SECTION 11F: DIGITAL METHODS OF TRANSMITTING TELEVISION INFORMATION

REPORT 629-4

DIGITAL CODING OF COLOUR TELEVISION SIGNALS

(Question 25/11, Study Programmes 18L/11, 25G/11, 25L/11 and 25M/11)
(1974-1978-1982-1986-1990)

1. Introduction

Study Group 11 has brought together, during the study period 1982-1986 and previously, a large amount of information concerning the coding, processing, transmission and recording of picture signals in digital component form in the studio. This work has resulted in Recommendation 601 concerning the encoding of the digital video signal for studio production, and Recommendation 656 concerning studio interfaces for the digital video signal.

Additionally, this work has been taken into account in the Recommendation for the digital recording format (Recommendation 657) and the studies by Study Group 11 on bit-rate reduction (Report 1089) and the CMTT studies concerning the transmission of picture signals.

This Report summarizes the work on coding methods for signals within the studio complex, derived from both analogue and digital sources, and provides the basis for Recommendation 601 concerning the encoding parameters of the digital television signal in the studio. This is complimented by Report 962 which concerns the filtering, sampling, and multiplexing of digital signals.

2. Basic principles

2.1 Studio digital encoding parameters for conventional television

Two different approaches to the coding problem have been proposed:

- *component coding:* in this approach the luminance and colour difference signal components are digitally coded separately and transmitted as separate bit streams, time-multiplexed together. When the colour television signal exists in the composite NTSC, PAL or SECAM form, it will be necessary first to separate the signal into its luminance and colour difference components;
- *composite coding:* in this method the composite colour signal is coded in its composite form as a single bit stream.

The first method has advantages over the second because, in the future, it will be possible for the signal to be transmitted in digital form, from the source to the broadcasting transmitter. Only at the broadcasting transmitter will it be necessary to generate the composite signal. Thus, at least for transmission purposes, the differences between NTSC, PAL and SECAM would disappear with a consequent simplification of the problems of the international exchange of programmes [CCIR, 1974-78a], except when different scanning standards are involved. (International programme exchange refers to the provision of the interface required for video tape recording equipment and of the interface with transmission equipment.) The second method is claimed to have advantages when, as is likely to happen during the period in which digital techniques are being introduced into broadcasting, the complete chain contains several digital and analogue sections in cascade.

Most administrations now agree that there would be considerable advantages in using component coding for studio standards. The reasons for this are as follows:

- recent technological developments, particularly in the fields of semiconductor storage and magnetic recording have opened up new and attractive possibilities in electronic picture processing and special effects. Such facilities have only been available in the past using expensive film techniques [CCIR, 1978-82a];

– component coding offers a uniform world standard, with the exception of field rate. Such a standard has the greatest number of significant parameter values common to 525-line and 625-line systems. It allows equipment and operation to have the maximum number of common features, a situation which is not achievable with analogue or composite digital standards. Except for field rate (which could be switchable), studios throughout the world would use many items of common equipment and programme production and exchange would be much simplified.

In determining the bit rate reduction method that might be used at the studio, prior to interconnection to any long-distance transmission facilities, it is important to take account of the digital hierarchies being standardized by the CCITT [CCIR, 1974-78b].

In [CCIR, 1978-82b], the EBU has proposed that, to facilitate international exchange of programmes, a signal based upon the separate coding of luminance and colour-difference signals should be used. Studies conducted by the EBU have clearly demonstrated the value of digital coding in avoiding some of the limitations associated with PAL and SECAM systems and indicate the feasibility of a universally compatible digital standard [CCIR, 1978-82c]. Considerations such as this, combined with similar proposals from other administrations, resulted in Recommendation 601 which suggests that the use of component coding is to be preferred for all studio and international exchange purposes.

2.2 Studio digital encoding parameters for HDTV

This subject has been dealt with by IWP 11/7 as required by Decision 60, and results as of May 1989 were contributed to the Extraordinary Meeting of Study Group 11 for HDTV [CCIR, 1986-90a].

The contributions discuss several approaches to a digital HDTV studio standard based on the concepts of a common image format or a common data rate.

