RECOMMENDATION ITU-R BO.786*

MUSE** system for HDTV broadcasting-satellite services

(Question ITU-R 100/11)

(1992)

The ITU Radiocommunication Assembly,

considering

a) that the MUSE system has been developed for HDTV satellite broadcasting in the 12 GHz band;

b) that the MUSE system has been tested for many years using a broadcasting satellite in operation;

c) that there exists a studio standard based on 1 125 lines and 60 Hz field rate, which is very well coupled to the MUSE system;

d) that a large number of programmes have been produced worldwide using the studio standard with 1 125 lines and 60 Hz field rate;

e) that a down converter from the MUSE system to the M-NTSC system has been developed and is operating in conventional television sets;

f) that the MUSE system can be used for terrestrial broadcasting, cable TV (CATV) distribution, and recording media, e.g. optical discs, VCRs,

recommends

that, for an administration or organization wishing to initiate a MUSE* 1 125 line, 60 Hz field rate based HDTV broadcasting-satellite service, the signals should conform to the specification contained in Annex 1.

ANNEX 1

Signal specification of MUSE system

1 Introduction

The MUSE system has been developed for HDTV satellite broadcasting in the planned 12 GHz band. Picture quality and system feasibility have been confirmed through various tests including daily operation using the BSS.

The major signal specification of the MUSE system is described in this Annex.

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* Radiocommunication Study Group 6 made editorial amendments to this Recommendation in 2001 in accordance with Resolution ITU-R 44.

** The MUSE (Multiple sub-Nyquist Sampling Encoding) system is described in Annex 1.

2 Technical bases for MUSE system

The major technical bases employed for the MUSE satellite emission system are listed below:

– a bandwidth compression technique using multiple sub-sampling and motion compensation. This compresses the HDTV signal bandwidth of 30 MHz to 8.1 MHz suitable for HDTV satellite broadcasting in the 12 GHz band;

– time division multiplexing of luminance *Y* and chrominance *C* signals. This makes a complete *Y*/*C* separation possible in the decoder, resulting in the elimination of interference, such as cross colour and cross luminance which often appear in the existing TV systems;

– a technique for automatic waveform equalization required for analogue sampled-value transmission. This enables the system to be used not only in the case of satellite emission but also in other transmission media, such as CATV;

– a synchronization system maintaining accurate re-sampling phase in the decoder. The system employs a positive synchronizing signal, which gives the received picture a signal-to-noise ratio (*S*/*N*) 3 dB higher than that of the conventional synchronization system;

– an efficient non-linear emphasis system suitable for satellite transmission. This gives an emphasis gain or *S*/*N* improvement of 9.5 dB;

– coding based on the principle of quasi-constant luminance. This not only reduces remarkably the cross-talk between the *Y* and *C* signals due to a narrower bandwidth limitation of the *C* signal, but also improves the *S*/*N* in highly saturated colour pictures. It leads to a lower carrier-to-noise ratio (*C*/*N*) required for BSS direct reception;

– a baseband multiplexing of digital sound and independent data. This allows a flexible usage of the system, as it is independent of the modulation system and transmission media.

3 MUSE signal specification

The definitions given are applicable to all parameters and terms specified in this Recommendation:

– tolerance is zero for the parameter values with digital definition;

– the values that express the sampling frequency, bit rate, and transmission rate have the frequency relationship with the line frequency ($f\,L$) of the input signal, as given in Table 1;

– the video signal value is represented by an 8-bit digital expression, unless otherwise noted;

– the "grey level" of the video signal is defined by value 128 for the luminance signal;

– the levels for the luminance signal corresponding to black level, grey level and white clip level are defined by the signal values immediately after the inverse gamma correction and white clipping processes;

– the signal level of the guard area is equal to the grey level;

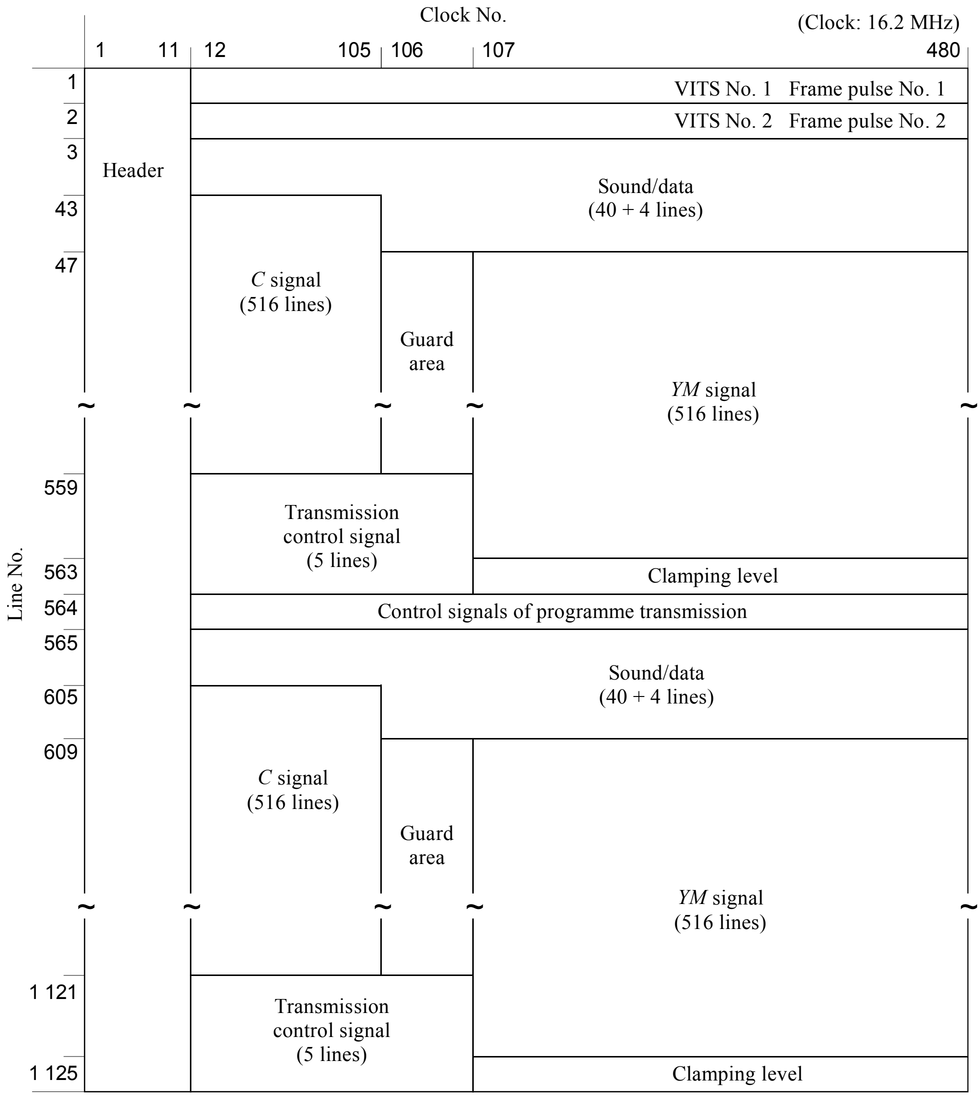
– undefined binary data in this specification will be filled in with either "0" or "1".

