DRAFT STANDARD FOR DIGITAL TRANSMISSION OF TELEVISION IMAGES

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ABSTRACT

This paper describes the characteristics of the HORACE digital protocol intended for transmission of black-and-white standard television images and associated data through a digital channel and reconstruction of an NTSC standard television picture at the receiving end, using adaptive transmission to allow maximum picture quality at a selected data rate. Tradeoffs are discussed for transmission rates in the range from near DC to over 40 Mbits/second. The HORACE protocol will be a government test range standard to be issued by the Telecommunications Group [TCG] of the Range Commanders' Council as RCC Document 209.

BACKGROUND

Various means exist to digitize television pictures, with most systems locked into a specific communications rate, generally from 2.048 Mb/s on down or 22 Mb/s on up. The higher bit rate systems are used for "entertainment" television, not for transmission of pictures viewed for instrumentation purposes; lower bit rates are for teleconferencing applications and do not deal well with objects in motion--a serious failing when object motion is the aspect to be measured. The specification described here is a digital protocol, independent of the type of transmission medium used or the logic family and voltages at both ends (which may differ), and offers various user-adjustable characteristics to allow transmission of an optimized picture from an NTSC black-and-white sourcee to allow maximizing the "important" aspects of the picture sent, whatever they are. The standard, issues related to encoders and to decoders, and the standard's features (both fixed and optional) are taken from the draft of Range Commanders' Council [RCC] document 209-88, now in preparation. A published standard allows multiple equipment sources, and allows cross-playability of signals received from a variety of sources within and between government test ranges.

THE HORACE STANDARD

1. System characteristics. The HORACE protocol is a digital data format for transmission of NTSC television pictures and incidental data via any digital channel. The protocol is defined in binary terms, and consists of variable word and frame lengths. For the purposes of this standard, a word may consist of from one to eight (or more) bits as defined herein. Words are grouped together into what are here called lines which correspond to lines in the reconstructed picture or lines of binary data. Lines are in turn grouped into pages, corresponding to picture fields. Standard telemetry terms "frame" and "subframe" are not used hereafter in reference to the digital signal to avoid confusion with the word "frame" as it applies to picture images.

1.1 Video input and output.

1.1.1 Inout. The video input shall conform to EIA RS-170 standards, except that field repetition rates of 59.4 to 60.6 and horizontal rates of 15,562.5 to 15,938 shall be permitted, with or without interlaced scanning.

1.1.2 Output. Sweep rates at the output shall conform to sweep rates at the input within ±1% and change no more than ±0.3% in the duration of a single field sweep. When in variable skip mode, video output sweep rates shall be derived from an internal crystal within ±0.25% of nominal or 60 Hz power line lock and shall not change by more than ±0.1% during the duration of a single field sweep.

1.2 Transmission format. The digital transmission signal shall be a continuous binary digital data stream at a fixed rate. A synchronization pattern and data header shall be sent at the beginning of each *line* transmission, followed by a variable-length set of variable-length words.

1.2.1 Line types. Lines transmitted shall be of two types:

1.2.1.1 Picture lines. Each picture line transmitted represents a physical line of picture information. Picture line format shall be as described in §1.9 ff.

1.2.1.2 Data lines. Transmissions sent in between picture fields of serial data not intended to be part of the reconstructed picture. Data line format shall be as described in §1.10 ff.

1.3 Active picture lines. The number of active picture lines transmitted and displayed per field shall be exactly 240.

1.4 Interlace. The encoder shall operate in all modes with input signals from interlaced (262.5 lines/field) or noninterlaced (262 lincs/field). If interface is present on the input picture, information regarding odd/even shall be sent in the picture format codes (see §1.9.2.5). Noninterlaced fields shall be identified as odd fields.

1.5 Error handling.

1.5.1 Error correction systems. Perfect reception and decoding of a television picture encoded as described herein requires a noiseless channel.

1.5.2 Error recovery. When an error in data occurs such that the resulting picture or data line is garbled, the decoder shall display an error indication and shall immediately commence seeking the start-of-line code for relock.

1.5.3 Clock slippage. After any clock slippage, the decoder shall reacquire line synchronization after reception of one valid start-of-line word (see §1.9.1), and page synchronization after reception of no more than three video lines or one data line. Video output signal shall be correct within less than one page.

1.6 Vertical data channel. Data may be emplaced in bits 61-98 and 101-238 of the vertical data channel (see 1.9.2.1): Bits 61-98 are assigned to a time-code transmission coincident with the start of the vertical scan; bits 101-238 can transmit data that changes or fixed data such as a source identification number. When any of these data bits are used, bit 59 is transmitted as a ONE. The vertical data channel is separate from the data transmissions described in §1.10 ff. The vertical data channel is *not* displayed as part of the picture.

