations of the speed of the film in the camera will give rise to variations of the frequency of the pilot signal. The absolute speeds of the two supports are not involved in the principle of synchron isation.

The signal leaving the camera has a tension of 1 volt. That signal is recorded on a very narrow track, not more than 0.5 mm in width, along the longitudinal axis of the tape. The programme itself is recorded over the full width of the tape. The pilot head is mounted at right angles to the programme-recording head (the recording is termed 'transverse') and the width of its pole-pieces does not exceed 1 mm. The spacing between the programme-recording head and the pilot head is 25 mm ± 2.5 mm. The pilot head has a separate radio-frequency polarisation circuit. The recording level is 6 dB below the level of the programme recording and the crosstalk suppression obtained in that fashion is in the neighbourhood of 55 dB.

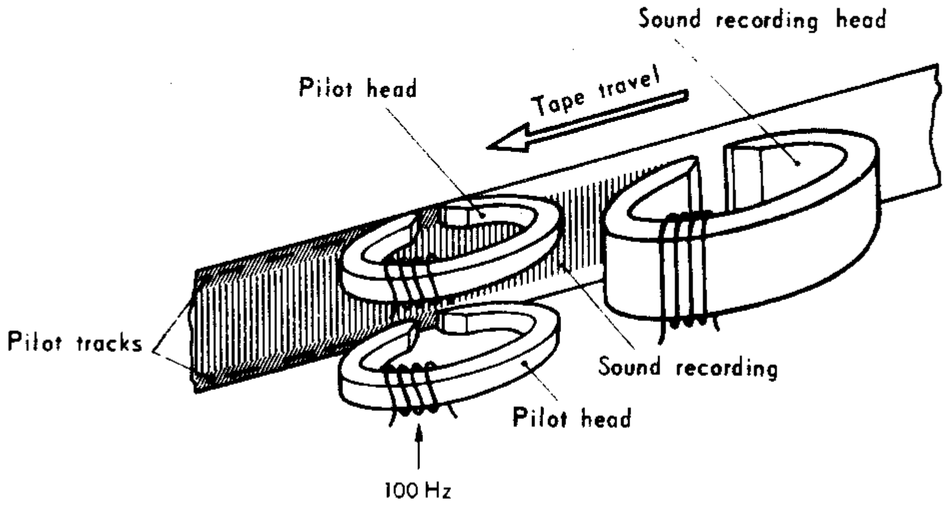
The Nagra company of Lausanne developed this system, and it is described in the German Standard DIN 15575 (October 1965). It constitutes an improvement of the earlier Maihak system, which did not use any polarisation and in which there was considerable disturbance of the programme recording by the synchronising signal, and vice versa.



In order to facilitate the editing operations, it is necessary to be able to readily identify the frame that corresponds to the beginning of the sound recording. The starting mark is obtained as follows: during the camera run-up period (200 ms), the first frames of the film are exposed by a small lamp which is switched off by a relay at the exact instant when the camera begins to send the pilot-tone. In this way, the last exposed frame of the film coincides with the start of the pilot-tone on the magnetic tape.

For the requirements of editing, the sound tape is dubbed on to a magnetic film. We do not propose to describe the methods adopted for effecting that transcription, which is outside the scope of this present document. We shall merely mention that the pilot-tone is utilised in the transcription to ensure the synchronisation of the picture film with the magnetic sound film, in order that they shall have exactly the same length and have the same number of perforations. The marker for the beginning of a shot is obtained by making use of the last "white" frame on the film and the beginning of the recording of the pilot-tone on the sound tape.

2.2 The Perfectone system



Just as in the case of the Nagra system, the principle of the Perfectone process is the recording, on the magnetic sound tape, of a synchronising signal representing the speed of movement of the film in the camera.

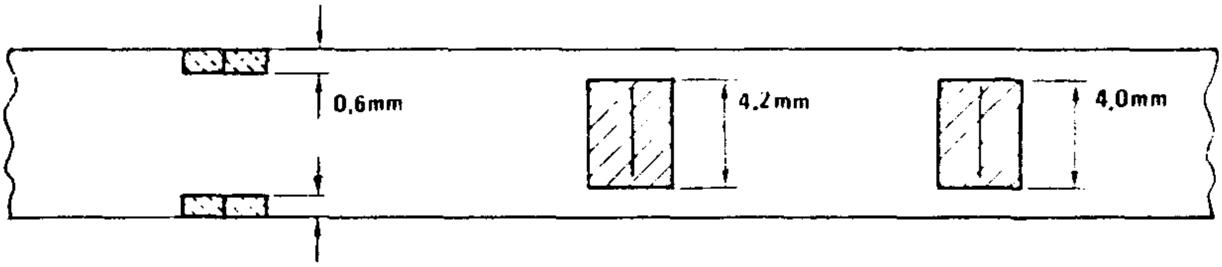
However, in order to reduce to the greatest possible extent the crosstalk of the pilot-tone into the programme recording, two synchronising signals, in phase-opposition, are transmitted to the tape-recorder. The opposing fields thus produced cancel out in the programme-reproducing head. In theory, the two half-tracks might be located symmetrically at any distance from the axis of the tape, but, because of the difficulty of manufacturing precisely symmetrical heads and the inequality of their wear, the half-tracks are located at the edges of the tape. The programme is recorded on the portion of the tape between the two synchronising half-tracks, and the programme-recording head is made with correspondingly smaller dimensions. The synchronising half-tracks are each 0.6 mm in width, and the two synchronising heads are mounted in the same sense as the programme head (the recording is termed ‘longitudinal’), and they are mounted on the same bracket.

Because the two synchronising tracks are outside the programme track, small errors of symmetry of the two tracks are of no importance and do not affect the crosstalk of the synchronising signal into the programme.

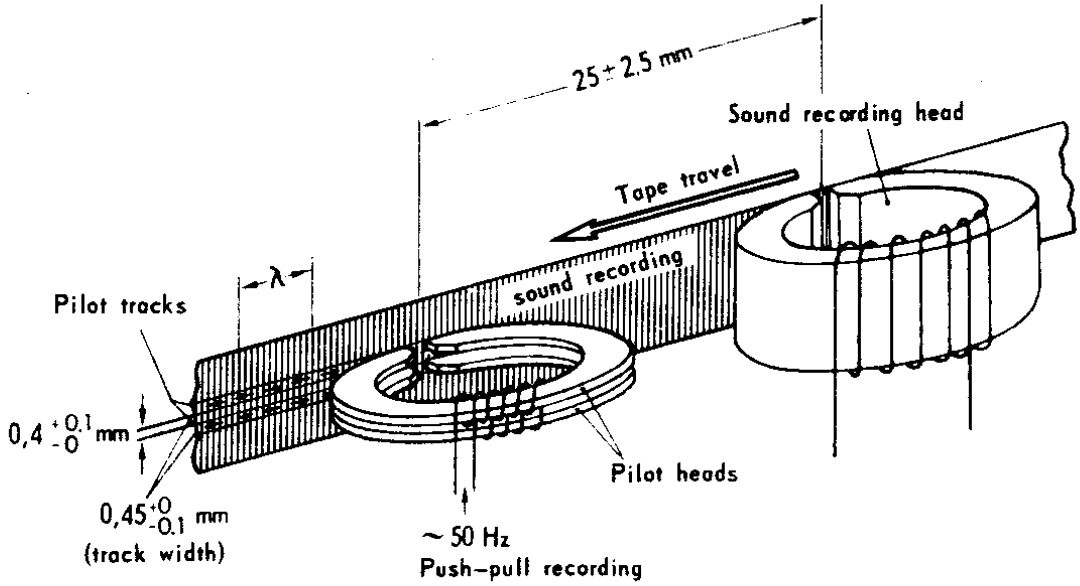
The frequency of the synchronising signal is twice that of the mains supply (that is to say, 100 Hz with 50 Hz mains supply). That feature has the following advantages:

- For the same recording current, the voltage across the synchronising replay head is twice as high.
- The crosstalk of the synchronising signal into the programme-replay head (in case of asymmetry of the two tracks) is reduced, because of the shorter wavelength of a 100 Hz signal, compared with the spacing between the synchronising tracks and the programme track;
- Having a synchronising frequency different from that of the mains supply makes it possible to filter out the supply-frequency components in the synchronising preamplifier.