The subject is still under consideration by IWP 11/7 and particular areas of study for which IWP 11/7 is seeking contributions are:

- digital signal characteristics
  - (a) digital signal levels
  - (b) form of coding
  - (c) dynamic range
- digital interface requirements
  - (a) parallel and serial interfaces
  - (b) synchronising words, number of bits, etc.
- digital synchronizing signals
- digital test signals
- requirements for digital image processing
  - (a) requirements for horizontal and vertical blanking
  - (b) image size change allowable through editing processes etc.

3. Coding methods

The initial processes in all digital coding methods which are under study are sampling and quantizing.

3.1 *Bandwidths and sampling*

The sampling process is determined by three basic factors:

- the sampling structure, i.e. the relative position of the samples in space and time;
- the number of samples per line;
- the filtering process, which may be one-, two-, or three-dimensional.

The sampling structure mentioned above may, or may not, be repetitive with respect to the picture. Likewise, the number of samples per line may, or may not, be constant from line to line.

The classical theory requires the sampling frequency to be equal to or greater than, twice the highest signal frequency, i.e. Nyquist sampling. However, studies have shown that lower sampling frequencies (i.e. sub-Nyquist sampling) can be used in practice [Messerschmid, 1969].

3.1.1 *For component signals*

The EBU [CCIR, 1974-78c] has suggested that those countries digitally coding the separate components should use a sampling structure repetitive from picture to picture. This approach is supported by [CCIR, 1974-78d]. Repetitive sampling structures may be either orthogonal [CCIR, 1974-78e] or interleaved.

Report 962 describes in some detail the work leading to the choice of sampling parameters listed in Recommendation 601 as the basis for a studio code and so only a brief summary is required here.

A number of sampling frequencies for the luminance signal of the 4 : 2 : 2 level were studied by administrations, in particular 12 MHz, 12.5 MHz, 13 MHz. 13.5 MHz and 14.3 MHz. The factors studied, which would have a potential bearing on the choice of sampling frequency, included basic picture quality, picture quality after processing, cost-performance relations, potential capacity of digital VTRs, bit-rate reduction to transmission hierarchy levels and compatibility with composite signals and composite coding.

During the course of their studies, some administrations saw advantages in choosing a sampling frequency related to their composite signal colour sub-carrier frequency, because this could be advantageous in a mixed use of component and composite coding nationally. However, they considered that the benefits of a world-wide unification of sampling-frequency might alter the balance of advantages in favour of the agreed value.

A luminance sampling frequency of 13.5 MHz was adopted for a world-wide standard. It is a compromise between, on the one hand, the need to choose values which allow practically realizable and economic equipment and, on the other, the need to allow a sufficient degree of picture processing. Also, this frequency is the only one in the range of 12 to 14.3 MHz that permits an integer number of samples per lines for both the 525 and the 625 line systems [CCIR, 1978-82d, e, f, g, h, i and j]. The sampling frequency applied to the colour-difference signals was set at half that applied to the luminance signal after checking that this would allow adequate quality in chroma-key (colour matte) processing. The digital interface for studio equipment is discussed in Report 1088 entitled "Interfaces for digital video signals in 525-line and 625-line television systems".

It was anticipated that present and envisaged applications of television are unlikely to be covered by a single set of digital parameters. *An extensible family of compatible digital coding standards* corresponding to different applications was therefore proposed [CCIR, 1978-82k, l and m].

The members of the family are denoted by a sequence of integer numbers such as 4 : 2 : 2 or 4 : 4 : 4. These numbers represent the relation of the sampling frequency for the luminance signal (first number) to the sampling frequencies for the colour difference signals (subsequent numbers). The convention adopted is that the number 4 represents the main sampling rate of 13.5 MHz (nominal). Thus, for example, the 4 : 2 : 2 member of the family is characterized by 13.5 and 6.75 MHz sampling frequencies for the luminance and the colour difference signals respectively as defined in Recommendation 601.

One possible set of such standards is considered in [CCIR, 1978-82m] as corresponding to the following levels:

– a studio standard;

– a lower standard using the same scanning parameters but resulting in lower bit rates and costs, suitable for lower quality applications;

– a higher quality standard having a capability beyond that provided by present scanning standards.

In [CCIR, 1978-82n] it is suggested that an internationally compatible digital code would be a component code incorporating line-locked (orthogonal) sampling, an identical number of samples per line for both the 525- and 625-line systems and membership in an extensible family of compatible digital codes having simply related sampling frequencies. The definition of preferred sampling frequencies should be the subject of further studies.