1.7 Pixel interleaving (stagger). When selected in encoders so equipped, alternating lines (*line stagger*) or fields (*field stagger*) shall be such that on staggered lines the first pixel on the line is delayed by half a pixel. When a staggered original is presented to the decoder, the decoder shall display the picture staggered as in the original. In field stagger, the undelaycd field shall be field one; in line stagger the undelayed lines shall be the odd-numbered ones.

1.9 Frame/field skipping option. The encoder may be provided with a field- or frame-and-field skipping capability. The user selects whether a frame or a field is transmitted (field skipping is recommended when motion is present in the picture; frame-skip option is not available on all encoders). This option provides better horizontal and gray scale resolution at a loss of temporal resolution. The display repeats the previous field or frame until a new one has been received. The frame or field selected for transmission is made of a single field or frame respectively, not a running composite of the input. Skipping is of two types:

1.8.1 Selected. The user may select the option of sending every other, third, fourth, etc., down to every sixteenth field (not all values need be present on any unit). The adaptive functions of the encoder are still engaged, so the encoder transmits the best picture possible for the bit rate.

1.8.2 Variable. When the variable rate is selected, the encoder transmits the picture with the full selected horizontal resolution and with entropy coding, transmitting a new field or frame, whenever the buffer is low enough to handle a complete new one. Variable skipping transmits the best still picture possible, but the temporal rate will vary with picture complexity.

1.9 Line format. Each line shall consist of the 8-bit start-of-line code, a ten-bit format code, fill bits (if present), a fill terminator bit, fixed- or variable-length pixel codes of a number indicated by the format code, and tail codes (if present).

1.9.1 Start-of-line code. The start-of-line code shall be 00000001. NOTE: This pattern can occur within a picture line or data line but must be constrained in tail codes. When the pattern occurs in a data or picture line, the pattern is ignored by the decoder because of position, since data in the format codes that follow can differentiate the two occurrences.

1.9.2 Format code, picture lines. The ten-bit format code that follows the start-of-line code shall be defined as described below:

1.9.2.1 Bit one: static parameter subcodes. Format bit one varies with its position in the field as specified below. Because the bit stream separated from this bit has one bit per line, it is also referred to as the *vertical data channel*.

Line number	Meaning		Values
1- 3	Start of field [Note 1]		000
4- 13	Alignment code [Note 2]		0101010010
14- 17	Pixels per line (full resolution):	128	0000
		160	0100
		225	1000
		256	0001
		320	0101
		450	1001
		512	0010
		640	0110
		900	1010
18	Frame/field skip ON [Note 3]		1

19	Skip type is FRAME [Note 3]		1
20- 23	Skip ratio [Note 3]	variable	0001
		2:1	0010
		3:1	0011
		4:1	0100
		:	:
		15:1	1111
		16:1	0000
24	Horizontal interleave ON [Note 4]		1
25	Interleave type is FIELD [Note 4]		1
26	Vertical interlace ON [Note 5]		1
27- 31	DPCM kernel identification [Note 6]		00000
32- 34	Entropy code identification [Note 7]		000
35- 36	Buffer status multiplier (bytes/line) [Note 8]	64X	01
		128X	10
		256X	11
		512X	00
37- 41	Encoder buffer capacity (bytes) [Note 9]	8K	00001
		16K	00010
		24K	00011
		:	:
		248K	11111
		256K	00000
42	Data multiplex ON [Note 10]		1
43- 52	Multiplex line length [Note 11]	1	0000000001
		2	0000000010
		3	0000000011
		:	:
		1023	1111111111
		1024	0000000000
53- 58	Field number (mod 64) [Note 12]		(varies)
59	Data in vertical [Note 13]		0
60	Data in horizontal [Note 14]		0
61- 98	Date/time [Note 15]		(varies)

99	Tail codes present [Note 16]		1
100	Color/3D indication [Note 17]		X
101-238	Undefined spares [Note 18]		0 (all)
239-240	End of field [Note 19]	00	

NOTES:

1. The format data bit in the first three lines of a field shall be ZERO. These bits may be used for error handling.

2. Format data bits 4 through 13 are used to establish synchronization f the format data bit channel.

3. When the <u>frame/field skip</u> format bit (18) is a ONE, fewer than during all frames or fields are being sent by the encoder. When format bit 19 is a one, frames are being sent; if format bit 19 in a ZERO, fields are being sent. Bits 20-23 indicate the ratio of pictures input to pictures sent. When skip ratio is <u>variable</u>, a frame or field is sent at any time the encoder buffer can hold an entire new picture. When frame or field skipping is ON, the decoder repeats the previous picture until the next picture is received, and switches to the new picture during vertical blanking.