A disadvantage of the system is the necessity of using special heads: a head 4.2 mm in width for recording the programme and a head 4.0 mm in width for reproducing it.

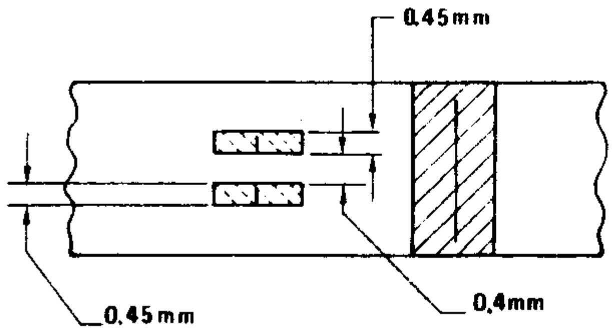


2.3 The Neopilot system



We have shown that the Perfectone system demands the use of special heads of width less than that of the magnetic tape, for recording and replaying the programme. In order to overcome that disadvantage, there has been developed the principle of arranging the synchronising tracks in the middle of the tape, as in the case of the pilot-tone system, while retaining the principle of two half-tracks in phase-opposition, as in the case of the Perfectone system. In this way, the so-called "Neopilot" system was obtained, developed by S. Kudelski of the Nagra company. Its characteristics are set out in the German Standard DIN 15575.

As in the pilot-tone system, the programme is recorded on the whole width of the tape. The two synchronising half-tracks have a width of 0.45 mm, and the separation between them is 0.4 mm in width. Unlike the pilot-tone system, the recording of the synchronising signal is longitudinal. The spacing between the assembly of the two synchronising heads and the programme head is 25 mm ± 2.5 mm.



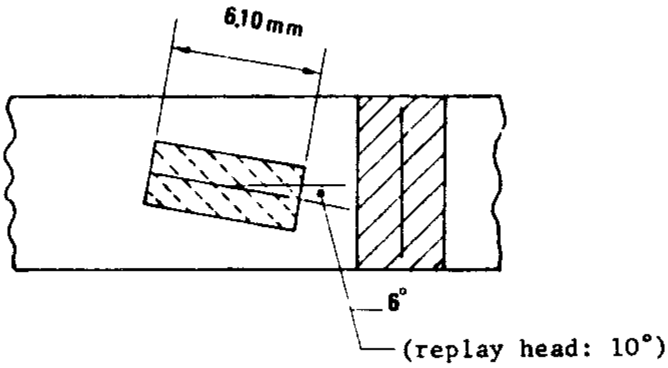
The recording currents in the two heads are adjusted in such a manner as to reduce as much as possible the crosstalk of the synchronising signal into the programme.

The total power needed for the polarisation is definitely less than in the case of the pilot-tone system.

The 'Neopilot' system is compatible with the pilot-tone system as far as the replay is concerned The same transverse head can be used for the dubbing process, to replay recordings made by either of the two systems.

Criticisms of the system (as of the pilot-tone system) point to the poor signal-to-noise ratio in the synchronising channel, as well as to the risk of interference by the mains supply, when the dubbing is carried out by means of equipment supplied from the mains.

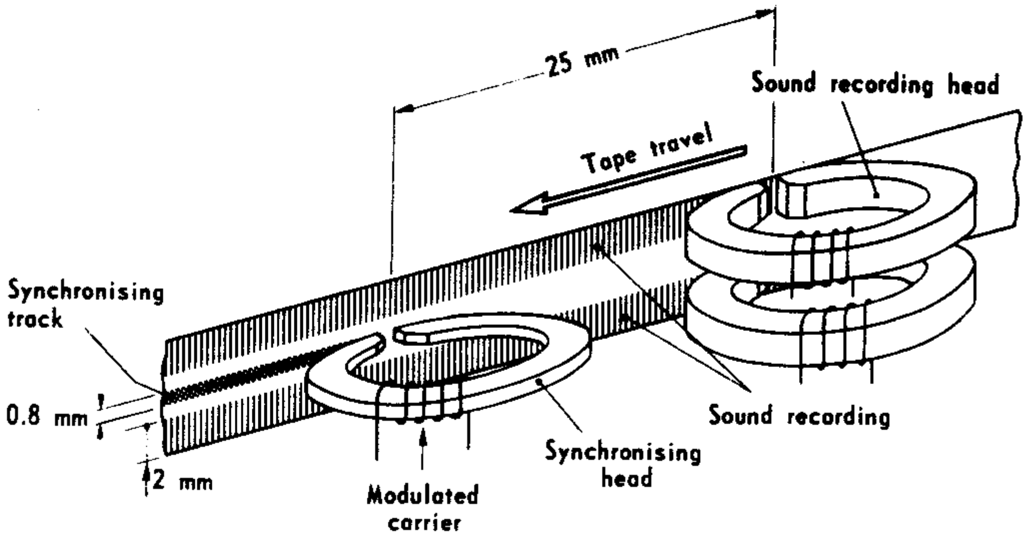
2.4 The Ranger system



This system, analogous to the pilot-tone system, was invented in the United States in 1949. The Ranger system consists in recording on a central track a sinusoidal synchronising signal, whereas the programme signal is recorded over the full width of the tape. The synchronising signal is at the frequency of the mains supply. In the beginning, the performance of the system was far from satisfactory, until the use of radio frequency polarisation was incorporated. The recording of the synchronising signal is transversal. Unlike the construction layout of the pilot-tone system, the synchronising head of the Ranger system is mounted at a small angle in order to provide a track of sufficient width, allowing easy reproduction even in case of abnormal movement of the tape.

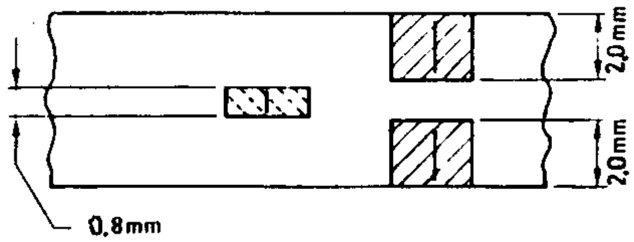
The operating characteristics, and in particular the signal-to-noise ratio, are similar to those of the pilot-tone system.

