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TEMPORAL FREQUENCY AS A TECHNIQUE TO MEASURE THE ABILITY OF A TELECONFERENCING SYSTEM TO REPRODUCE MOTION

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This report covers investigations and measurements of temporal frequency responses as a means to numerically analyze the motion performance capability of a digital video teleconferencing codec. The effort described in this report contains a more detailed analysis, refinement of measuring techniques and a large selection of parameters on three different codec models. It reviews the parameters which can be observed in the picture. It covers the development of the test procedure and reviews the test signals and describes the methodology of their applications. It contains a discussion of the test results and shows them to be fully logical and in accordance with expectation and limited observations. It also gives a brief review of the program and contains recommendations to further efforts in the objective performance evaluation of digital video codecs.

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NCS TECHNICAL INFORMATION BULLETIN 91-2

TEMPORAL FREQUENCY RESPONSE AS A TECHNIQUE TO MEASURE THE ABILITY OF A TELECONFERENCING SYSTEM TO REPRODUCE MOTION

JANUARY 1991

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FOREWORD

Among the responsibilities assigned to the Office of the Manager, National Communications System, is the management of the Federal Telecommunication Standards Program. Under this program, the NCS, with the assistance of the Federal Telecommunication Standards Committee identified, develops, and coordinates proposed Federal Standards which either contribute to the interoperability of functionally similar Federal telecommunication systems or to the achievement of a compatible and efficient interface between computer and telecommunication systems. In developing and coordinating these standards, a considerable amount of effort is expended in initiating and pursuing joint standards development efforts with appropriate technical committees of the International Organization for Standardization, and the International Telegraph and Telephone Consultative Committee of the International Telecommunication Union. This Technical Information Bulletin presents and overview of an effort which is contributing to the development of compatible Federal, national, and international standards in the area of teleconferencing. It has been prepared to inform interested Federal activities of the progress of these efforts. Any comments, inputs or statements of requirements which could assist in the advancement of this work are welcome and should be addressed to:

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TEMPORAL FREQUENCY
AS A TECHNIQUE TO MEASURE
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SYSTEM TO REPRODUCE MOTION

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1.0 INTRODUCTION AND SUMMARY

This document summarizes work performed by Delta Information Systems, Inc. (DIS) for the National Communications System (NCS), Office of Technology and Standards. This office is responsible for the management of the Federal Telecommunications Standards Program, which develops telecommunications standards, whose use is mandatory for all Federal departments and agencies. This study was performed under task order number 88-009 of contract number DCA100-87-C-0078.

This report covers investigations and measurements of temporal frequency response as a means to numerically analyze the motion performance capability of a digital video teleconferencing codec. This performance parameter was previously introduced under task order number 87-010 of the same contract. The effort described in this report contains a more detailed analysis, refinement of measuring techniques and a large selection of measured values of temporal frequency response and other related performance parameters on three different codec models. The techniques described herein provide a complete objective analysis of moving pictures which is an important factor in the performance evaluation of any digital video teleconferencing system.

Section 2.0 gives the background of previous NCS programs which are directly related to this effort. Section 3.0 reviews the parameters which can be used to describe the motion performance of a digital video codec, and the related artifacts which can be observed in the picture. It also establishes the requirements for a practical method to evaluate such artifacts. Section 4.0 covers the development of the test procedure in accordance with these requirements. It reviews the test signals and describes the methodology of their application, giving details of the test setup and the standard test equipment used in the process. The test results are summarized in Section 5.0, covering temporal frequency response and related parameters. The results are illustrated by typical examples of each covered parameter. Section 6.0 contains a discussion of the test results and shows them to be fully logical and in accordance with expectations and limited observations. Section 7.0 gives a brief review of the program and contains recommendations for further efforts in the objective performance evaluation of digital video codecs.

2.0 BACKGROUND

2.1 Previous NCS Programs

Two closely related previous tasks of the same overall NCS program form a direct basis for the ongoing investigation of the applications of temporal frequency response measurements. They are Task No. 87-011, Development of a Video Tape to Correlate Subjective and Objective Testing of Teleconference System (Final Report dated May 18, 1990), and Task No. 87-010, Standardization of End-to-End Performance for Full Motion Video Teleconferencing (Final Report dated May 21, 1990). Both these tasks in turn use background material prepared in previous years as part of other NCS programs.

Task No. 87-011 covers the steps taken in the development of a tape for objective testing of motion performance. The Final Report gives the pertinent data of the various test patterns and the background for their application to the measurement of temporal frequency response. Task No. 87-010 includes details of the design and development of the test patterns. It shows preliminary measurement results and sample graphs of temporal frequency responses. The results are generally as expected and logical but indicate that the test methodology needs refinement to achieve more consistency. Such refinements are addressed in the task on hand.