4. The <u>interleave</u> function, when engaged, causes the A:D converter to sample selected lines of the video signal at a point midway between the normal sampling points for each pixel. When line interleave is engaged, alternate lines in each field will have the sampling points delayed on all of the odd lines of the field. When field interleave is selected, field one of each frame will be sampled in the normal position and field two will be sampled in the delayed mode. Format data bits 24 and 25 are used to inform the decoder of the presence and type of interleaving in use. The decoder uses this information to properly interleave the display as an exact reproduction of the encoded picture. See also §1.14 of the standard.

5. Format data bit 26 is ZERO when the input picture is not interlaced and ONE with an interlaced source.

6. A DPCM kernel consists of a set of normal DPCM codes, high-level DPCM codes, and two-bit delta DPCM codes. The set defined in §§1.9.5.1-1.9.5.3 are identified as kernel <u>00000.</u> If other kernels are defined, they will carry a different identification and be addenda to this specification.

7. The entropy code identification number defines the variable-length coding scheme used for the transmitted codes that use it. The table in §1.9.5.4 has been assigned the entropy code identification 000. Any other code defined in revisions of this specification will carry a different identification number.

8. These bits indicate the multiplier to be used to obtain the encoder buffer status. The number of lines having bit seven (see §1.9.2.6) set to a ONE is multiplied by the value given (64X to 512X) to obtain the buffer level in bytes.

9. These bits specify the encoder buffer capacity in (8-bit) bytes, and are fixed for a given encoder.

10. When this bit is set to a ONE, the encoder should expect at least one data multiplex line in the following page (see §1-10 ff).

11. When data multiplexing is enabled, these bits specify, the number of bits in each data line. Normally this will be fixed for a given transmission (volume). If the number varies, the number applies to the page that follows the page in which the number is transmitted (see §1.10.5).

12. The modulo-64 field number is used to identify missing fields resulting from frame or field subsampling. Starting point is arbitrary. Numbered fields are input fields, not fields sent.

13. When static parameter bit 59 is a ONE, it indicates that a binary data signal is sent at the edge (normally the left-hand edge) of the picture and is intended to be an attribute of the displayed figure. When this capability is used, horizontal unblanking timing and pulse duration an more critical than when this feature is not used.

14. When static parameter bit 59 is a ONE, it indicates that a binary data signal is sent at a horizontal edge (top or bottom) of the picture and is intended to be an attribute of the displayed figure. When this capability is used, vertical unblanking timing and pulse duration are more critical than when this feature is not used. Encoded data should be confined to lines 24 to 262 counting from onset of vertical blanking in the individual, with a test to ascertain that compatibility exists.

15. Format data bits 60-97 shall be used to transmit day of year and time of day in hours, minutes, and seconds time coincident with the start of vertical unblanking (i.e., the first picture line) in the input picture. Code assignment shall be as described in §1.15. When not used, theme format data bits shall be all ZEROs.

16. When tail codes an present (for color or anaglyphic separation), static parameter bit 99 should be a ONE. If tail codes are not present, static parameter bit should be set at a ZERO since the absence of tail codes when known can assist in error recovery. Tail codes an discussed In §1.12.

17. When tail codes an not present, vertical channel bit 100 shall be a ZERO. When tail codes are present and 3D separations are being sent, vertical channel bit 100 shall still be a ZERO. When tail codes are present and color is being sent, vertical channel bit shall be a ONE.

18. Undefined spares, shall be transmitted as ZEROs.

19. The format data bits in the last two picture lines of a field shall be ZERO, and may be used in error handling.

1.9.2.2 Bit two: DPCM type. When format bit two is a ZERO, DPCM with entropy coding is engaged for the line. When format bit two is a ONE, two-bit DPCM without entropy coding is used for that line.

1.9.2.3 Bit three: horizontal subsampling. When format bit three is a ZERO, horizontal subsampling shall not be engaged for the line indicated. When format bit three is a ONE, horizontal subsampling shall be engaged, and only the odd-numbered samples sent for that particular line. When a subsampled line is received, the decoder shall display each received pixel twice. Any field may consist of lines that are subsampled and lines that are not.