2.5 The Telefunken system



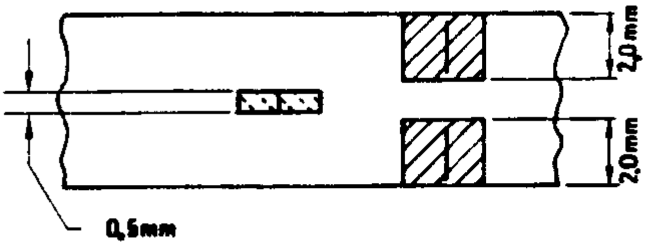
The layout adopted for the pilot-tone system (a single synchronising track along the axis of the tape) can be adapted to stereophony – two parallel tracks are used for the audio channels and the synchronising track being in that case used individually for the two channels. That is the principle of the Telefunken system, in which the synchronising signal consists of a sinusoid of frequency 50 Hz frequency-modulating a carrier of frequency 10 kHz, that signal being recorded in the longitudinal mode (as in the Neopilot system).

The synchronising track has a width of 0.8 mm, the two programme tracks being each of width 2 mm. The crosstalk from the synchronising head into the programme heads can be heard in the recording phase, but cannot be heard in the reproduction, being better than –60 dB.



The use of a carrier for the synchronising signal makes it possible, if required, to identify the numbers of the cameras used in the same recording, by modulating the carrier by a different frequency for each camera (for example, three cameras could use 440, 1100 and 2700 Hz). On the other hand, the need for demodulation presents disadvantages. The demodulated signal normally has a stable amplitude and a known signal-to-noise ratio, but it can be seriously affected by poor head-to-tape contact, or by dust, which produce an erratic output signal subject to noise.

2.6 The Synchrotone system



A more recent process employs the same arrangement whereby the two halves of the tape are used to provide a stereophonic pair. This is the Synchrotone process in which the synchronising track is

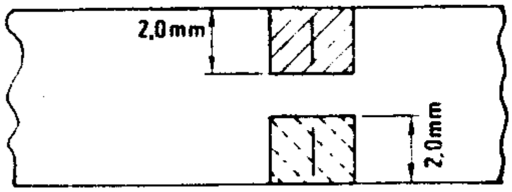
0.5 mm wide and suitable for all audio frequencies in the range 40 Hz – 12 kHz. As in the pilot system, the tone recorded is usually 50 Hz.

The crosstalk attenuation is approximately 50 dB.

This system may be used in dubbing with "pilot" or "neopilot" synchronisers by means of a special adaptor.

2.7 The Leevers-Rich system

ordinary model



For monophonic recordings, the sub-division of the tape into two parallel tracks, such as are found in the Telefunken and Synchrotone systems may be retained, but one of them used for the programme and the other for the synchronisation. That is the solution adopted in the Leevers-Rich system.

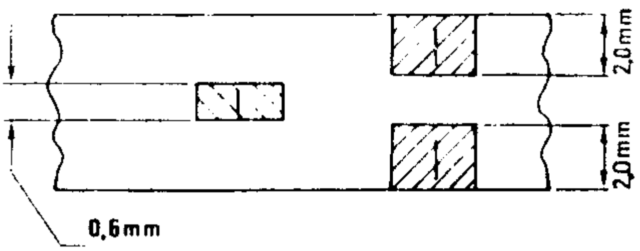
The tracks have a width of 2 mm each. The synchronising signal consists of a carrier modulated by pulses at the mains supply frequency (or at the camera-motor speed). In the earlier versions, the carrier frequency was 1 kHz, but, in the present portable version, the carrier frequency is 400 Hz.

The respective arrangement of the programme and synchronising heads renders the crosstalk from the synchronising signal into the programme virtually negligible, the crosstalk from the programme into the synchronisation being also very slight.

According to the manufacturer, the use of a carrier results in a signal-to-noise ratio that is about 20 dB better than can be obtained when the audio frequency is recorded direct; the carrier frequency is in the region of maximum efficiency of the tape, where the crosstalk between the heads is close to the optimum.

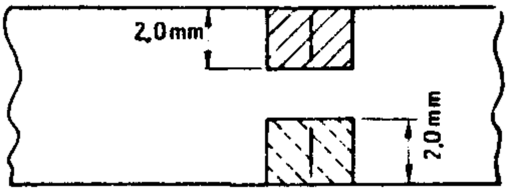
The Leevers-Rich system has been adapted also to stereophony. An arrangement rather similar to that of the Telefunken system has been adopted, consisting of two parallel tracks for the programme, on either side of a central track for the synchronisation.

stereo model



The signal level, both for monophony and stereophony, is 12 dB below the level giving 2% of distortion on the tape.

2.8 The BBC System



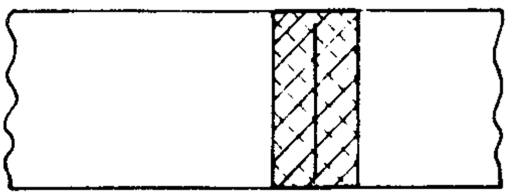
As in the case of the Leevers-Rich system, the BBC system uses two parallel tracks, one for the programme and the other for the synchronisation.

According to the BBC, the loss of signal-to-noise ratio, resulting from the use of only part of the tape-width for the programme, as compared with systems using the full width of the tape, is never greater than 5 dB (its theoretical value is 3 dB).

The tracks have a width of 2 mm.

The synchronising signal consists of a sinusoid of frequency 50 Hz recorded directly at 8 dB below the level of 2% distortion on the tape. That level is sufficiently high to avoid, in the reproduction, any crosstalk of the programme into the synchronisation. The crosstalk of the synchronisation into the programme is in the neighbourhood of –38 dB; it is even better in weighted terms, in view of the relative insensitivity of the ear at the frequency in question.

2.9 The Fairchild system



This system appears to be the only one to use, for the synchronising signal, the complete width of the tape. The synchronising signal is recorded by means of a normal head, at a slight angle relative to the programme-recording heads. That arrangement makes possible a reduction of the crosstalk of the synchronisation into the programme, but does not prevent crosstalk in the reverse direction.

The synchronising signal consists of a carrier of frequency 14 kHz modulated by a reference signal from the camera. Amplitude modulation is used.

At the normal speed of movement of the tape, that carrier does not work in the region of maximum efficiency of the tape, and the level of the reproduced signal is affected by a variety of factors, including among them the orientation of the head, the head-to-tape contact, drop-outs in the tape and the design of the heads.

In reproduction, a filter is used to retrieve the synchronising information required for dubbing. The Q-factor of that circuit has to be high enough to suppress the crosstalk of the audio channel, which is very high. On the other hand, the pass-band of the filter has to be wide enough to suit the relatively slow response of the dubbing equipment, if violent mechanical hunting of that equipment is to be avoided.

3. Synchronisation of an audio tape-recorder with several film cameras

Danmarks Radio's system

The systems described in the foregoing were designed essentially for obtaining synchronism of the pictures and the sound when the scene was being shot by means of a single camera. Their effect is to make it possible to correct fluctuations of the relative speed of the film and sound tape. If it is desired to use several cameras with a single tape-recorder, it is necessary to develop some means of identifying the origin of the pictures for each sequence of the accompanying sound.

Over a period of about sixteen years, Danmarks Radio produced 16 mm films using a system wherein coded time-markers were used for productions shot with two or three cameras. This system is no longer used but, at that time, it proved to be entirely satisfactory. Visual indications (for the film) and audible indications (for the sound tape) of the same instant of time made it possible to ensure that the sound was synchronised with the picture, whichever of the cameras was used to shoot that picture.