Subjective assessments of an extensible family of component coded digital television systems were performed during 1980 and 1981 by the EBU [CCIR, 1978-82d and f], the SMPTE [CCIR, 1978-82g], and by NHK in Japan [CCIR, 1978-82o; Nishizawa *et al.*, 1981]. The tests included the binary derived family members 4 : 4 : 4, 4 : 2 : 2 and 4 : 1 : 1 with luminance sampling frequencies ranging from 12 MHz to 14.3 MHz. The results of all these tests were consistent and tended to verify the 4 : 2 : 2 member as the preferred selection for the standard studio interface and verified the choice of a sampling frequency of 13.5 MHz as an appropriate compromise between acceptable picture quality after processing and bit-rate requirements. This is also supported by [CCIR, 1978-82e].

The possibility of using the 4:2:2 level of Recommendation 601 with pictures having a wider aspect ratio (16:9 instead of 4:3) is presented in [CCIR, 1986-90b], which points out that most studio equipment requires only minor modifications and the same interface as in Recommendation 656 can be used. However, in such applications it should be noted that wider aspect ratio signals should not be intermixed with conventional (4:3) aspect ratio signals.

[CCIR, 1978-82k] presents a description of an extensible family of compatible digital codes which is based upon a component code bearing the ratios of sampling rates of 4 : 1 : 1 (luminance to colour-difference). Such codes would be easily transcodable to an NTSC composite digital interface code and the family could be readily extensible upward to be suitable for higher definition television when advances in technology warrant it. Also, the family of codes is extensible downward to lower definition interface codes for special applications, e.g. electronic news gathering.

The 4:4:4 level described in the Annex to Recommendation 601 is under study by both the EBU and the SMPTE. The intended purpose of a 4:4:4 interface is for complex graphics and post-production. It is not the intent to replace the 4:2:2 interfaces already specified in Recommendation 656, as they are deemed more than adequate for normal studio operations. The 4:4:4 interface is expected to stipulate PCM coding with more than eight bits per sample. Agreement has been reached within the EBU and SMPTE to include consideration of the keying signal as part of the basic signal set. This level of Recommendation 601 is now referred to as 4:4:4:4 or 4x4. Work is concentrated on fitting the information within the current interface described in Recommendation 656. Amongst the issues still under investigation are the effects of various algorithms for dynamic rounding, to minimize the number of bits per sample, also the filtering characteristics and the requirements for keying signals. Dynamic rounding is a process which conceals the errors which arise when a sample is reduced in word-length, as from 10 bits to 8 bits.

[CCIR, 1978-82p] suggests design criteria and a possible application for a lower level within an extensible family of compatible digital codes. System parameters and test results are given for an experimental codec operating at half of the bit rate of the main studio standard. This system features non-binary relationship between luminance sampling frequencies of related levels and a 3:1 relationship between sampling frequencies of luminance and line sequentially encoded colour difference signals. [CCIR, 1982-86a] describes a subjective evaluation, using static text pictures of a number of possible lower level standards, including the effects of line- and field-offset sub-sampling and of line sequential processing of the colour-difference signals. [CCIR, 1982-86b] contains a theoretical study of the picture distortion encountered when using line sequential transmission of colour-difference signals with a cycle of two fields.

[CCIR, 1986-90c] suggests parameter values for a cost effective lower level of signal coding using 2 2/3: 1 1/3: 1 1/3 sampling rates. Use of these parameters, rather than 2:1:1, allows a slow roll-off response to be used, thus simplifying the filters.

There appears to be little further interest in lower members of the Recommendation 601 digital encoding standards. The current effort appears to be directed towards achieving the goals originally identified for the lower members of the family, such as ENG and field operations, with the 4:2:2 member, by use of bit rate reduction techniques.

Rossi [1981] describes a set of digital filters adapted for a binary family, that accomplishes a two-to-one sampling rate down conversion, a one-to-two sampling rate up conversion, by comb filter interpolation.

There are equipment advantages for members of a family to have compatible numbers of samples per line. The members of the digital family should be chosen having regard to other possible television signal representations, in order to limit the number and complexity of transcoding operations in the signal chain. [CCIR, 1982-86c] lists some of the representations that have been proposed.