3.1 Transmission signal format

Figure 1 shows the transmission signal format.

FIGURE 1

Transmission signal format



VITS: vertical interval test signal

Note 1 – The transmission control signal is valid for the next field following the field that contains it.

Note 2 – Line No. 564 is assigned to uses such as control signals of programme transmission by broadcasters.

Note 3 – Timing relationship with the studio video signal is as follows:

C signal in line No. 43 and *YM* signal in line No. 47 correspond to the studio signals in line No. 42.

D01

3.2 Video transmission signal

3.2.1 Formulation of transmission signal

A luminance signal, *YM*, as specified below is used so that the inverse matrix in a receiver can be made simple.

$$YM = 0.588\ G + 0.118\ B + 0.294\ R$$

The matrix for the receiver is expressed by the following equation:

$$\begin{bmatrix} G \\ B \\ R \end{bmatrix} = \begin{bmatrix} 1 & -1/5 & -1/2 \\ 1 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 5/4 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} YM \\ B - YM \\ R - YM \end{bmatrix}$$

$$= \begin{bmatrix} 1 & -1/4 & -1/2 \\ 1 & 5/4 & 0 \\ 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} YM \\ B - YM \\ R - YM \end{bmatrix}$$

TABLE 1

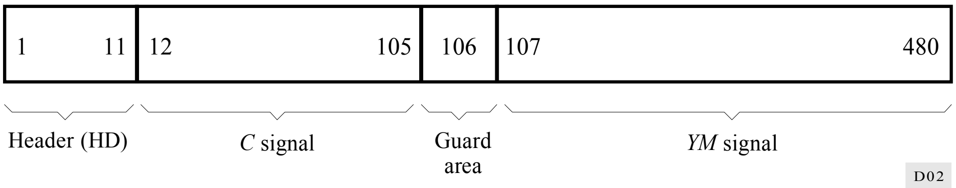
Relationship of frequencies used in the MUSE system with the line frequency

Frequency		
97.2	MHz	$= fL \times 2\,880$
74.25	MHz	$= fL \times 2\,200$
48.6	MHz	$= fL \times 1\,440$
44.55	MHz	$= fL \times 1\,320$
32.4	MHz	$= fL \times 960$
24.3	MHz	$= fL \times 720$
16.2	MHz	$= fL \times 480$
14.85	MHz	$= fL \times 440$
12.15	MHz	$= fL \times 360$
8.1	MHz	$= fL \times 240$
6.075	MHz	$= fL \times 180$
4.05	MHz	$= fL \times 120$
1.35	MHz	$= fL \times 40$
128	kHz	$= (fL/1\,125) \times 1\,600 \times (8/3)$
112	kHz	$= (fL/1\,125) \times 1\,600 \times (7/3)$
48	kHz	$= (fL/1\,125) \times 1\,600$
32	kHz	$= (fL/1\,125) \times 1\,600 \times (2/3)$
1	kHz	$= (fL/1\,125) \times 1\,600 \times (1/48)$

where $fL = 33\,750$ Hz.

3.2.2 Multiplexing of chrominance signal

3.2.2.1 A line sequential time compressed integration (TCI) signal is employed for the multiplexing, where the chrominance signal is time-compressed to 1/4 and is time-division multiplexed with the luminance signal *YM*. The 480 samples per line are assigned to the luminance and chrominance signals as follows:



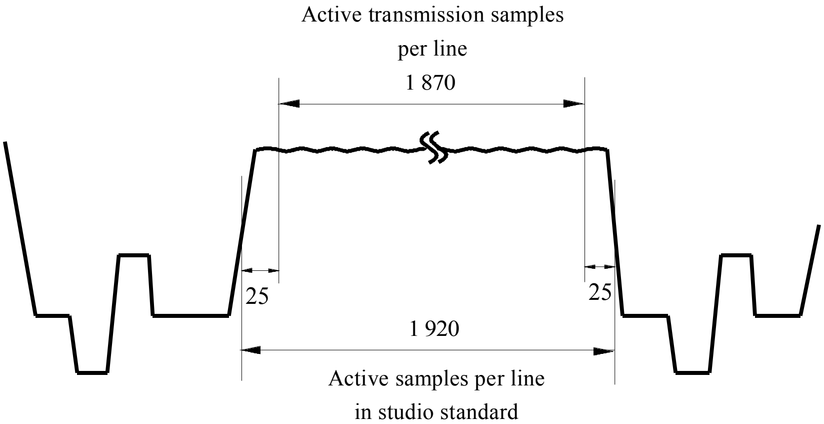
3.2.2.2 The *R-YM* signal is multiplexed into odd lines and *B-YM* into even lines, respectively. (The *C* signal is advanced against the *YM* signal by 4 lines.)

3.2.3 Relationship of active line periods between studio and transmission signals

Figure 2 shows the relationship of active line periods between the studio and transmission signals. The active line period of the transmission signal corresponds to 1 122 sample duration at the sampling frequency of 44.55 MHz.

FIGURE 2

Relationship of active line periods between the studio and transmission signals



Note 1 – The number of samples denoted here is counted by the clock of 74.25 MHz used for the studio sampling frequency.