Synchronous functioning of the cameras was ensured by the use of synchronous motors fed with a 220V/50 Hz supply from the public mains. The synchronism of the tape-recorder with the cameras was achieved by using the frequency of the mains supply as a reference, in the form of a pilot signal.

Basic construction

The system consists basically of a mains frequency-controlled time-code generator, which continuously delivers coded time signals in the form of modified "morse" signals. The signal generator can supply data as "numbers" from 000 to 999, employing the following code:

1:	· -	6:	- ·
2:	· · -	7:	- · ·
3:	· · · -	8:	- · · ·
4:	· · · · -	9:	- · · · ·
5:	· · · · ·	0:	- - -
separation:	- -		

The data frequency is one number every four seconds, which equals one hundred picture frames per number at 25 frames per second. During these one hundred frames the digits and separation signs are positioned in the following way: -

Digit or sign	*Beginning at frame No.:*	*Duration (in number of frames)*
1st figure	0	
2nd figure	20	
3rd figure	40	
1st separation stroke	60	10.5
2nd separation stroke	80	10.5
sign elementsin each figure:		
point		1.5
stroke		3.5
space		0.5

The code signal is exposed on the edge of the film in each camera by means of a glow lamp placed in the magazines, and recorded on one of the two tracks of the tape in the form of a 440 Hz tone. The other track is used for the programme sound and for the pilot signal, which is carried by a l6 kHz tone. Fig. 1 shows an example of the appearance of a marked picture film.

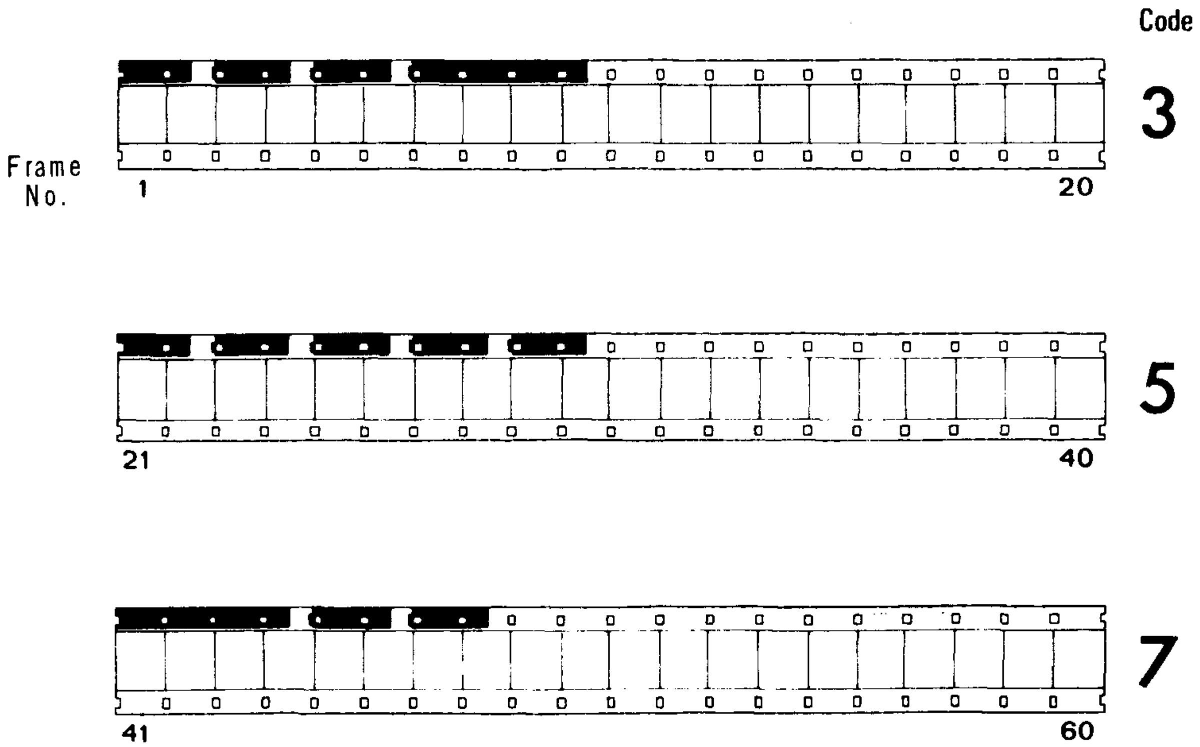


Fig. 1. - Appearance of a picture film with a time-code marking 357.

Applications

The system is normally used in three different ways:

1. Live filming with sound.
2. Filming while simultaneously re-recording the original sound.
3. Filming using pre-recorded original sound without re-recording.

1. Live filming with sound

As shown in Fig. 2, the time-code generator delivers identical time data to all three camera-lamps (which expose the films) and to a special recording head on the tape recorder.

2. Filming while simultaneously re-recording the original sound

As shown in Fig. 3, the time-code generator delivers time data to the films and to the recording tape-machine, which however in this case re-records the sound programmes from another playback tape-recorder or another playback sound source. This method is not very satisfactory, and normally method 3 is used instead.

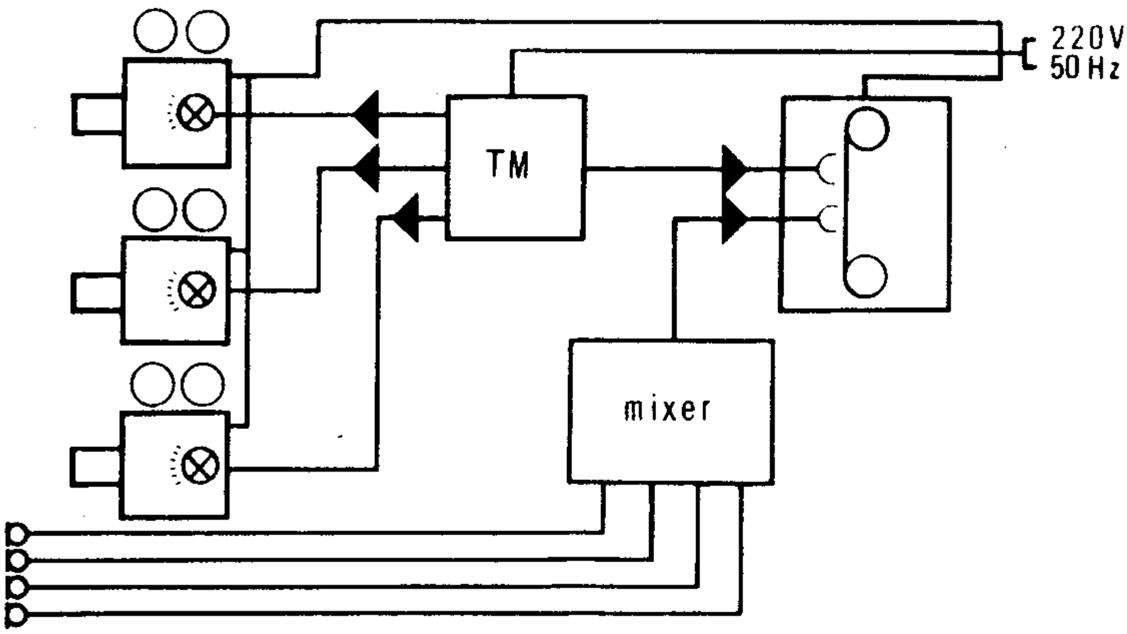


Fig. 2. - Diagram showing the arrangements using the time-code marking generator (TM) to mark live picture and sound recordings.