2.2 T1Q1.5 Committee Contributions

The Subworking Group on Video Teleconferencing/Video Telephony of the American National Standards Institute (ANSI) Committee T1Q1.5 is developing Analog Interface Performance Specifications for Digital Video Teleconferencing/Video Telephony Service. During this process, numerous contributions were submitted by experts from various organizations covering motion performance degradations and possible methods of their measurement. These contributions furnish a thorough overview of observed motion artifacts and provide material for the analysis of their relation to temporal frequency response. This makes it possible to judge the utility of temporal frequency response measurements for the overall evaluation of the ability of a teleconferencing system to reproduce motion.

3.0 MOTION PERFORMANCE PARAMETERS

3.1 Spatial and Temporal Performance

A digital video teleconferencing system requires establishment of more performance parameters than an analog system. Conventional parameters used for instance in EIA RS-250B or ANSI T1.502 are spatial which means that they can be evaluated with stationary signals. Most additional parameters are temporal and concerned with motion rendition. New definitions and motion test signals are being developed to evaluate temporal performance.

A very simplified block diagram of a digital video system is shown on Figure 3.1. It contains the main system elements that determine transmission quality and indicates the sections which influence spatial and temporal performance.

The NTSC decoder and encoder determine essentially all spatial performance parameters. The design of these circuits is well developed and normally produces flawless performance. Linearity is generally no problem since most elements producing non-linearities in analog systems are not present. Spatial performance of codecs is largely independent of encoding algorithms and bit rate and in most cases meets or at least approaches high quality video specifications. This has been proven by conventional tests on several different codecs over the full range of bit rates. The only important exception to this statement is spatial frequency response which is controlled by the bandwidth of the filters on the transmit and receive side which must be matched to the sampling rate of the digital encoder and thus is indirectly dependent on the transmission bit rate.

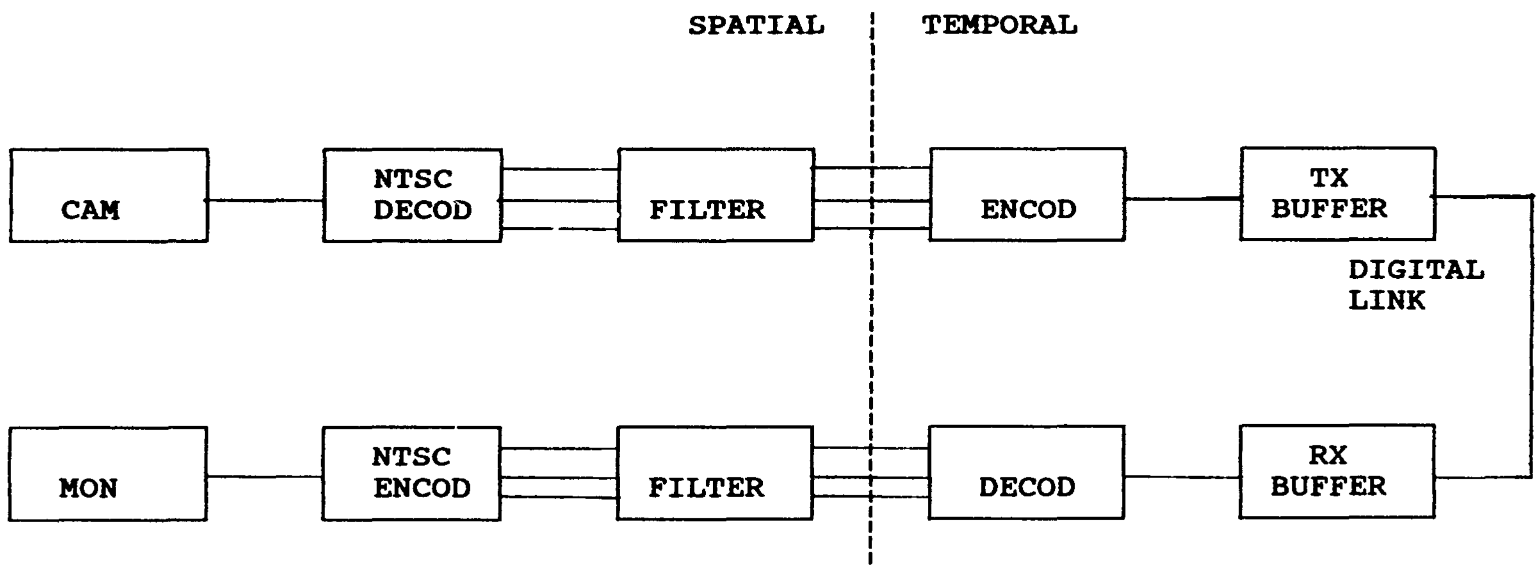


FIGURE 3.1

TYPICAL DIGITAL VIDEO SYSTEM

Temporal performance parameters are determined by the digital system elements namely encoder, decoder and buffers which are typical for all interframe coding techniques. Numerous artifacts are produced by limitations in the encoding algorithm and buffer size. A typical motion artifact catalogue is contained in Document T1Q1.5/90-106. Many test methods have been proposed which generally measure one specific artifact. Such tests are to yield numerical results which can be correlated with subjective evaluation.