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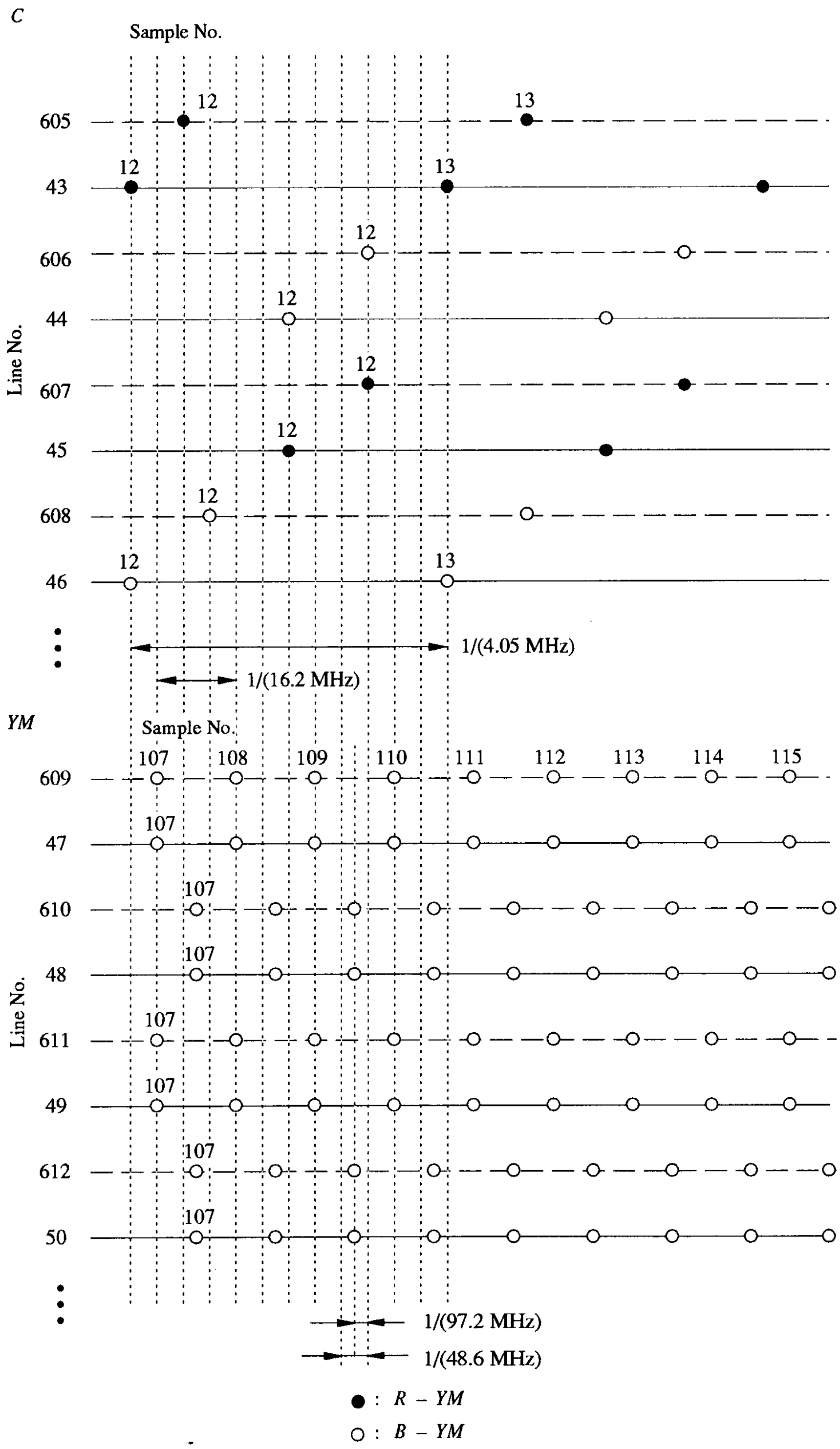
3.2.4 Phase relationship of *YM* and *C* signals relative to the original sampling lattice

Figure 3 shows the sampling points of transmission signals, *YM* and *C*, in relation to the original sampling lattice.

FIGURE 3

Relationship between sampling points of transmission signal and the original sampling lattice



Note 1 – This figure illustrates the sampling structure of transmission signals in one frame. The alternate sampling phase is taken for transmission signals in the subsequent frame.

Note 2 – The frequency 48.6 MHz corresponds to the original sampling frequency of 44.55 MHz after time compression with the ratio of 12:11.

D04

3.2.5 Video encoding

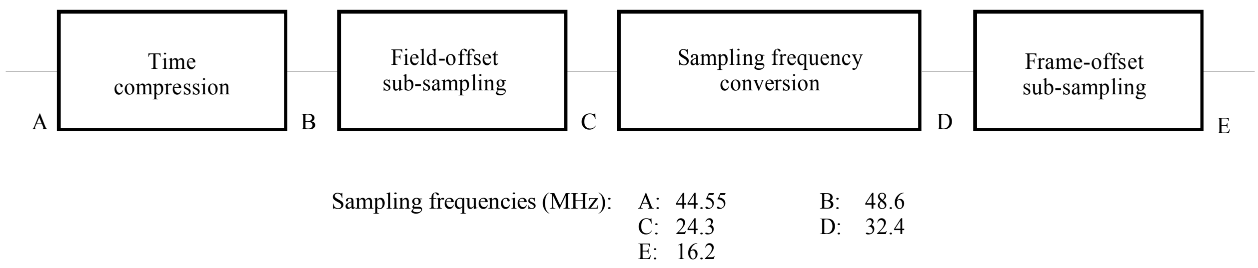
Multiple sub-Nyquist sampling with inter-field and inter-frame offset is used for video encoding. Figure 4 shows the sub-sampling sequence in the encoder.

Motion compensation is applied to the *YM* signal. In signal processing of the stationary picture area, from the output of field offset sub-sampling in the encoder to the input of inter-field interpolation in the decoder, the overall frequency characteristics should satisfy the distortion-free condition required for sampled-value transmission.

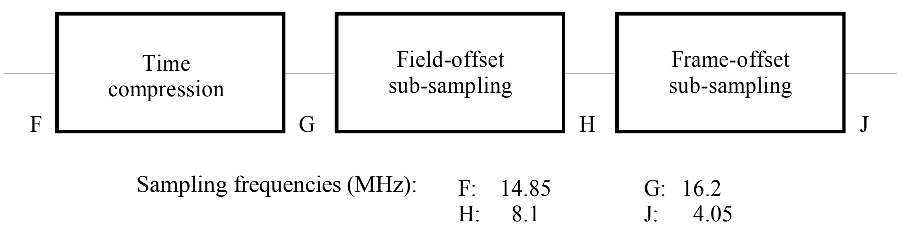
The frequency characteristics after the field-offset sub-sampling process of the encoder should be such that they give the overall characteristics of a linear-phase roll-off with attenuation of 6 dB at 12.15 MHz, when the reference filter having the impulse response defined in Table 2 is used. Note that the values in the table represent the impulse response at the sampling frequency of 97.2 MHz, and that the values are symmetric with respect to the centre tap (Tap No. 0). The amplitude gain of the filter is set to 3 at d.c.