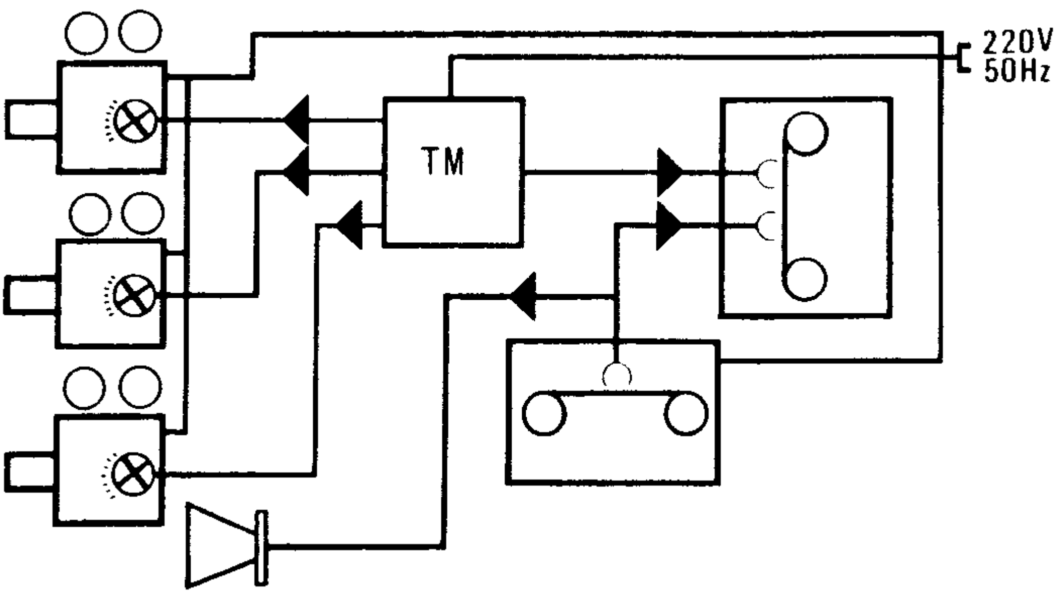


Fig. 3. - Diagram showing application of the time-code marking system to filming while simultaneously re-recording the original sound.

3. Filming using a pre-recorded sound tape without re-recording

In this case the time-code signal has already been recorded from the time- code generator at the time when the sound programme was recorded. During playback filming the already recorded time data is transferred to the cameras (Fig. 4).

During repeated rehearsals of certain sequences the sound engineer can listen to the time data, and this facilitates to a great extent the job of finding the right spot in the sound programme.

As it is still the very same time code signal which is transferred to the cameras from a sequence of the sound record, it is possible to film synchronously not only simultaneously, but also successively at any number of different times.

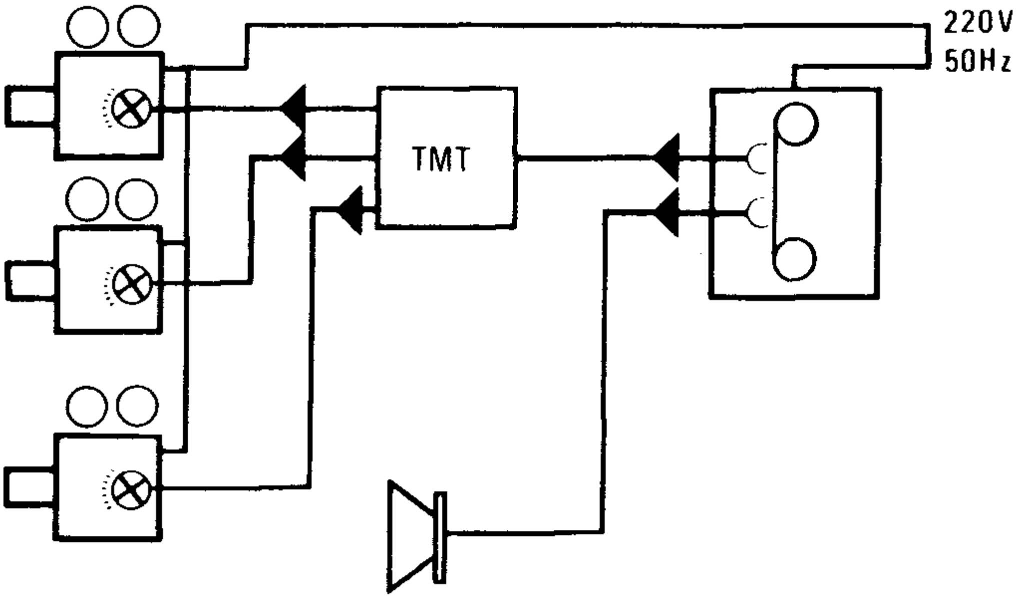


Fig. 4. - Diagram showing the time-code marking system as used for filming in synchronism with a pre-edited and pre-time-coded sound record. The sound record does not need to be re-recorded or edited later on. (TMT: time-code marking transfer box.)

Editing

Before editing the programme, the 6.25 mm (¼-inch) sound record is transferred to 16 mm magnetic film, and at the same moment the time-code signal is recorded on the edge track of the magnetic film.

At the editing table the time code can be made audible, and so it is possible to find the pieces of picture film that have the same visible time code on the edge and therefore also the pictures corresponding to the sound.

By means of the time-code signal alone it is possible to re-establish synchronism on the editing table within plus or minus half a frame.

PART TWO

RECORDING SYSTEMS REQUIRING NO CABLE FOR SYNCHRONISATION

1. Introduction

The cable undoubtedly constitutes a brake on the possibilities of movement of the camera crew. The problem is how to get rid of it.

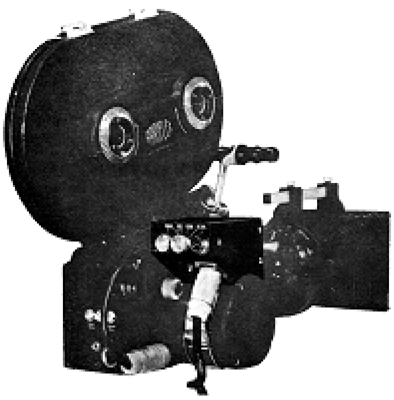
Radio transmission of the pilot-tone

A simple method, at first sight, consists in transmitting the pilot-tone by a radio channel. This method has been used, but the users were disappointed in it. In effect, it does not offer the reliability guaranteed by a cable. Very often fading is experienced, and the loss of synchronism occasioned in that way is very difficult to make good. Moreover, that method can be used with only a single camera.

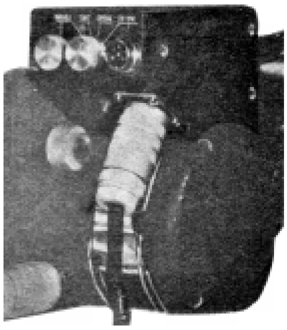
Generation of the pilot-tone in the audio tape-recorder

The miniaturisation of electronic components has made it possible to produce means of driving cameras, as well as pilot-tone generators of high stability capable of maintaining synchronism with adequate precision throughout the whole duration of a shot, without requiring any tangible connection between the camera and the tape-recorder. In that way the transmission of the pilot-tone, whether by radio or over a cable, can be obviated. It is possible also to work with several cameras at the same time, without its being necessary to drive them by means of synchronous motors from a common supply.