The nominal durations of the active-lines for 525/60 and 625/50 systems are slightly different. To bring the two systems together in the digital component domain, a "digital active line" (DAL) is defined. This has sufficient digital samples to cover either the 525/60 or 625/50 active lines. There are obvious advantages in that both systems now need precisely the same amount of digital line storage, and the DAL can be processed in exactly the same way for either the 525 or 625 line systems. The number of samples associated with analogue blanking is different, but this need not be carried through into the digital component domain. Blanking appropriate to the national broadcasting standard should be applied at the point where the signal is converted to analogue.

The 525 active line is the longer of the two, and with the tolerances currently in practical use, more than 710 samples are needed to cover a line. The 720 samples per digital active line given in Recommendation 601 was chosen because it conveniently meets this requirement.

Definition of luminance (E'_Y) and colour-difference ($E'_R - E'_Y$) and ($E'_B - E'_Y$) signals

A proposal for the construction of luminance and colour difference signals forms part of Recommendation 601 as follows:

$$E'_Y = 0.299\ E'_R + 0.587\ E'_G + 0.114\ E'_B \qquad \text{(See Note)}$$

whence

$$(E'_R - E'_Y) = E'_R - 0.299\ E'_R - 0.587\ E'_G - 0.114\ E'_B$$

$$= 0.701\ E'_R - 0.587\ E'_G - 0.114\ E'_B$$

and

$$(E'_B - E'_Y) = E'_B - 0.299\ E'_R - 0.587\ E'_G - 0.114\ E'_B$$

$$= -\ 0.299\ E'_R - 0.587\ E'_G + 0.886\ E'_B$$

Note. – Report 624 Table II refers.

Taking the signal values as normalized to unity (e.g., 1.0 V maximum levels), the values obtained for white, black and the saturated primary and complementary colours are as follows:

TABLE I

Condition	E'_R	E'_G	E'_B	E'_Y	$E'_R - E'_Y$	$E'_B - E'_Y$
White	1.0	1.0	1.0	1.0	0	0
Black	0	0	0	0	0	0
Red	1.0	0	0	0.299	0.701	−0.299
Green	0	1.0	0	0.587	−0.587	−0.587
Blue	0	0	1.0	0.114	−0.114	0.886
Yellow	1.0	1.0	0	0.886	0.114	−0.886
Cyan	0	1.0	1.0	0.701	−0.701	0.299
Magenta	1.0	0	1.0	0.413	0.587	0.587

While the values for E'_Y have a range of 1.0 to 0, those for ($E'_R - E'_Y$) have a range of +0.701 to −0.701 and for ($E'_B - E'_Y$) a range of +0.886 to −0.886. To restore the signal excursion of the colour-difference signals to unity (i.e. +0.5 to −0.5), coefficients can be calculated as follows:

$$K_R = \frac{0.5}{0.701} = 0.713; \ K_B = \frac{0.5}{0.886} = 0.564;$$

Then

$$E'_{C_R} = 0.713\ (E'_R - E'_Y) = 0.500\ E'_R - 0.419\ E'_G - 0.081\ E'_B$$

and

$$E'_{C_B} = 0.564\ (E'_B - E'_Y) = -\ 0.169\ E'_R - 0.331\ E'_G + 0.500\ E'_B$$

where E'_{C_R} and E'_{C_B} are the re-normalized red and blue colour-difference signals respectively.

In the case of a uniformly-quantized 8-bit binary encoding, 2^8, i.e. 256, equally spaced quantization levels are specified, so that the range of the binary numbers available is from 0000 0000 to 1111 1111 (00 to FF in hexadecimal notation), the equivalent decimal numbers being 0 to 255, inclusive.

In the case of the 4 : 2 : 2 system described in Recommendation 601, levels 0 and 255 are reserved for synchronizing data, while levels 1 to 254 are available for video.

Given that the luminance signal is to occupy only 220 levels, to provide working margins, and that black is to be at level 16, the decimal value of the luminance signal, $\overline{Y}$, prior to quantization, is:

$$\overline{Y} = 219\,(E'_Y) + 16,$$

and the corresponding level number after quantization is the nearest integer value.

Similarly, given that the colour-difference signals are to occupy 225 levels and that the zero level is to be level 128, the decimal values of the colour-difference signals, $\overline{C}_R$ and $\overline{C}_B$, prior to quantization are:

$$\overline{C}_R = 224\,[0.713\,(E'_R - E'_Y)] + 128$$

and

$$\overline{C}_B = 224\,[0.564\,(E'_B - E'_Y)] + 128$$

which simplify to the following:

$$\overline{C}_R = 160\,(E'_R - E'_Y) + 128$$

and

$$\overline{C}_B = 126\,(E'_B - E'_Y) + 128$$

and the corresponding level number, after quantization, is the nearest integer value.