FIGURE 4

Sub-sampling sequence in encoder



a) Sampling sequence for luminance signal



b) Sampling sequence for chrominance signal

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3.2.6 Transmission sampling frequency

16.2 MHz is used for the transmission sampling frequency.

3.2.7 Video signal levels

–	*YM* signal	black level:	16
		white clip level:	239
–	*C* signal	achromatic level:	128

In the encoder, the amplitude of the *C* signal is increased by 3 dB, followed by clipping at the level of either 16 or 239.

TABLE 2

Filter impulse response of reference decoder

Tap No.	Response
0	1.05194
1	0.86489
2	0.43802
3	0.09126
4	–0.09500
5	–0.20629
6	–0.25266
7	–0.17670
8	0.02178
9	0.14519
10	0.12800
11	0.04417
12	–0.01207
13	–0.01473
14	–0.00396
15	0.00214

3.2.8 Quasi-constant luminance processing

The quasi-constant luminance principle is applied to reduce the *YM* and *C* signal interference. The block diagram of signal processing and the characteristic curves for gamma correction are given in Figs. 5 and 6 to 8, respectively.

3.2.8.1 Inverse gamma curve for *R*, *G* and *B* signals

The curve is expressed by the equation below, where the maximum value of quantization is normalized to unity and black level of the video signal is assumed to be zero.

$$y = A\,(x - B)^g + C$$

where $g = 2.2$

(both coordinates (0,0) and (1,1) belong to the curve and the ratio of gradient at (0,0) and (1,1) is 1:5).

3.2.8.2 Transmission gamma curve for *YM* signal

The curve resulting from the following expression is parabolic, where the maximum value of quantization is normalized to unity, and the black level of the video signal is assumed to be zero. Processing of the gamma signal should be applied only during the *YM* signal period.

$$x = (3/5)\, y^2 + (2/5)\, y$$

FIGURE 5

Block diagram of signal processing based on quasi-constant luminance principle

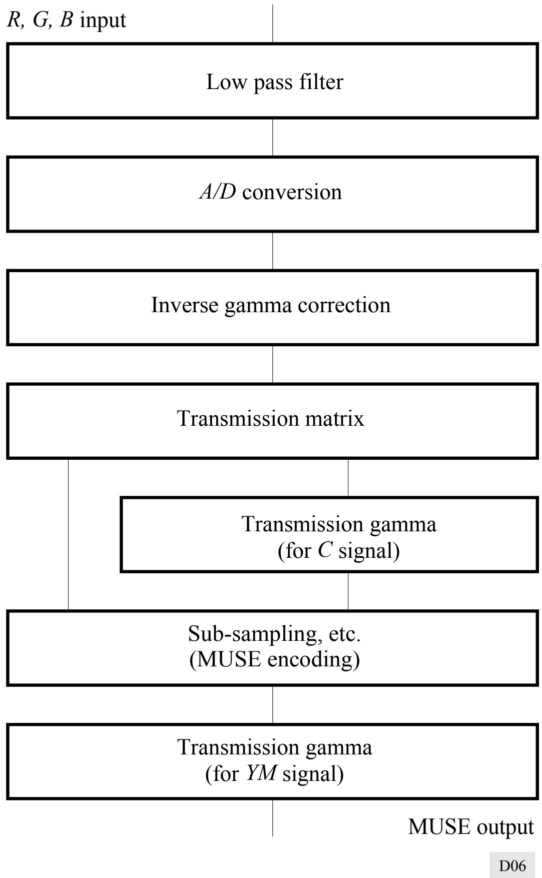


FIGURE 6

Inverse gamma curve for *R*, *G* and *B* signals

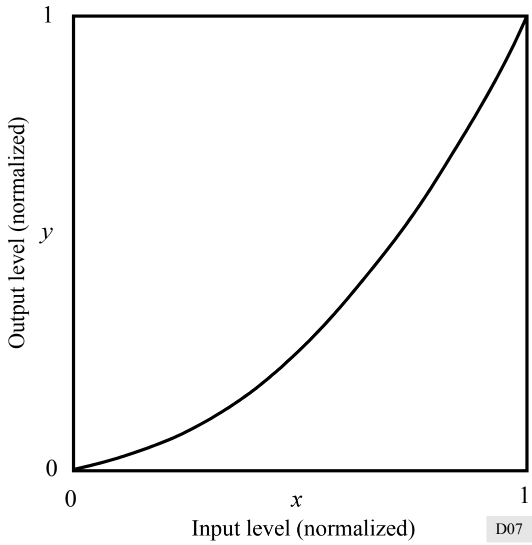


FIGURE 7

Transmission gamma curve for *YM* signal

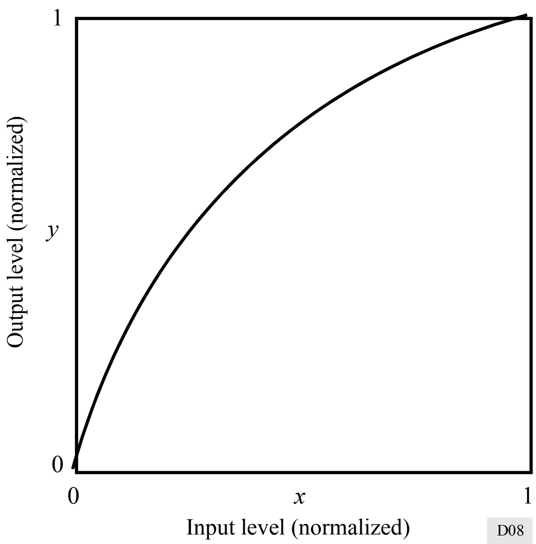
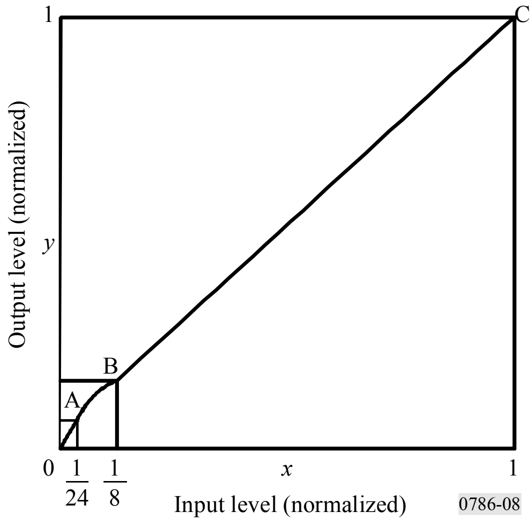


FIGURE 8

Transmission gamma curve for *C* signal



3.2.8.3 Transmission gamma curve for *C* signal

The curve shown in Fig. 8 is for positive values of x, while it has origin symmetry for negative values. The curve is expressed by the following equations, where half of the full quantization range is normalized to unity. This transmission gamma process should be applied only during the *C* signal period.