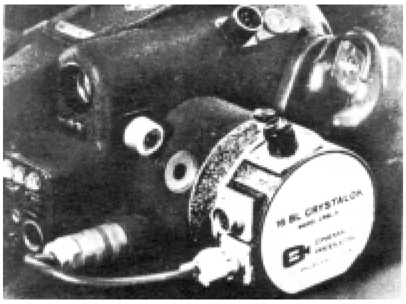
It was the adoption of quartz-crystal control that made it possible to obtain the precision and stability necessary. Several systems are available on the market, suitable for application to ordinary film-cameras and audio tape-recorders. The camera units are in most cases designed for use with cameras of this or that part icular type, to which they can be fitted without modifications to the motor; the pilot-tone generator is an even smaller unit that can readily be accommodated inside the tape-recorder. The precision of present-day crystals is in the vicinity of 1 or 2 parts in 10^5.



Left: camera equipped with crystal control



Right: close-up view of the control unit shown in the above photograph



Opposite: close-up view of another control unit for the same camera

Synchronising markers

There remains, however, the need to provide for the synchronisation of the starts of the recordings. In the case of completely self-contained cameras and tape-recorders, the instant of the start of the camera might be indicated by a clapper-board, but that method is really too old-fashioned and, in any case, it would not be possible to adopt it in most applications at present. A variant that is hardly more developed would be to have recourse to a lamp mounted on the sound-recording equipment. At the beginning of a shot, the sound recordist causes the lamp to flash and a tone to be recorded on the tape, while the cameraman points his camera so that pictures of the lamp are photographed on the film. It is easy to see the disadvantages of such a system.

It is possible, at the expense of some effort, to effect the editing without timing marks of film shot by a single camera. However, it is completely impossible to do so with more than one camera. It is in that case essential to provide both indications of the starts and identification of the camera in use, by means of the automatic recording of synchronising signals on the film and on the sound tape. In the equipment at present on the market, those synchronising signals are transmitted from the cameras to the tape-recorder by radio links. They “modulate” the pilot tone recorded on the sound tape.

The application of timing markers to the film does not require any modification in the camera, apart from the addition of a lamp which, as in the pilot-tone system, exposes the first frames of each shot. The transmitting equipment is separate and is mounted on the side of the camera. It consists usually of a unit ready for use, suitable for attachment without difficulty to any camera having crystal control. In the same way, the receiving equipment can be connected to or incorporated in the tape-recorder without difficulty.

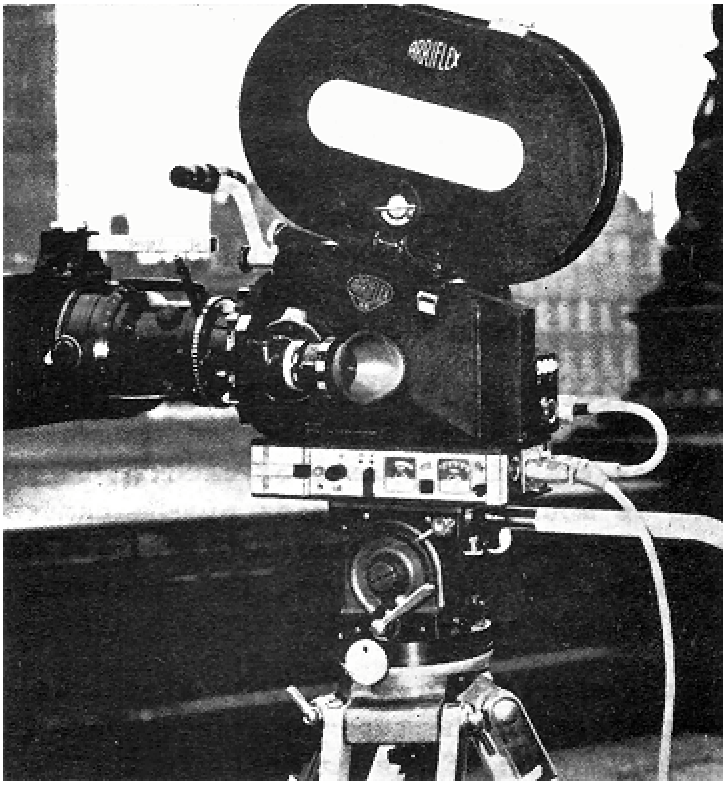
When the camera starts, a short signal is transmitted, and this is recorded on the pilot track in the tape-recorder, where it serves both as a *start marker* and an *identification of the camera*. In the systems that will be discussed below, that signal consists of a train of pulses. The identification of the camera is followed by the *identification of the shot*, which can also be effected by means of pulses: this may be looked upon as a modern form of the traditional clapperboard. Finally, in addition to the start marker, these systems include a *stop marker*, the purpose of which is, not only to determine the duration of the shot on the sound tape, but also to provide an alternative synchronising marker, in case of disturbance of the start marker.

Disadvantages of the systems

These systems have been adversely criticised on account of the complication of the devices needed to obviate interference between different camera crews working in the same area. It is not always possible to know in advance whether other cameras will be in use in the vicinity and on similar frequencies. Moreover, the range of frequencies available in the existing systems is limited.

Furthermore, the self-contained crystal-stabilised control units have some times been found to be defective, and losses of synchronism have been observed in cases of unfavourable weather conditions, such as in very low temperatures. Nevertheless, modern components have made it possible to improve the temperature effects very considerably.

2. The Crystomatic system



In this system, the instant of starting is indicated by recording a long (600 ms) pulse, followed by a train of short pulses of the duration of one frame (40 ms), the number of which corresponds to the number of the shot. That number may be from 1 to 9 and, when the shot number is greater than nine, the counter is reset to zero, and the cycle starts again. The same number of short pulses is recorded at the end of the shot.

The pulses may be transmitted with any of four frequencies (250, 440, 880 and 1700 Hz), whereby it is possible to make a distinction between four cameras.

In order to record these pulses simultaneously on the film and on the sound tape, two auxiliary units are used; one of them attached to the camera and the other to the tape-recorder. On the one hand, the pulses produced control the normal marking of the shots in the camera, in the form of light signals (filament lamps) which expose the frames at the beginning of the shot. On the other hand, they are fed to the incorporated radio transmitter, which transmits them to the equipment on the tape-recorder, where they may be recorded either on the usual sound track or on the pilot track (a generator of the pilot-tone frequency is incorporated in the tape-recorder equipment). The repetition of the number of the shot when the camera stops constitutes a safety measure, in view of the possibility of fading at the time when the start marker was transmitted.

It is the back edge of the long pulse that is used as a marker for the start of a shot, following the run-up time of the motor in the camera.

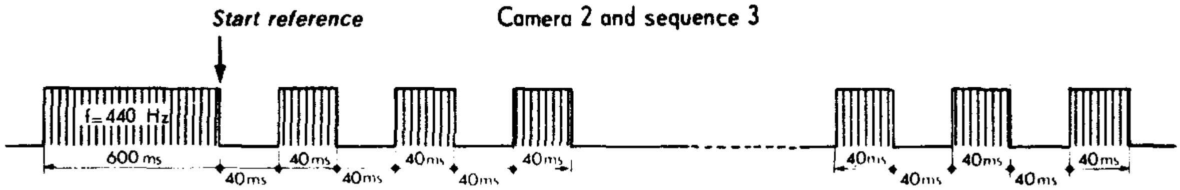
When the camera is at rest, the transmitter can be used for transmitting messages from the cameraman to the sound recordist, by means of a miniature microphone mounted in the camera unit. For that purpose the tape-recorder unit incorporates a three-channel receiver. That possibility is a precaution against the limitation of the number of numbered shots to nine; it makes it possible in effect for the cameraman to identify a group of shots orally.