1.9.2.4 Bit four: coarse/fine. When format bit four is a ZERO, normal delta coding (“fine”) shall be engaged. When format bit four is a ONE, high-level (“coarse”) delta coding shall be engaged, both operating with the entropy code described in §1.9.5 ff. Any field may consist of both types, but only one type may be transmitted on any single line.

1.9.2.5 Bits five and six: line type. Format bits represent the position of a transmitted line in the vertical scan, and can be used in conjunction with format bits 8 and 9 for error handling (see 1.9.2.7). Format bits 5 and 6 are 00, for the last line of field two (even) and the first three lines of field one (odd). For the next-to-last line of all fields, bits 5 and 6 are 01. For the last line of field one and the first three lines of field two, bits 5 and 6 are 10. For all other picture lines, bits 5 and 6 are 11. For noninterlaced pictures, or even-divisor field subsampled pictures, all fields shall be treated as a field one.

1.9.2.6 Bit seven: encoder buffer status. Format bit seven in conjunction with static parameter bits 35 and 36 ("buffer status multiplier", see §1.9.2.1, note 8) indicates the fullness of the transmit buffer in thermometer style. This information is used by the decoder to establish output picture line rate. The more ONES transmitted, the fuller the buffer. Buffer status is reported only once per field. This feature is not used in variable frame/field skip mode.

1.9.2.7 Bits eight and nine: modulo-four line counter. Bits eight and nine shall provide a modulo-four count of lines transmitted, starting with 00 for the first line of the field and line five, nine, thirteen....(4N + 1); 01 for line two, six, ten....(4N + 2); 10 for line three, seven, eleven....(4N + 3); and 11 for lines four, eight, twelve....(4N); N an integer.

1.9.2.8 Bit ten: spare. No meaning is presently attached to format bit ten, which should be sent as a ZERO. Any assignment of a meaning to format bit ten will be made in extensions of this standard.

1.9.3 Fill bits. The encoder shall transmit one to 960 fill bits per line when required to prevent buffer underflow. Fill bits shall be ONEs.

1.9.4 Fill terminator. The fill terminator signifies the end of the fill bit interval, or indicates that no fill bits were transmitted in a line. The fill terminator is a single ZERO.

1.9.5 Pixel codes. Pixel codes are variable length or two-bit fixed length codes which indicate the change in brightness from the previous pixel (or from black at the start of each line). Pixel codes can represent one of three different schemes, which may be used adoptively in a single system. (The decoder identifies the type of pixel code sent in any given line from the format codes (see 1.9.2 ff). Only one type of pixel code is used on any line.) At least one bit per pixel is present on each line (corresponding to a black line with 256 pixels per line) to 7200 bits (the 8-bit L-code at 900 pixels per line), although pictures resulting in very long lines are uncommon.

1.9.5.0 Clipping levels. When any pixel code is transmitted that would cause the resulting pixel value to be greater than 127 or less than 0, the resulting pixel value shall be clipped at 127 or 0, respectively. No out-of range pixels shall be permitted, and rollover shall not be used.

1.9.5.1 Delta codes, normal DPCM kernel 00000. Eight jump values are used, corresponding to brightness changes between the predictor and the input pixel over the 128-point (7-bit) range between 0 (black) and 127 (white). For normal DPCM these values are:

L-code number	Jump value
1	0
2	+ 3
3	- 3
4	+ 8
5	- 8
6	+20
7	-20
8	Maximum jump (see 1.9.5.1.1).

1.9.5.1.1 Maximum jump. When L-code #8 is called, it indicates a jump of 60 brightness steps in the direction that the largest jump can be taken; i.e., if the previous pixel value were 30, a maximum jump would take pixel value to 90. If previous pixel value were 63, a maximum jump would take pixel value to 123. If previous pixel value is 64 or more, the maximum jump would subtract 60 steps.

1.9.5.2 Delta codes, high-level ("coarse") DPCM kernel 00000. Eight jump values are used, corresponding to brightness value changes between the predictor and the input pixel expressed in the 128-point range between 0 (black) and 127 (white). For high-level (coarse) DPCM these values are:

L-code number	Jump value
1	0
2	+ 4
3	- 4
4	+10
5	-10
6	+25
7	-25
8	Maximum jump (see 1.9.5.1.1).

1.9.5.3 Delta codes, two-bit DPCM kernel 00000. Four jump values can be expressed in two bits, corresponding to brightness value changes between the predictor and the input pixel expressed in the range between 0 and 127. Since entropy coding is not used with 2-bit DPCM mode, the code value is transmitted directly. For 2-bit DPCM, these values are:

Code value	Jump value
00	+ 4
10	- 4
01	+20
11	-20

1.9.5.4 Entropy code table, kernel 000. When either normal or high-level entropy delta coding is engaged, the transmitted code is determined by the previous code value, as shown. The "previous" L-code level is shown on the left (rows); the "next" level is shown in columns.