Between 0 and A: $y = (5/3)\, x$

Between A and B: $y = -(48/11)\, x^2 + (67/33)\, x - (1/132)$

Between B and C: $y = (31/33)\, x + (2/33)$

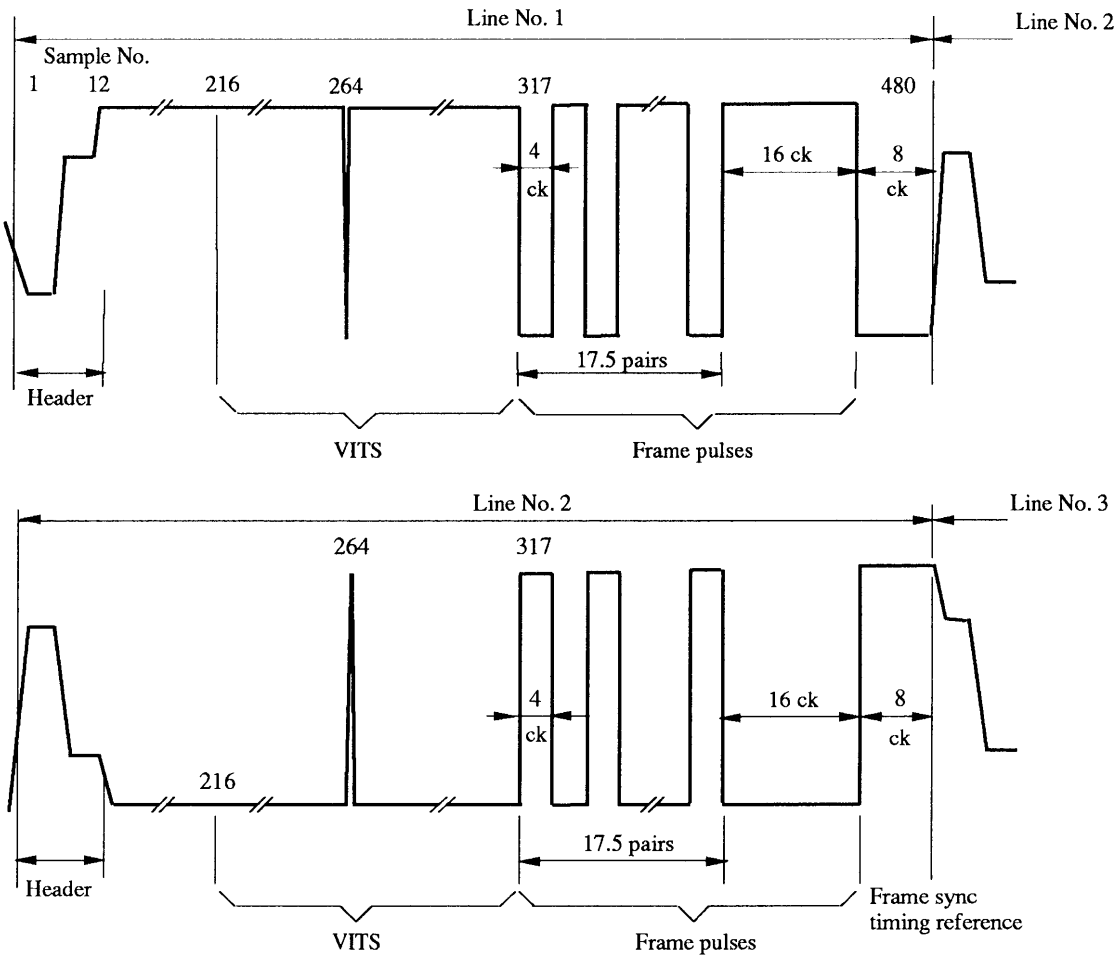
3.2.9 Synchronizing signal

– The positive sync with digital frame pulses is employed. The waveforms are shown in Figs. 9 and 10.

– The frame pulses are inserted in the latter half of lines No. 1 and No. 2 respectively, as shown in Fig. 9.

FIGURE 9

Synchronizing signal waveform



Note 1 – ck: one transmission clock duration (16.2 MHz).

Note 2 – Top and bottom levels of the frame pulses are 16 and 239 respectively.

Note 3 – The interval denoted by samples from No. 216 to No. 316 is used for vertical interval test (VIT) signals.

D10-sc

3.2.10 Others

3.2.10.1 Clamping level signal

The signal level of samples Nos. 107 to 480 in both lines No. 563 and No. 1 125 takes the value 128.

3.2.10.2 VIT signals

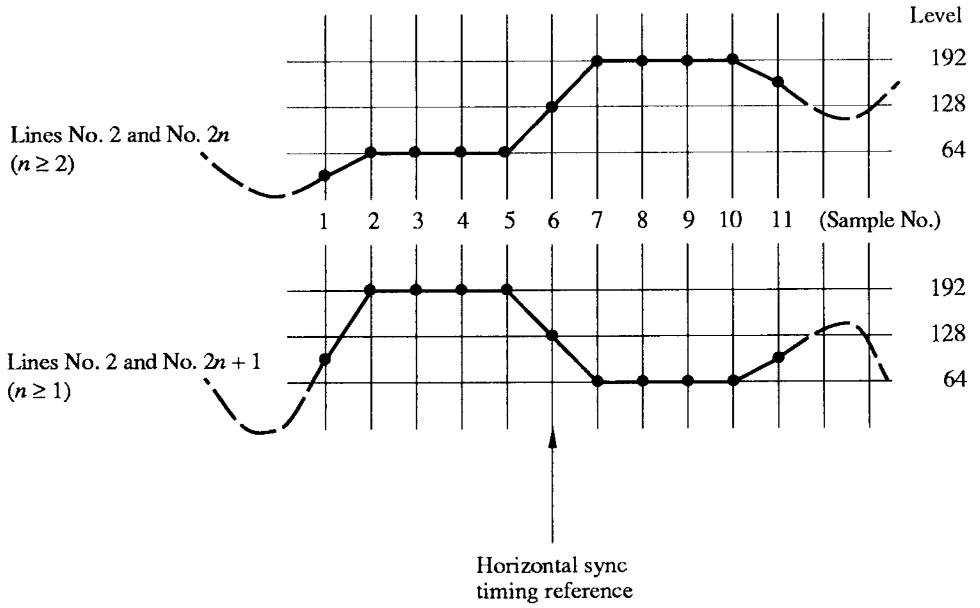
The following signals are inserted at sample No. 264 in lines Nos. 1 and 2:

line No. 1: negative impulse with the duration of 1 clock of 32.4 MHz;

line No. 2: positive impulse with the duration of 1 clock of 32.4 MHz.