In spite of the considerable past effort to define and measure motion artifacts, there has been no consensus between the many involved parties. The main problem is that different encoding algorithms often produce artifacts which are only slightly different and thus difficult to distinguish. The exact wording of artifact definitions also causes many differences of opinion. The following artifact list is a composite of several contributions edited to fit into typical distinct categories.

A. **Resolution Degradation** - The deterioration of motion video such that the received video imagery has suffered a loss of temporal resolution and response. It is largely caused by Temporal Slope Overload which appears mainly in predictive coding schemes. It is generated when the prediction error signal increases and exceeds the greatest representative value of the quantizing characteristics.

   - **Blurring/Smearing** - The deterioration of a motion video picture in which the received image has lost edges and detail of the original imagery. Fast moving objects may appear completely wiped out.

   - **Edge Busyness** - The deterioration of motion video such that the outlines of moving objects are displayed with randomly varying activity.

   - **Loss of Contrast** - The received video imagery is unable to reproduce the contrast range of the original because of temporal slope limitations. The picture has a "washed out" appearance.

B. **Spurious Signals** - The received video imagery contains elements not present in the original.

   - **Blocking** - The received video imagery possesses rectangular or checkerboard patterns not present in the original.

- **Mosquito Noise** - The quantizing noise generated by the block processing of moving objects that gives the appearance of false small moving objects (e.g. a mosquito flying around a person's head and shoulders).

- **Dirty window** - Dirty window is a kind of granular noise which remains after all objects have gone away. It occurs when conditional picture element replenishment is used in coding based on interframe correlations. When threshold values are made too high to control the effective number of picture elements across the input video, part of the noise in the picture remains, so it seems as though one is looking into a room through a dirty window.

C. **Jerkiness** - The continuous motion in the original picture is disturbed. The received picture may show any degree of motion deterioration from a slight loss of smoothness to a "series of distinct snapshots".

D. **Image Persistence** - The appearance of parts of earlier video frames of a moving and/or changing object within the current video frame.

- **Erasure** - An object that was erased continues to appear in the received video imagery.

- **Retention** - After a frame cut, distinct portions of the previous image remain visible for several frames. It takes several frames to build up the new image to full amplitude.

3.2 Artifact Evaluation

In spite of frequent similarities of the various artifacts listed above, each of them has some distinct features which can be extracted and measured. This, however, is much more easily said than done. A good overview of potentially applicable techniques is given in ANSI Committee T1 Contribution, Document Number T1Q1.5/90-108, entitled "Feature Extraction for Automated Quality Assessment of Digitally Transmitted Video" dated Jan. 30, 1990. Many proposed techniques depend on the simultaneous availability of the original (undistorted) picture and the digitally processed (distorted) codec output picture. Such a requirement represents a serious and often unsurmountable constraint since in practice most measurements must be made on an installed system and not on equipment connected back-to-back in a laboratory. Implementation of the proposed feature extraction and artifact measurement techniques can be fairly complex and requires sophisticated test equipment.

The user of a video teleconferencing system is concerned with the overall appearance and acceptability of the received picture and not with the exact value of a specific artifact. That is particularly true since many artifacts are so similar that only a digital video expert is able to distinguish them. Therefore, it would be desirable for a system to measure the ability of a teleconferencing system to reproduce motion to have the following properties.

- Firmly defined and easily applied test signals
- Numerical results describing system performance
- Ability to perform measurements when only the processed picture is available
- Stability and repeatability of test results
- Ability to measure multiple performance parameters and artifacts with the same test signal
- Ability to determine numerical limits of acceptability for various system applications
- Ease of numerical evaluation

Though almost any picture can be used to test digital video performance subjectively, the need for consistent repeatability and numerical evaluation calls for an artificially generated test pattern for objective tests. Such a pattern can be produced by a number of available computer video generation equipments. The ultimate solution will be a specially designed test pattern generator but more research is needed to make the design of such a unit practical.

4.0 TEST PROCEDURE

4.1 Concept

Modern technology has eliminated motion as a significant factor in standard broadcast TV. Therefore, all conventional test signals for evaluation of broadcast TV performance are static. However, the large amount of bit rate reduction necessary in digital video teleconferencing/video telephony service makes use of the frame-to-frame redundancy of picture content which in turn affects the fidelity of motion rendition. This calls for a test technology utilizing time variant test signals.