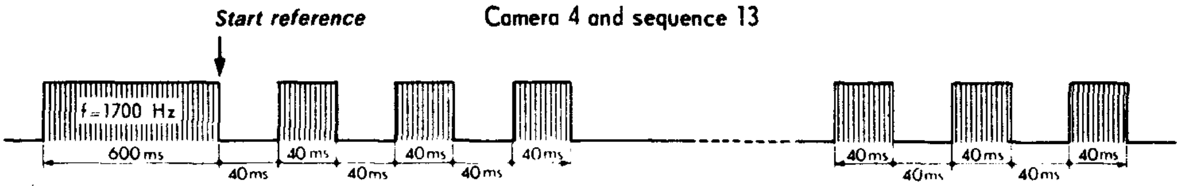
Other accessories further facilitate the operation of the system. Thus, the number of the shot may be displayed on a dial. If, in certain circumstances, the train of short pulses should have too long an overall duration, they can be suppressed at the beginning of the shot - in that case, there remains only the long “start” pulse and the short “stop” pulses.

Each item of equipment is controlled by reference to a high-frequency crystal oscillator (7 MHz). The stability of the frequency is approximately 2.2×10^5 in the temperature range -20°C to + 70°C.

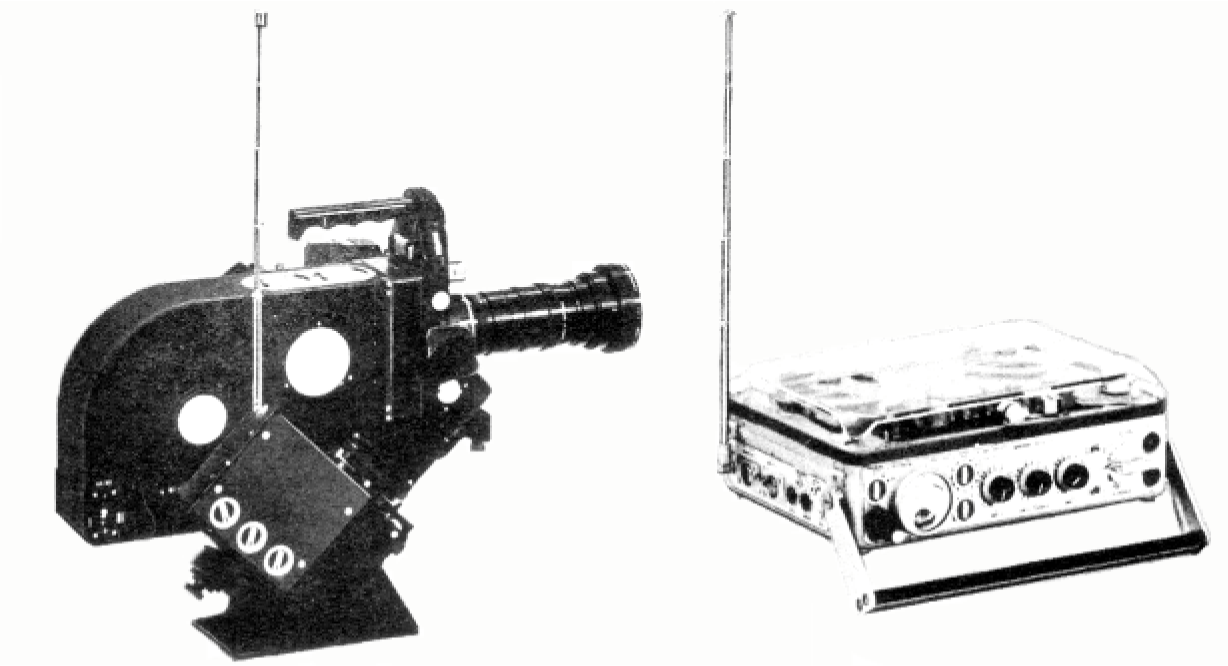
When dubbing the tape on to 16 mm magnetic film, the pulses recorded on the pilot-track are filtered and then recorded, for example, on the edge track of the film, the sound being recorded on the centre track.

During shooting, in order to avoid interference caused by other camera crews working in the vicinity, it is necessary to agree beforehand on the frequencies to be used.





3. The Kudelski system



In this system, when the camera starts, a pulse of about 250 ms duration, corresponding to the classical automatic start marker of the pilot-tone system, is recorded. Following this there is a number of 40 ms pulses (that duration corresponding to one frame of a film running at 25 frames per second) separated by intervals of 80 ms. Those intervals are grouped, and their number indicates, before the first short pulse, the number of the camera (which may be from 1 to 9), and after that pulse, the number of the shot (which may be from 11 to 99). Each pulse causes the exposure of one frame of film; at the output of the receiver mounted on the tape-recorder, it results in the removal of the pilot-tone for 40 ms (that is to say, two periods at 50 Hz). The equipment, as in the Crystamatic system, includes a transmitter mounted on the camera or connected to it by a cable, and a receiver in the form of a unit that can be plugged into the tape-recorder. The transmission frequency is normally 40.68 MHz.

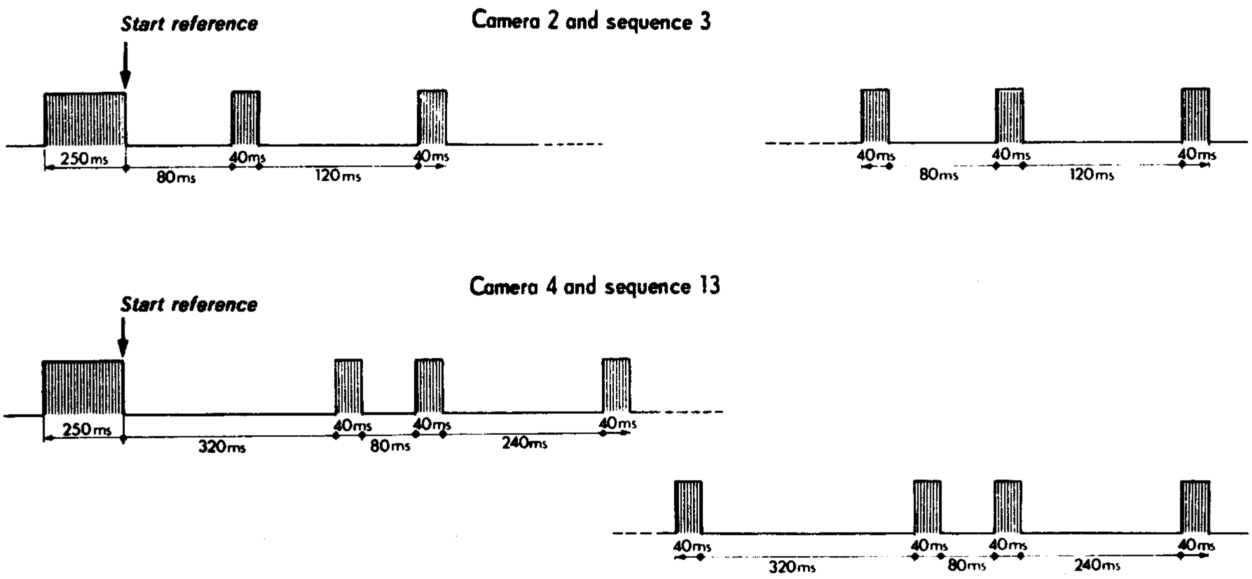
The end of the shot can be marked by means of a push-button which triggers, before the camera stops, the same train of pulses which was used to mark the start. The start in that case takes 40 ms, instead of 250 ms.