FIGURE 10

Details of the header (HD) waveform



Note 1 – The polarity of the header (HD) waveform is alternated by line, and the alternation is reset after sending the frame pulses. (The HD waveform in line No. 3 is negative going.)

Note 2 – The signal levels of samples No. 1 and No. 11 take the following values:

Sample No. 1: average value between the level at sample No. 2 of header (HD) waveform and the signal level of sample No. 480 in the previous line.

Sample No. 11: average value between the level at sample No. 10 of header (HD) waveform and the signal level of sample No. 12.

D11-sc

3.2.10.3 Transmission control signals

– The signals consist of 32 bit data, of which the information is listed in Table 3.

– The 32 bits are divided and arranged into eight groups of 4 bits, in incremental order. Each group consists of an 8-bit word with the (8,4) extended Hamming error protection code. The four information bits are allocated on the left half of the word, while four check bits are on the right half. The bits are transmitted from left to right.

– Generator matrix for the extended Hamming code is defined as follows:

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 & 1 \end{bmatrix}$$

– Each bit is transmitted in two transmission clock periods in NRZ form. The levels of the NRZ signal are as follows:

logical 1: value 239

logical 0: value 16

TABLE 3

Transmission control signal

Bit No.	Parameter	Description
b_1	Field offset subsampling phase for *YM*	Set to "1", when sampling point is in the right hand position
b_2 b_3 b_4 b_5	Horizontal motion vector	The values are expressed in "2s complement", and set to positive when motion is to the right. The motion estimation accuracy corresponds to 1 clock period of 32.4 MHz. Bit denoted by b_2 represents LSB
b_6 b_7 b_8	Vertical motion vector	The values are expressed in "2s complement", and set to positive when motion is downward. The motion estimation accuracy corresponds to one line spacing. Bit denoted by b_6 represents LSB
b_9	Frame offset subsampling phase for *YM*	Set to 1, when sampling points of odd lines are in the right hand position
b_{10}	Frame offset subsampling phase for *C*	Set to 1, when sampling points are in the right hand position and when the quotient of line number divided by 2 is odd
b_{11} b_{12}	Control of noise reducer in the decoder	Four levels of noise reduction will be performed in the decoder according to the values expressed by the two bits (b_{11} is LSB). The reduction is larger with the higher value
b_{13}	Equalization flag	The bit is set to 1 when equalization is in progress at the encoder
b_{14}	Sensitivity control of motion detection	Set to 1 when low sensitivity
b_{15}	Inhibit flag for two-frame motion detection	When 1, two-frame motion detection is inhibited in the decoder
b_{16} b_{17} b_{18}	Motion information	The values expressed by the three bits (b_{16} corresponding to LSB) show the following conditions: 0: normal 1: complete still picture 2: slightly in motion 3: scene change 4 to 7: represents the extent of motion
b_{19}	Receiving mode control	0: standard mode 1: non-standard mode
b_{20}	Modulation mode	0: FM 1: AM
b_{21} b_{22} b_{23}	Extension bits	Undefined
b_{24}	Flag for still picture	0: normal mode 1: still picture mode
b_{25} to b_{32}	Extension bits	Undefined, but are used for control of still picture application when b_{24} is 1

3.3 Sound/data signal

3.3.1 Sound encoding

Mode A and Mode B are provided for the transmission of the sound; a four-channel sound signal with 15 kHz bandwidth for Mode A, and a 2-channel signal with 20 kHz for Mode B.

	Mode A	Mode B
Signal bandwidth (kHz)	15	20
Sampling frequency (kHz)	32	48

3.3.1.1 Quantization and companding for the sound signal

Quantization and companding of the sound signal are described in Table 4. The differential value between two successive samples of the linearly quantized PCM signal is compressed nearly instantaneously.

The sound signal transmission data are expressed in 2s complement and are sent from MSB to LSB. The bit length of each sample is 8 bits in the case of Mode A, and 11 bits in the case of Mode B.

TABLE 4

Quantization and companding method for sound signal

	Mode A	Mode B
Quantization	15 bit linear	16 bit linear
Coding	2s complement	
Companding method	Near instantaneous companding DPCM	
Companding law	15 to 8 bits with 8 ranges	16 to 11 bits with 6 ranges

3.3.1.2 Range bits

The construction of the range bits for each single sound channel is shown below. The range data comprised of 3 bits is valid for the sound signal being transmitted in the same sound/data frame. Table 5 shows the relationship between compression ratios and the corresponding range data.

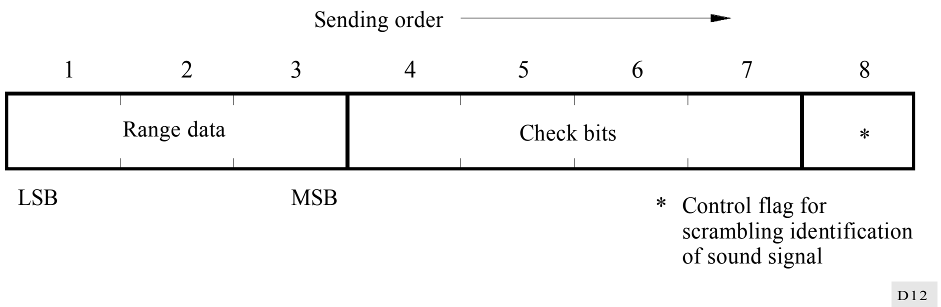


TABLE 5

Relationship between compression ratios and range data

Range data			Compression ratio	
MSB		LSB	Mode A	Mode B
0	0	0	1/128	1/32
0	0	1	1/64	1/16
0	1	0	1/32	1/8
0	1	1	1/16	1/4
1	0	0	1/8	1/2
1	0	1	1/4	1/1
1	1	0	1/2	–
1	1	1	1/1	–

3.3.2 Multiplexing of sound/data signal

3.3.2.1 Multiplexing

Method	Baseband time-division multiplexing
Signal format	Ternary, NRZ
Instantaneous baud rate	12.15 MBd

Binary/ternary conversion is specified as below. The ternary coded word is transmitted from left to right.