Motion measurements should follow the well established techniques of static video measurements as much as feasible. A prime static performance parameter is spatial frequency response which can be defined as the dependence of video amplitude on different spacings of black and white picture elements as produced by the conventional resolution test chart or a video sweep. Its temporal equivalent is temporal response which can be defined as the ability of a television system to respond to periodic changes (varying periodicity) from frame-to-frame (the time domain).

However, while the measurement of spatial frequency response is generally straightforward and independent of the test signal, the techniques of digital video make the measurement of temporal frequency response more complex. The stress on the codec algorithm depends on the amount of detail in the whole picture, and the temporal response will change accordingly. Thus, the same temporal frequency may produce different response values with test patterns containing different amounts of detail.

Most motion artifacts, as listed in para. 3.1, result in distortions of the produced video amplitude. A subjective evaluator is not inclined to separate many of these often very similar artifacts but judges the picture quality based on the integrated total impression. Since temporal response measures video amplitude distortion, it also gives a composite of the effects of most of these artifacts. It does not require complex extraction of individual features followed by a sophisticated mathematical analysis but provides a practical objective measure of the integrated effect of a wide range of motion deteriorations, thus simulating what the observer's eye sees during subjective tests.

One temporal cycle is produced by one black-white-black transition at one picture element in the moving test pattern, either by motion or by switching. This transition ideally generates a square wave which is degraded after passing through a teleconferencing video codec. This degradation manifests itself as a reduced or otherwise distorted slope and/or loss of peak-to-peak amplitude of the transition. Both of these factors can be readily measured by the RMS value of the resulting waveform amplitude.

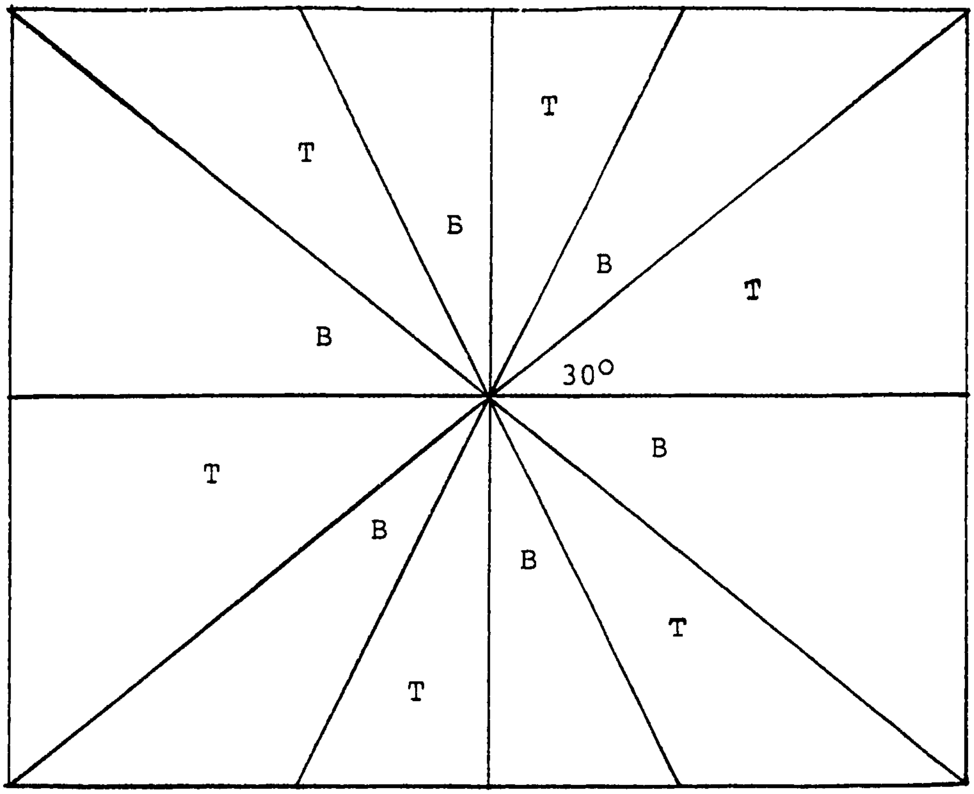
4.2 Implementation

Any motion in a picture results in a change of pixels in consecutive frames. Motion artifacts occur when the amount of change is such that the codec cannot reproduce it faithfully. In order to achieve repeatable numerical results, the pixel change must be implemented with firmly defined patterns. It can be produced either by actual motion of the same pattern or by switching between two different patterns (scene cut).