The digital equivalents are termed Y, C_R and C_B.

It has been pointed out in [CCIR, 1982-86d] that further consideration of the relationship between analogue video levels and quantization levels may be necessary in the light of current operational margin requirements.

Note. – The quantization and encoding for the construction of Y, C_R, C_B from signals other than luminance and colour difference signals are considered in § 2.4 of Annex II to Recommendation 601.

Digital coding in the form of Y, C_R, C_B signals can represent a substantially greater gamut of signal values than can be supported by the corresponding ranges of R, G, B signals. Because of this it is possible, as a result of electronic picture generation or signal processing, to produce Y, C_R, C_B signals which, although valid individually, would result in out of range values when converted to R, G, B. [Devereux, 1987] explains that it is both more convenient and more effective to prevent this by applying limiting to the Y, C_R, C_B signals than to wait until the signals are in R, G, B form. Also, techniques are described by which limiting can be applied in a way that maintains the luminance and hue values, minimising the subjective impairment by sacrificing only saturation.

3.1.2 *For composite signals*

The sub-Nyquist technique can be applied by sampling the PAL composite signal at a rate of twice the sub-carrier frequency [Devereux and Phillips, 1974]. The digital codec employing such sampling uses filtering which introduces minor losses of diagonal luminance resolution and vertical chrominance resolution. However, further filtering of this nature in any subsequent sub-Nyquist sampling process should not cause any further resolution impairment [Stott and Phillips, 1977].

For system M/NTSC there is a tendency to use a sampling frequency of three or four times the colour sub-carrier frequency. However, [CCIR, 1974-78f] describes studies of a coding system which uses a sampling frequency that is an integer multiple of line frequency. The sub-Nyquist sampling technique has also been used with NTSC signals [Rossi, 1976].

Patel [1980] describes the effects of low-pass filtering on the analogue composite signal of system I/PAL. It is concluded that chrominance ringing is dominant and that improved delay correction can mitigate the resulting impairment.

3.1.3 *Compatibility between composite and component signals*

In [CCIR, 1974-78c] the EBU draws attention to the need for compatibility between the proposed methods for composite and component coding of 625-line signals.

EBU experiments [CCIR, 1978-82b] have shown that good quality analogue PAL to digital *YUV* coding and decoding, when using line-locked sampling, can be achieved provided a sophisticated codec is used.

In [Clarke, 1986], details of digital techniques are given for generating, from a line-locked sampling frequency, quadrature subcarrier signals for use in composite colour encoders and for locking these signals to the incoming reference burst in colours decoders. This allows the advantages of more stable, better defined performance produced by digital implementation to be obtained in coders and decoders without the need for sample rate conversion. The description also includes the modifications necessary to provide operation with NTSC signals.

Further, in [Clarke, 1988], a number of filtering methods for achieving high quality separation of the luminance and chrominance components of a PAL signal are described, primarily for obtaining digital Y, C_R, C_B signals from PAL in a digital studio context. These range from filters using relatively simple line-delay combs to three-dimensional comb filters using multiple line, field and picture delays. The results of subjective tests comparing the different methods indicate that, while a modest degree of temporal filtering can improve performance significantly, greater use of this technique can lead to impairments to moving objects.

3.1.4 *Change of sampling frequency*

Within a given system (using either composite or component coding) it may be necessary to change the sampling frequency.

A method is described in [CCIR, 1974-78g] which may be used with system M/NTSC for changing the sampling frequency from 4 to 3 times the NTSC sub-carrier frequency and vice versa.

In [CCIR, 1974-78h], which proposes the possible use of two sampling frequencies in the digital PAL studio, it is pointed out that a signal sampled at 4 f_{sc} may be very easily converted to a signal sampled at 2 f_{sc} and vice versa. However, when the sampling frequency is changed from 2 f_{sc} back to 4 f_{sc} the minor impairments associated with 2 f_{sc} sampling remain; nevertheless, the effect upon resolution is not cumulative.

3.1.5 *Sampling frequency tolerance*

The sampling frequencies used should comply with the requirements of associated television systems. In particular the tolerance for component signal sampling frequencies should be equal to that for line frequency in the relevant colour television standard [CCIR, 1982-86e, f].