When only a single camera is being used, the first interval may be utilised also for the shot number, which in that case may attain a value of 999.

When dubbing onto magnetic film, a coding system reconstitutes, by a relatively simple process, the shot numbers and the identification of each of the cameras: the synchroniser produces, on the basis of the pulses, an audible signal, but a digital-display decoder may also be used.

The camera equipment is designed to be installed on a camera using a crystal reference oscillator. The tape-machine equipment may be supplied with crystal control if required; this operates at 307.2 kHz.

During shooting, protection vis-â-vis other camera crews working in the same area is ensured by a special device that involves, for each channel, the demodulation of two frequencies.



Arrangement of the synchronising pulses

4. The NRK system

This system is at present in the course of development.

The principle consists, as in the foregoing, in recording on the sound tape coded markers generated in the camera, defining the instant when each camera starts, as well as its identification. The system is intended for up to three cameras.

The following is a description of the method of controlling the motor in the camera, by means of a quartz-crystal oscillator.

The system

The control circuit is basically a phase lock loop, the main parts of which are the reference oscillator, phase detector, camera motor and pilot-tone generator.

Fig. 5 shows a block diagram of the system. The reference and pilot frequencies are compared with respect to phase in the phase detector, which produces a control signal for the motor. The function of the circuit is to reduce the phase difference between these signals to a minimum. Any change in relative phase will be corrected, and hence the motor will be locked to the reference frequency.

When the system is locked in phase, there is no frequency error. This follows from the relationship that the frequency is the derivative of the phase, i.e. $\omega = \frac{d\theta}{dt}$

The derivative of the angle θ_i. for the reference frequency is equal to the derivative of the angle for the pilot frequency, θ_0, i.e. $f_i = f_0$.

The governor. The second loop of the system consists of the governor and the camera motor. The function of this ioop is to accelerate the motor to the right speed at the start and to control the motor speed to the centre frequency (50 Hz) with a coarse tolerance.

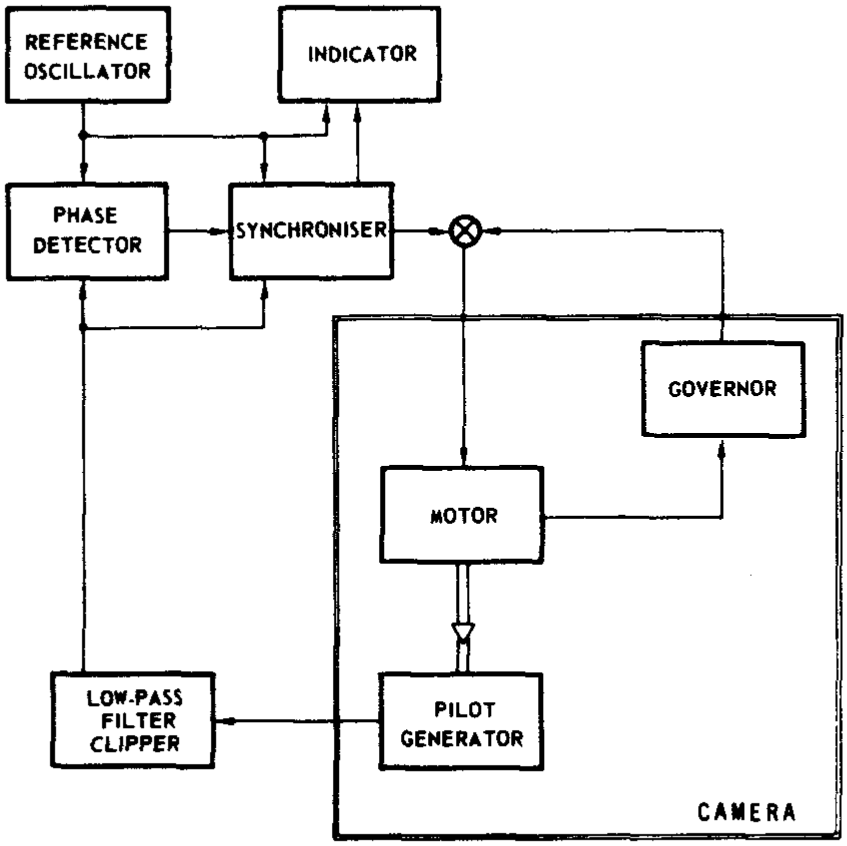


Fig. 5 - Block diagram of the NRK system

Components of the system

The system consists of the following parts:

Reference oscillator. This unit operates at 1 MHz. The crystal used has a stability of ± 10 Hz over the temperature range -20°C to +70°C. This signal is divided to 50 Hz, which is the reference frequency.

Low-pass filter/clipper. Noise and harmonics are here filtered from the pilot tone, which is normally a 50 Hz sinusoidal signal. The signal is then amplified and clipped to form a squarewave.

Phase detector. This is an "exclusive OR" circuit which compares the reference and pilot frequencies with respect to phase. The circuit gives a pulse-width-modulated signal, where the modulation corresponds to the phase difference between the signals.

Synchroniser. The function of the synchroniser is to prevent the control-signal from reaching the motor until the latter has reached approximately the correct speed.

Synchronising procedure

When the starting switch is closed, the motor accelerates to 50.4 Hz, controlled by the governor. The latter is used for starting due to the dynamic range of the phaselock loop being too small for this purpose. During acceleration, the synchroniser prevents the control signal from reaching the motor. After a certain time, determined by a time constant, the synchroniser allows the control signal to take effect and the camera motor becomes locked in phase to the reference frequency. The camera motor and the pilot frequency meet the same specifications as the reference frequency. A green light indicates that the system is locked.

If errors should result in the loss of synchronisation, the green lamp will blink with a frequency equal to the difference between the reference and pilot frequencies.

CONCLUSION

The systems described above have not all been equally popular. The system used most extensively in Europe is the “Neopilot”. Most users are, however, aware of the disadvantages of systems that require cable connections between camera and sound recorder. A synchronising system that does not require cables and that transmits start, stop and camera identification signals undoubtedly provides greater freedom in operation. Problems arise from the lack of compatibility among the present systems, it is difficult to guarantee perfectly reliable synchronisation, and the choice of the frequency for transmitting the control signals has to be considered again on each occasion of use.

The present state of technical progress is such that a system free from these constraints may be envisaged. Sub-group G3 of EBU Working Party G has examined the various possible solutions, and has concluded that a crystal-controlled system employing a time code marked on the film and sound tape would provide the required precision and reliability in operation. It would not only guarantee continuity equivalent to that of systems using cables but would also confer the advantages of the other crystal-controlled systems.

To facilitate the interchange of equipment and recording materials, standardisation is of course desirable. For this reason the EBU recommends the use of a single code, which is described in EBU document Tech. 3096, entitled “EBU standard for the synchronisation between film cameras and audio tape recorders”.