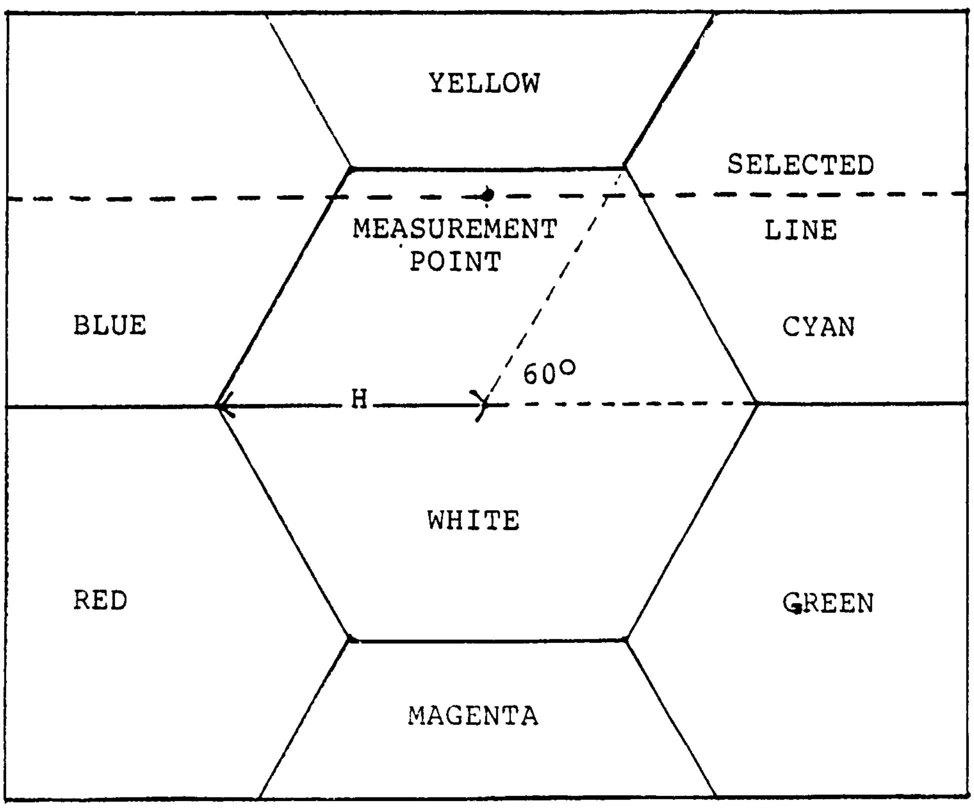
Two different motion test patterns were generated on a Cubicomp computer controlled special effects equipment and recorded on video tape. The first was a simple scene cut while the second employed a rotating wheel pattern. The scene cut pattern was produced by switching between white circles on a black background and a black field. Size and spacing of the circles and the rate of switching are variable, forming 32 different scene cut test patterns. They result in pixel changes of about 60% and 30% at each switching and temporal frequencies between 0.125 and 7.5 cycles per second.

The rotating wheel pattern has two parts, namely a static background with a white center section and segments of bar chart colors around the perimeter, and a rotating overlay consisting of black spokes. These spokes have 3 different width, each using between 6 and 9 rotation speeds, forming 23 different rotating wheel test patterns. These patterns produce pixel changes of between 2.2% and 25% per frame and temporal frequencies of between 0.33 and 3.75 cycles per second. One of the patterns is shown on Figure 4.1.

Full details on the test patterns are contained in the previously submitted final reports referenced in para. 2.1 of this report. For ease of reference, the basic parameters of all implemented patterns are listed on Tables 4-1 and 4-2. The fastest switching rate



ROTATING OVERLAY



BACKGROUND

FIGURE 4.1

ROTATING WHEEL TEST PATTERN - 30 DEGREE SPOKES

CIRCLE SPACING (%)		7		4		2.25	
CIRCLE RADIUS (%)		3.25	2.25	1.75	1.25	1	.75
SWITCHING RATE (FRAMES)	TEMPORAL FREQUENCY (CPS)	TEST PATTERN NO.					
120	.125	A-1	-	A-13	-	A-25	-
60	.25	A-2	-	A-14	-	A-26	-
30	.5	A-3	-	A-15	-	A-27	-
15	1.0	A-4	-	A-16	-	A-28	-
8	1.875	A-5	A-9	A-17	A-21	A-29	A-33
4	3.75	A-6	A-10	A-18	A-22	A-30	A-34
2	7.5	A-7	A-11	A-19	A-23	A-31	A-35
1	15	A-8	A-12	A-20	A-24	A-32	A-36

NOTE: CIRCLE SPACING AND RADIUS VALUES ARE GIVEN AS PERCENTAGE OF PICTURE WIDTH.