Three binary symbol	Two ternary symbol
0 0 0	0 0
0 0 1	0 1
0 1 0	1 2
0 1 1	0 2
1 0 0	1 0
1 0 1	2 0
1 1 0	2 2
1 1 1	2 1

3.3.2.2 Sound/data signals

Bit rate	1.35 Mbit/s
Number of sound channels	4 (Mode A) or 2 (Mode B)
Capacity of data channel	128 kbit/s (Mode A) or 112 kbit/s (Mode B)
Framing code	16 bits/frame (0001001101011110)
Control code	22 bits/frame
Word interleave	16 samples
Bit interleave	16 bits
Error correction code	
Sound/data	BCH (82,74) SEC-DED
Range data	BCH (7,3) SEC-DED in addition to the above

3.3.2.3 Generator polynomials for error correction code

Sound/data $(x^8 + x^7 + x^4 + x^3 + x + 1)$

Range data $(x^4 + x^3 + x^2 + 1)$

3.3.2.4 Sound/data frame frequency

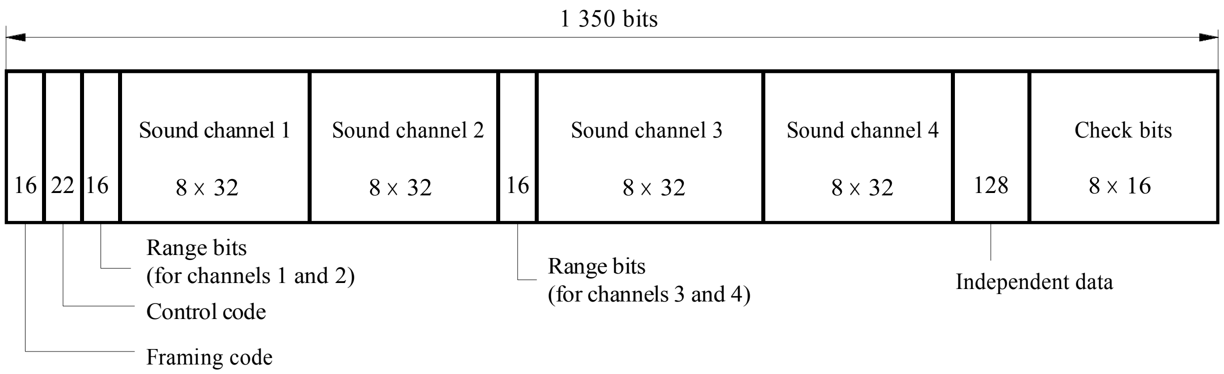
1 kHz is employed for the sound/data frame frequency.

3.3.2.5 Sound/data frame format

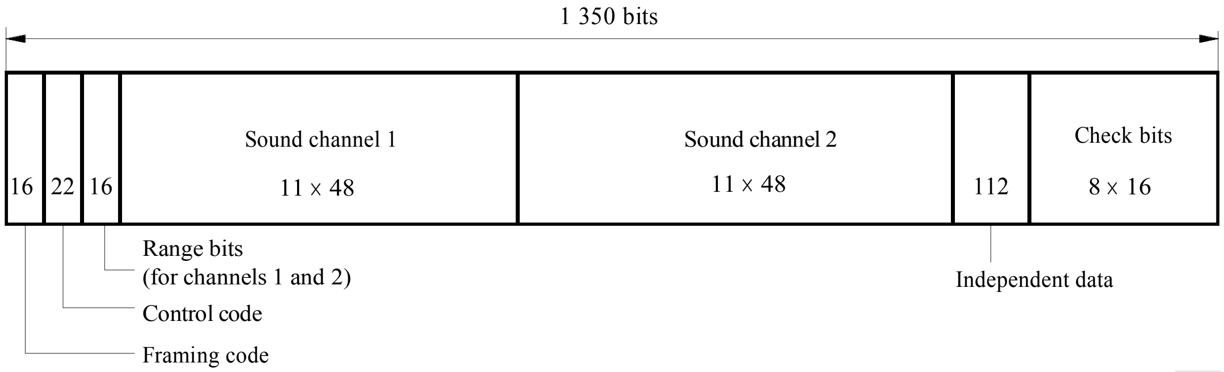
Figure 11 depicts the frame formats of Mode A and Mode B for the sound/data signals.

FIGURE 11

Sound/data frame format



a) Mode A



b) Mode B

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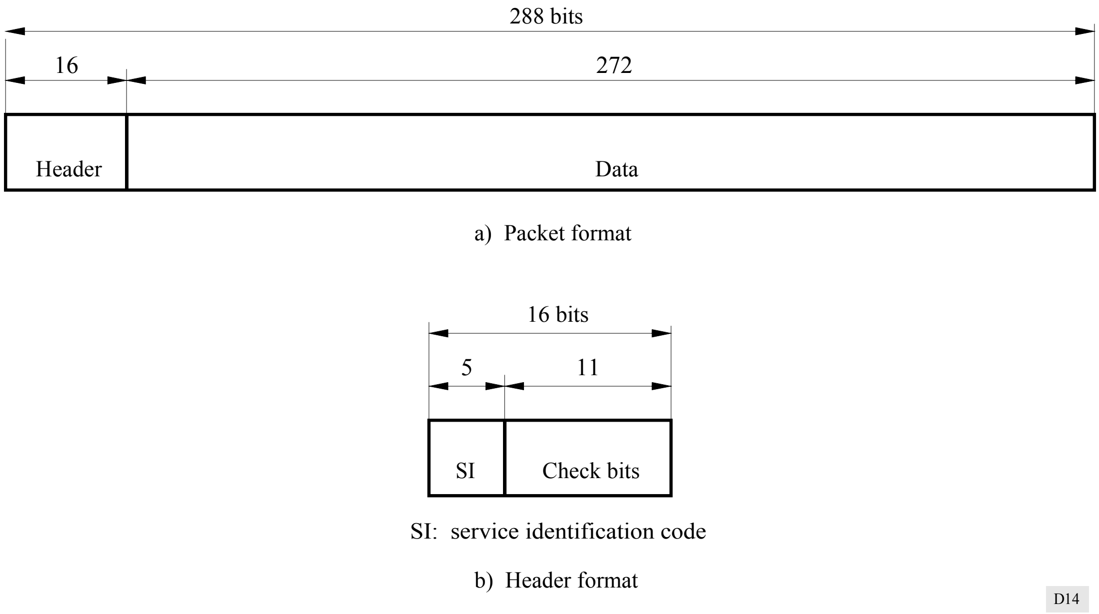
3.3.2.6 Data packet

A packet multiplexing system is used for data transmission. The packet format is shown in Fig. 12.