	1	2	3	4	5	6	7	8
1	1	001	01	00001	0001	0000001	000001	00000001
2	1	01	001	0001	00001	000001	0000001	00000001
3	1	0001	01	00001	001	0000001	000001	00000001
4	001	01	00001	1	000001	0001	0000001	00000001
5	001	00001	01	000001	1	0000001	0001	00000001
6	0001	001	00001	01	000001	1	0000001	00000001
7	001	00001	0001	0000001	01	000001	1	00000001
8	1	001	01	00001	0001	0000001	000001	00000001

1.10 Data line format.

1.10.1 Data line identification. Data lines may be transmitted to send data not intended to be part of the reconstructed picture. Data lines, if present, are usually inserted between picture pages (fields). Data lines commence, as do picture lines, with the code 00000001, followed by the format code 1101010110 and the fill terminator 0, followed by the data.

1.10.2 "Data lines present" identification. The presence of data lines in a signal is identified by the presence of a ONE in bit 42 of the vertical channel (see §1.9.2.1, note 10).

1.10.3 Data line length. Length of the data line is indicated by codes in bits 43-52 of the static parameter subcodes described in §1.9.2.1, note 11.

1.10.4 Number of data lines. Any number of data lines may be transmitted, as long as they are all of the same length. When lines are transmitted between fields (pages), they carry line numbers from 241 up, for reference purposes, since 240 picture lines are sent per page. For any given transmission rate, the larger the data lines in length and number, the lower the resolution of picture that is sent, as a direct consequence of the added data overhead.

1.10.5 Dynamic switching, of data lines. The number and length of data lines may be varied dynamically within the constraints of a single data volume. When this is done, the subcodes sent on lines 42-52 on a given page, they are effective on lines 241 and beyond on the following page, not the page that contains those changes.

1.10.6 Message constraints. No constraints arc placed on the data transmitted in a data line, which may therefore contain synchronization codes including those in §1.10.1.

1.11 Level extensions. While eight brightness level changes arc defined herein for the two entropy-coded modes, the system is not limited to eight levels. Extensions can be made to define more than eight brightness changes, thus lengthening the entropy code tables.

1.12 Tail codes. Picture-related data may be transmitted at the end of each picture line after the identified number of pixel values are transmitted. The presence of tail codes is indicated by a ONE in bit 99 of the vertical channel. The status of vertical channel bit 100 identifies the meaning of the data sent, as described in note 17 of §1.9.2.1.

1.13 Data in picture. In accordance with RCC/OSG 452-86, data may be added at the left-hand edge of the picture, appearing as a white dot where a ONE is sent. Pulse duration is 3 ± 1 microseconds, or at least 7 pixels duration at the lowest resolution (128 pixels/line).

1.14 Pixel stagger. Pixel stagger (or *interleave*) is defined as an operating mode where alternating lines or fields have pixels delayed by half a pixel interval, so objects in the picture tall enough to cross two lines in a single field (line interleave) or frame (field interleave) can be located to half-pixel accuracy, doubling resolution of such measurements. Staggered transmission is identified by bits 24 and 25 of the vertical channel (see §1.9.2.1, Note 4).

1.15 Time and date code transmission. Bits 61-98 are assigned for time and date transmission, as described in §1.9.2.1, Note 15.

1.16 Vertical channel spares, Bits 101 through 238 of the vertical data channel may be used for fixed data (such as the system identification) or data that changes from field to field.

2. Encoder characteristics. Encoders can take any size and shape, so long as they conform to the HORACE interchange protocol specified in §1 above. Encoders need not be capable of all output data rates nor all resolutions, and in some uses need not have all operating modes.

2.1 Output levels. The encoder produces an output at standard TTL levels, and can be specified to have sufficient drive to operate into 50- or 75-ohm coaxial lines. When an external clock signal is applied, it should also be at TTL levels, with one unit load (3000 ohms to the +5-volt rail) maximum load.

2.1.1 Auxiliary output interfaces. Other output interfaces may be required to use with other equipment.

2.2 Input characteristics.

2.2.1 Video signal. The input video signal fed to the encoder should be a standard RS-170 black-and-white signal with one-volt peak-to-peak amplitude for termination with 75 ohms, or as otherwise specified. The video signal may be either AC- or DC-coupled. Synchronization pulses should be negative. The encoder can operate with NTSC signals with 525 lines per frame, or with noninterlaced signals consisting of fields with 262 or 263 lines. The encoder accepts vertical sweep rate of 60 Hz ±1%. Color burst should not be present.