TABLE 4-1

SCENE CUT PATTERNS

ROTATION SPEED

TEST PATTERN NO.	SPOKE WIDTH (DEGREES)	FRAMES/ REVOLUTION	DEGREES/ SECOND	TEMPORAL FREQUENCY (CPS)	FRAMES/ SPOKE	% PIXEL CHANGE/ FRAME	% BLOCK CHANGE/ FRAME
1	30	540	20	0.33	45	2.2	18
2	30	360	30	0.50	30	3.3	
3	30	240	45	0.75	20	5.0	
4	30	180	60	1.00	15	6.7	22
5	30	144	75	1.25	12	8.3	
6	30	120	90	1.50	10	10.0	
7	30	90	120	2.00	7.5	13.3	34
8	30	72	150	2.50	6	16.7	
9	30	60	180	3.00	5	20.0	43
10	18	720	15	0.42	36	2.8	31
11	18	540	20	0.55	27	3.7	
12	18	360	30	0.85	18	5.6	
13	18	240	45	1.25	12	8.3	
14	18	180	60	1.67	9	11.1	42
15	18	144	75	2.10	7.2	13.9	
16	18	120	90	2.50	6	16.7	
17	18	90	120	3.33	4.5	22.2	57
18	10	720	15	0.75	20	5.0	50
19	10	540	20	1.00	15	6.7	54
20	10	360	30	1.50	10	10	
21	10	240	45	2.25	6.7	15	
22	10	180	60	3.00	5	20	70
23	10	144	75	3.75	4	25	75

TABLE 4-2

ROTATING WHEEL PATTERNS

(highest temporal frequency) on Table 4-1 is not usable in practice because all codecs use frame repetition rates of 2 or higher which wipes out the fastest switching.

The test patterns are recorded on 3/4" tape and processed through codecs of different manufacture operating at various bit rates covering the full range of 64 to 1544 Kbps. The outputs are again recorded on 3/4" tape which is analyzed in the test setup shown on Figure 4.2. The VO-9850 Tape Recorder allows manual tape advance and identification of each frame by means of a frame counter. The KM-F250 Frame Synchronizer re-generates the degraded synch waveform of the still picture from the tape recorder and makes it compatible with the VM-700 Video Measurement Set. This equipment allows amplitude measurement at any exactly defined point in the picture with an accuracy of better than one IRE unit. It also makes it possible to recognize all temporal advances of the test pattern. An amplitude measurement is made after every advance even if there has been no change in amplitude. Measurements are taken over about 4 to 10 temporal cycles, depending on pattern detail, rotation or switching speed and the amount of recognized amplitude variations.

Several series of tests were performed, using both types of patterns through various codecs. During the performance of these tests, it became apparent that the results obtained with the rotating wheel pattern were more consistent than those with the scene cut. Furthermore, the rotating wheel patterns, though artificial, more closely simulate actual motion which makes them preferable. In addition, the motion simulated by a scene cut is unique and various codec algorithms may respond to it quite differently. The scene cut pattern may unduly favor one codec design over another. It therefore was decided to use only the rotating wheel pattern for further temporal frequency response measurements, though the scene cut pattern turned out to be useful for other purposes.

The rotating wheel patterns as originally designed appeared to be adequate for the range of codecs and bit rates to be tested and have been left unchanged for further tests. However, the test instrumentation was modified to remove possible ambiguities and

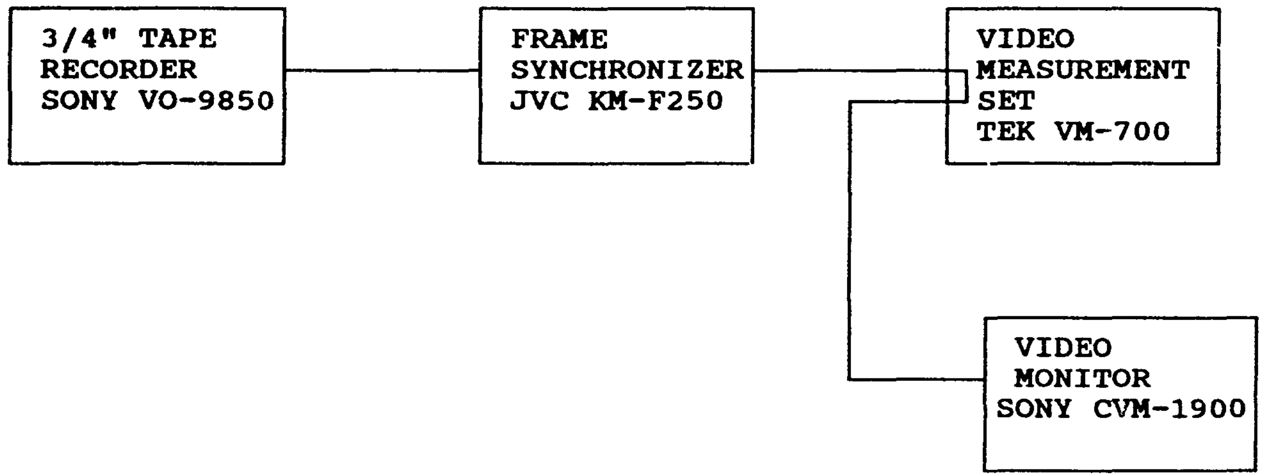


FIGURE 4.2

TEST SETUP - TEMPORAL FREQUENCY RESPONSE improve convenience and accuracy. Originally, the measurement was made on the line passing through the center of the picture (approximately line 140) but at this location there often is a difference between the two fields of one frame just at the critical moment of the white-black transition which produces an ambiguity in signal level. Making the measurement near the center (approximately 36 microseconds after the start of horizontal blanking) of a line near the top of the white portion (approximately line 70, exact location not critical) as shown on Figure 4.1, eliminates this problem.