FIGURE 12

Data packet format



4 Conditional access

Line rotation, line permutation and a combination of these are applicable as scrambling methods for the MUSE video signal.

The access control methods of the MUSE system are quite similar to those of the digital subcarrier/NTSC system, which is described in Chapter 1 of the ITU-R special publication “Specifications of Transmission Systems for the Broadcasting-Satellite Service”.

5 Modulation

Frequency modulation is used for the BSS. The major parameter values are listed below.

5.1 Type of modulation

Frequency modulation with keyed AFC (Level 128 corresponds to the centre frequency of the channel).

5.2 Modulation polarity

Positive polarity.

5.3 Channel bandwidth

27 MHz or 24 MHz.

5.4 Baseband signal bandwidth

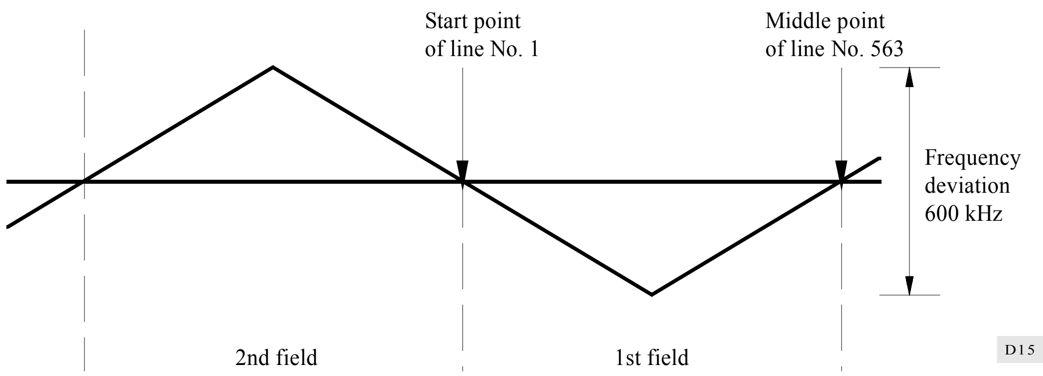
8.1 MHz (with 10% root-cosine roll-off characteristics).

5.5 Energy dispersal signal

Symmetric triangle waveform of 30 Hz (see Fig. 13). The frequency deviation for energy dispersal is set to 600 kHz peak-to-peak.

FIGURE 13

Energy dispersal signal



5.6 Frequency deviation

– *Video signal:* 10.2 ± 0.5 MHz peak-to-peak (for 27 MHz channel bandwidth) 9.0 ± 0.5 MHz peak-to-peak (for 24 MHz channel bandwidth), where the corresponding signal levels are values 16 (black level) and 239 (white clip level).

– *Ternary signal for sound/data:* 8.6 ± 0.5 MHz peak-to-peak (for 24 MHz channel bandwidth) 9.8 ± 0.5 MHz peak-to-peak (for 27 MHz channel bandwidth).

5.7 Emphasis

– The emphasis characteristics $E(f)$ are derived from those of the de-emphasis $D(f)$ below, as $E(f) = 1/D(f)$.

$$D(f) = (1/2) + (5/16)\cos(2\pi f / f_s) + (1/8)\cos(4\pi f / f_s) + (1/16)\cos(6\pi f / f_s)$$

where:

$f_s = 16.2$ MHz.

– Emphasis gain = 9.5 dB.

– Non-linear characteristics: see Fig. 14.

– The emphasis is applied during the following periods:

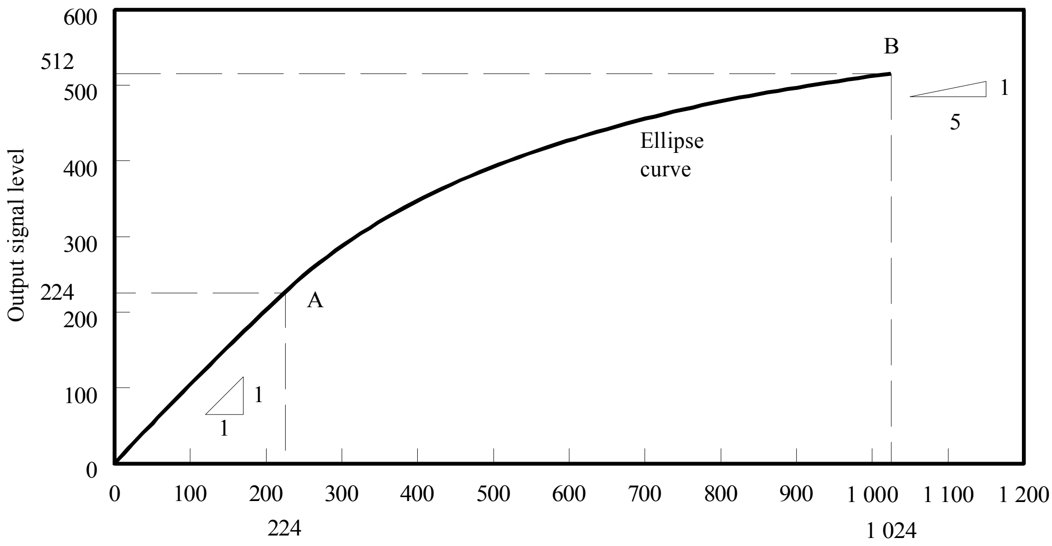
  – video signal periods (*YM* and *C*);

  – those samples, among the samples No. 1 and No. 11 in the header (HD) period, that are adjacent to video signals;

  – guard area (sample No. 106).

FIGURE 14

Non-linear characteristics for emphasis



Note 1 – The curve in the figure shows only positive values. It has origin symmetry for negative values.

Note 2 – The curve is specified as follows:

between 0 and A: straight line with gradient unity,

between A and B: ellipse curve with gradient of 1/5 at point B.

Note 3 – In the figure, the level expression is different from that defined previously. The level 0 in the figure corresponds to the grey level of the signal, while the level 224 in the figure corresponds to the white clip level.

D16