2.2.2 Data inputs.

2.2.2.1 Data lines. Data inputs for data lines (see §1.10) are accepted at TTL levels with one unit load maximum. The number and maximum length of data lines is fixed at manufacture.

2.2.2.2 Vertical channel data inputs.

2.2.2.2.1 Timing inputs. Parallel inputs to the vertical input channel bits 60-97, if used, are provided at time of manufacture.

2.2.2.2.2 Undefined spares. Fixed patterns in the undefined spares positions (bits 101 through 238) are specified at time of manufacture. Variable inputs shall be loaded in parallel.

2.3 Status indicators. Status indicators can be provided to indicate the status of certain internal circuits not otherwise easily verified, and video outputs can be provided to drive a monitor (video display and/or waveform monitor) with the picture produced by the encoder's predictor.

2.4 Maximum clock rate. Maximum clock rate is defined by the user. The HORACE protocol operates at any data rate, but serves little purpose at data rates below 9600 b/s or above 60 Mb/s.

2.5 User-selectable options. For a given bit rate, the user must select the number of pixels per line and the frame/field skipping to produce the desired picture quality.

2.5.1 Pixels per line. The encoder has one or more choices for the number of pixels per line in the highest-resolution mode (when the encoder approaches overload due to picture complexity, the horizontal resolution is cut in half on selected lines).

2.5.2 Picture skipping.

2.5.2.1 Selected. If field skipping (if available) is engaged, picture quality (i.e., number of pixels per line and/or use of fallback modes) is increased at a loss of temporal resolution, which is preferable in some instances. *Frame* (rather than *field*) skipping preserves all vertical detail on interlaced originals, but blurs any object in motion.

2.5.2.2 Variable. If variable field skipping (if available) in engaged, picture quality will be at the encoder's resolution mode selected by the user, with no fallback modes used. Pictures will be sent as often as possible for the resolution selected, hence setting a lower number of pixels per line will increase the number of pictures (pages) sent.

3. Decoder characteristics. The standard defined in §1 does not specify a particular package style for the decoder. When not specifically part of the requirements, characteristics of the decoder are identified as optional or recommended.

3.1 Operation. The decoder shall operate and produce an NTSC-compatible picture when fed the data signal and 0° clock signal, without any adjustment, internal or external.

3.1.1 Input characteristics. Clock and data signals shall be at TTL levels. For other levels or transmission formats, a bit synchronizer/signal conditioner [BSSC] or line adapter card (see 3.1.2) shall be used. Input impedance at the TTL ports shall be 75 ohms, produced by a resistor located near the inputs. When this resistor is removed, input impedance shall be as a single TTL unit load (3000 ohms pullup) or less. Data polarity at the decoder input shall be as the encoder output. The decoder shall operate with a rising clock edge (measured at the 50% point) coincident with and up to 9° following the onset (rising or falling edge) of data.

3.1.2 Optional plug-in cards. Provisions shall be made on the decoder to allow use of plugin cards to facilitate certain additional uses or interfaces on the decoder. These functions may also be provided by separate boxes, connected to the decoder inputs and/or outputs.

3.2 Operating bit rates. Any decoder shall have a specified maximum operating data rate. No minimum data rate need be specified, but data rates have a lower limit because of practicality. Any decoder shall operate at any rate up to and including the maximum rate, when a clock signal of appropriate frequency and phase is presented to it.

3.3 Pixels per line. The decoder shall respond to signals with 128, 225, 236, 320, 450, 512, 640, and 900 pixels per line, and adjust automatically to display any of these rates received. Decoders with a maximum input data rate of 20 Mb/s (see §3.2) are not required to decode 512, 640, and 900 pixel per line inputs unless specified at the time of purchase.

3.4 Interlace. Input signals containing alternating field information (see 1.9.23, Note 5) shall be reproduced with interlace in the correct order. Signals containing one field only shall be reproduced without interlace or by replication on alternating vertical sweeps. Line interpolation shall not be used.

3.5 Status indicators. The HORACE protocol is such that status indicators can be provided on the decoder to indicate proper operation and modes of operation when an input signal is present.

3.6 Environmental conditions. Decoders are normally intended for rack mounting applications in a benign (generally manned) environment. Nothing in the standard prevents manufacture of smaller environmental decoders; smaller or more rugged decoders can be made if the maximum bit rate and number of modes and outputs is reduced, thus executing a smaller subset of this standard.