In cases where the sampling frequencies are generated from the reference synchronization signal arriving from a distant main synchronization generator, special centralized synchronization signals containing reference frequency packets may prove useful for the purpose of increasing the phase stability of the generated frequencies [CCIR, 1986-90d].

3.2 *Linear PCM*

The basic form of digital coding is linear PCM, where the value of each digital "word" represents the uniformly quantized amplitude of a sample of the baseband signal [CCIR, 1970-74a and b].

Preliminary results of an experiment using 7 PCM codecs in cascade when coding NTSC composite signals are presented in [CCIR, 1974-78i].

[CCIR, 1978-82q] describes experiments to determine the picture impairments introduced when up to 10 codecs are used. Composite NTSC signals were coded using various numbers of bits per sample and sample frequencies of 3 f_{sc} and 4 f_{sc}. The signal-to-noise ratio of the source was high.

A study on PCM codecs using 8 bits per sample [CCIR, 1982-86g; Devereux, 1983] draws attention to the importance of the performance of both the basic coder/decoder and associated circuitry in determining the performance of a cascaded chain of codecs. Of particular importance are: pre- and post-filters; blanking-level stabilization; quantization distortion, particularly on signals with high rate-of-rise (or fall); timing jitter on clock pulses; line-time non-linearity. In a well-designed codec where the foregoing have been taken into account, quantization noise is likely to be the dominant impairment, and this is shown to be about 2 dB worse than theoretical in the codecs tested. A cascaded connection of 8 codecs is shown to increase the quantization noise by approximately the expected 9 dB.

Experience suggests that, within PCM signal processing equipment, more than 8 bits per sample should be retained to avoid a rapid accumulation of quantizing disortion from repeated rounding after each arithmetic process. However, 8 bits per sample has been found satisfactory for interconnections between equipment using digital Y, C_R, C_B signals coded according to Recommendation 601, provided that effective rounding is applied when converting from a higher number of bits to 8 bits at the equipment output. [Croll, Devereux and Weston, 1987] describe a suitable form of rounding, called error feedback, in which those lower significance bits truncated from one sample are added to the following sample before truncation thus accumulating, rather than discarding, lower significance residues. With 8 bits per sample, rounding signals in this way causes higher frequency quantizing distortions which are not visible, whereas simple truncation can cause visible contouring.

4. **Bibliography**

In addition to the references explicitly cited in this Report, a Bibliography of several publications on the subject of digital television is appended. The referenced papers are not repeated in the Bibliography.

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[1970-74]: **a.** 11/246 (United Kingdom); **b.** 11/298 (Japan).

[1974-78]: **a.** 11/64 (Japan); **b.** 11/354 (Japan); **c.** 11/374 (EBU); **d.** 11/354 (France); **e.** 11/317 (Japan); **f.** 11/314 (Japan); **g.** 11/329 (USA); **h.** 11/410 (United Kingdom); **i.** 11/331 (USA); **j.** 11/409 (USSR); **k.**11/65 (France); **l.** 11/330 (USA).

[1978-82]: **a.** 11/36 (United Kingdom); **b.** 11/14 (EBU); **c.** 11/15 (EBU); **d.** 11/330 (EBU); **e.** 11/328 (USSR); **f.** 11/285 (EBU); **g.** 11/292 (USA); **h.** 11/339 (OIRT); **i.** 11/342 (Canada); **j.** 11/344 (Japan); **k.** 11/31 (USA); **l.** 11/16 (EBU); **m.** 11/114 (France); **n.** 11/33 (USA); **o.** 11/343 (Japan); **p.** 11/278 (Germany (Federal Republic of)); **q.** 11/80 (Japan); **r.** 11/87 (Japan); **s.** 11/248 (Japan).

[1982-86]: **a.** 11/22 (Japan); **b.** 11/90 (USSR); **c.** 11/81 (United Kingdom); **d.** 11/23 (Japan); **e.** 11/46 (EBU); **f.** 11/135 (OIRT); **g.** 11/65 (United Kingdom); **h.** 11/19 (Japan); **i.** 11/26 (Japan).

[1986-90]: a. 11/323 (Chairman, IWP 11/7); b. 11/545 (France); c. 11/185 (USSR); d. 11/86 (USSR).

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