FEATURES OF HORACE

The HORACE protocol is an adaptive system, which adjusts gray-scale and horizontal resolution on a line-by-line basis to provide the best possible picture without overloading the transmission channel. If the (user-selectable) full-scale horizontal resolution is selected correctly, “most” pictures can be sent with a minimum use of the lower-resolution fallback modes. If higher resolution is desired than can be obtained at the bit rate selected, frame or field subsampling can be used to get higher picture quality at a fixed bit rate. The variable frame/field transmission rate is generally set to operate in the highest resolution mode only, transmitting a new picture anytime the channel can accept another. When picture subsampling is used, the decoder displays the last picture received until replaced (during vertical blanking) with a new one.

The HORACE protocol is coded in the horizontal direction only, so no degradation of vertical resolution occurs. No *interframe* coding is used, which would blur of objects in motion.

When high-resolution measurement of the space between two objects or the distance between an object and either edge of the screen is critical and the resolution of the original picture is high enough to warrant it, pixel stagger can be engaged. When line stagger is engaged, the beginning pixel on even-numbered lines in a single field is delayed by one half pixel period on the original encoding and on the display. Objects that are at least two lines tall in any field can thus be resolved in horizontal position by half a pixel period, creating 1800 distinct locations when 900 pixel-per-line transmission is used. The resolution thus obtained, even with 256 pixels per line, generally exceeds that obtainable with analog transmission links and analog tape recorders, and many CCD-based cameras.

The HORACE signal is a highly-compressed version of the original analog video signal, and consists of variable-length words and lines to make best use of the data channel. Long runs of ONEs can result from the compression algorithm, and the distribution of ONEs and ZEROs is not symmetrical. As a consequence, bit slippages and lack of low-frequency response introduce system errors and decrease overall data quality. Consequently, a stable clock is required on systems where data dropouts may occur, and use of randomization or encryption of the type that will produce high transition densities for any data and remove DC components is advised. Experimentation has shown, however, that operation in an AC-coupled system without randomization is possible.

The HORACE protocol allows transmission of data not intended to be part of the picture display in two ways: (1) One or more lines of data may be transmitted in between fields of the picture. The number of lines transmitted is fixed at the time of manufacture of the encoder; line length, which can be from one to 1024 bits per line may be fixed or varied depending on the type specified. Loading of the data on data lines is serial, with a strobe/clock stepping in the data serially from an external (user-supplied) buffer. External buffer fullness can be used to modify the number of bits transmitted on any set of lines. When the number of bits per line is allowed to vary (if more than one data line is used, all must be of the same length) the change in line length transmitted on bits 43 to 52 of the vertical channel (see next paragraph) pertain to the transmitted page that follows, not the data lines transmitted at the end of that page. A single data line of 933 bits and a 60 page/second rate (no field skipping) can supply a T-0 data or voice signal. (2) Bit one of the format word that follows the horizontal synchronization character is used to produce a data channel which has one bit per picture line, or 240 bits per page (bit one in data lines, if present, is not considered to be part of the *vertical channel* thus defined. Some of the vertical channel bits are constrained or serve various housekeeping channels (see 1.9.2.1); others are available to the user for external parallel inputs if specified at the time of encoder manufacture. Vertical channel bits 61-98 are assigned for use in transmitting time codes; bits 101-238 may be used for other data.

The HORACE protocol allows transmission of data signals added to and intended to be part of the picture, so long as those signals are not wholly nor in part located within the vertical or horizontal blanking interval. Vertical edge coding, per RCC 452 is supported. Data codes in picture lines below line 23 are removed by the encoding process and cannot be used for data transmission.

The user determines the bit rate and pixels per line when setting up the HORACE encoder. The standard supports pixel-per-line resolutions from 128 to 900, although not all choices may be present on all units. The decoder will automatically determine (from the codes transmitted in the vertical data channel) what is being sent and adjust to decode and display it accordingly. The user sets the data rate, by selecting any of the several internal clock rates available on the encoder, or feeding the encoder an external clock if the encoder is to be driven in synchronization with something else (the camera, a computer, a channel bank, etc.). The user selects whether pixel stagger is to be engaged or not, and frame/field subsampling used.

Since the HORACE system is adaptive, it strives to present the best picture possible for any scene. To determine the highest rate needed for any combination, one assumption is made: the eight possible brightness changes allowed, can be represented by a three-bit number (because eight is two to the third power), are distributed in such a way that entropy coding is *at least* as good as sending the codes as three-bit numbers. (In a complex ("busy") picture, the figure for a HORACE-encoded picture is on the order of 2.2 bits per pixel). Then the bit rate needed for any given horizontal resolution is calculated by taking the nineteen-bit overhead on each line, (8-bit sync, 10-bit format, one-bit fill terminator) plus three times the number of pixels per line, and multiplying the result by 240 (the number of lines per field) and multiplying by 60 (the nominal number of fields per second). By so doing, we obtain:

Pixels/line	Required bit rate
900	39,153,600
640	27,921,600
512	22,392,000
450	19,713,600
320	14,097,600
256	11,332,800
225	9,993,600
160	7,185,600
128	5,803,200

The HORACE system, when operating on a totally black screen input, uses only one bit per pixel because of the entropy coding (since "no change" is the most likely value of the "next" pixel and each line starts at black). These values are:

900	13,233,600
640	9,489,600
512	7,646,400

450	6,753,600
320	4,881,600
256	3,960,000
225	3,513,600
160	2,577,600
128	2,116,800

Variations in the vertical sweep rate will change the numbers shown; variations in the horizontal rate do *not* affect these numbers. If tail codes or data lines are added, these figures will increase.

When the picture gets too "busy" to allow full resolution at the given pixel rate, the encoder goes first to a more coarse quantization (reducing the number of steps in the gray scale) on a line-by-line basis, then switching to a two-bit-per pixel code without entropy (thus the number of bits per pixel is fixed at two), and finally to a horizontal subsampling which decreases the number of pixels per line by a factor of two. "Fill" bits are added to selected lines to make the data rate stay constant. At the lowest resolution fallback mode rate (i.e., two bits per pixel, horizontal subsampling), if engaged for all lines, the data rates are the same as the second table.

On a "real" picture, the required number of bits will be somewhere between the two sets of values, since almost any picture contains areas where there are no contrast changes. For a given number of pixels per line, a bit rate between the minimum and maximum values shown in the tables above is the proper choice; experimentation with the actual input picture will determine what will work most optimally. A system with a 5.1 Mbit data rate can produce a slightly better picture than one with a 5 Mbit/second rate. No specific rate is "golden"; the system can be used on whatever rate is available that will cause an acceptable picture.

With frame- and field skipping, the channel bit rate may be greatly reduced. The reduced temporal resolution rate allows greater latitude for horizontal resolution. Sending alternating fields (ie., every second field) reduces the motion rate to 30 per second, still higher than motion picture film.

Variable field skipping may be used when full horizontal resolution is desired but motion is not a serious concern. When variable skipping is engaged, a full resolution, entropy-coded picture is sent at the (fixed) data rate and then no picture is sent until a complete picture can replace the last one sent in the encoder buffer. The decoder outputs the last complete picture received until the next is received. Because entropy coding is used, time required to send a picture is a function of the data rate and picture complexity, but should generally be less, as much as one-third the time, necessary to transmit a picture at 3 bits per pixel. For a 256 pixel/line picture, and assuming three bits per pixel, a single field contains (19 + [256 X 3]) X 240 = 188,800 bits; at one bit per pixel the number is 66,000 bits. At the 56 kb/s rate proposed for ISDN, then, pictures could be transmitted at a rate of one every two seconds or so. At the T-1 rate of 1.544 Mbits/second, about ten pictures could be transmitted per second, approximating what many teleconferencing systems do.

When the channel to be used dictates the bit rate, the HORACE system can be externally clocked to operate at whatever data rate is available, including the standard T-3 rate of 44.736 Mb/s. The signal produced by the HORACE encoder does nor produce long runs of ZEROs, which can cause trouble in maintaining synchronization; long runs of ONEs are possible, but do not cause a synchronization problem because of the alternating polarity of ONEs in such a system. At the 44.732 Mb/s rate, a 900-pixel/line signal can be sent, about twice the resolution available with good NTSC equipment. With pixel stagger, resolution of 1800 points is possible. Even at this highest resolution rate, two pixels can differ by the maximum jump value, or nearly half the distance from full black to white. Such a system requires utmost care in selection of cameras and video displays, and cannot be recorded on any known analog videotape recorder. At the T-3 rate at least 4 Mb/s is available or data transmissions between fields as described in §1.10 of the standard.

CONCLUSIONS

The HORACE standard, with extensions for color and three-dimensional images, is a test range standard that will allow interchange of data between and within ranges through various systems. Because it is a published standard, multiple vendors are anticipated. RCC publication of the standard will occur in late 1988.