All codecs use frame repetition to limit the total amount of data to be transmitted. This reduces the frame rate to 15 or below but, depending on type and use of the picture, is largely not seriously objectionable. Due to this repetition, it is not necessary to measure the signal level of every frame, only whenever an actual frame advance occurs. These points can easily be identified using the cursor on the VM-700 display, providing enhanced convenience and accuracy. Printouts of two consecutive typical displays are shown on Figures 4.3 and 4.4, demonstrating that a frame advance is easily recognizable.

The measured levels are processed in a computer, resulting in a printout a sample of which is shown on Figure 4.5. It contains the graph of signal level vs. frame number, the RMS value of the signal levels and the average distance between frame advances, giving the effective frame repetition rate. The RMS value provides one point on a temporal response curve derived from test patterns of one spoke width at different rotation speeds. With increasing rotation speed and temporal frequency, the frame repetition rate increases provided the codec algorithm has an adaptive repetition rate which is common with low bit rate codecs.

In cases of a severe challenge imposed by the test pattern on the codec algorithm, buffer overload may produce additional distortions toward the bottom of the picture. This is easily recognized and measured using the line selection feature of the VM-700. If desired, a pattern analysis on about line 210 gives a "picture bottom" equivalent to the usual measurement on line 70.

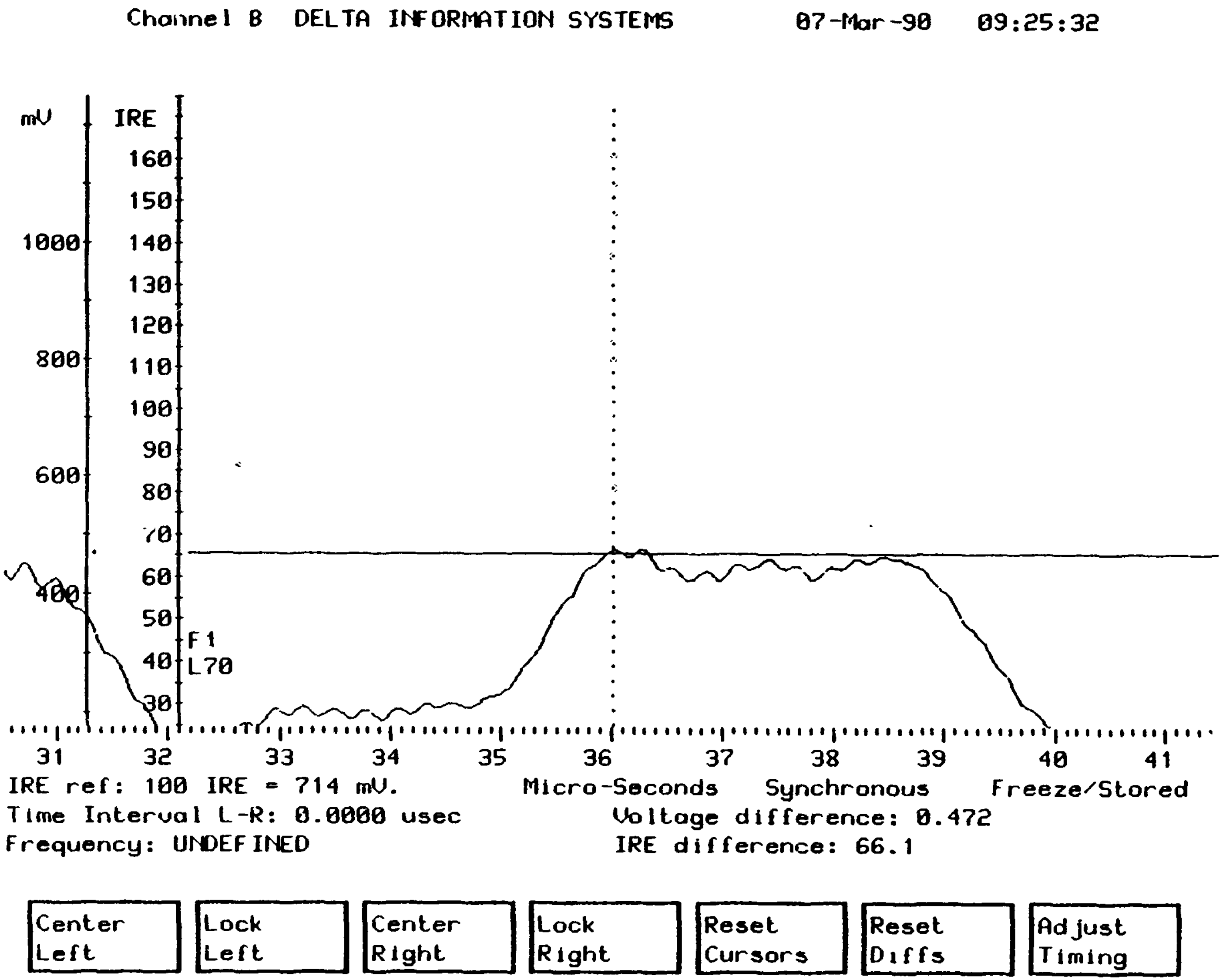


FIGURE 4.3

VM-700 DISPLAY AND AMPLITUDE MEASUREMENT

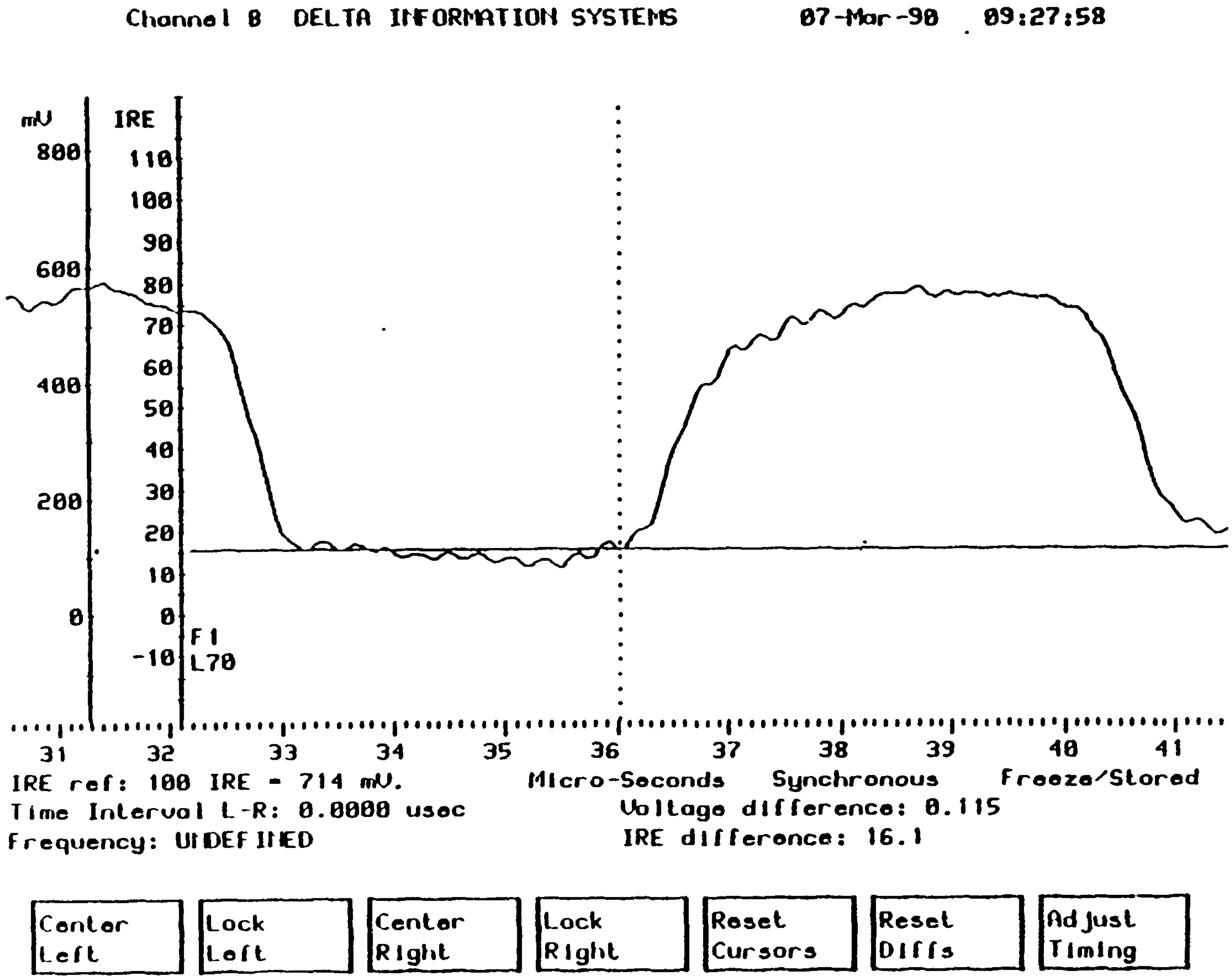


FIGURE 4.4
VM-700 DISPLAY AND AMPLITUDE MEASUREMENT

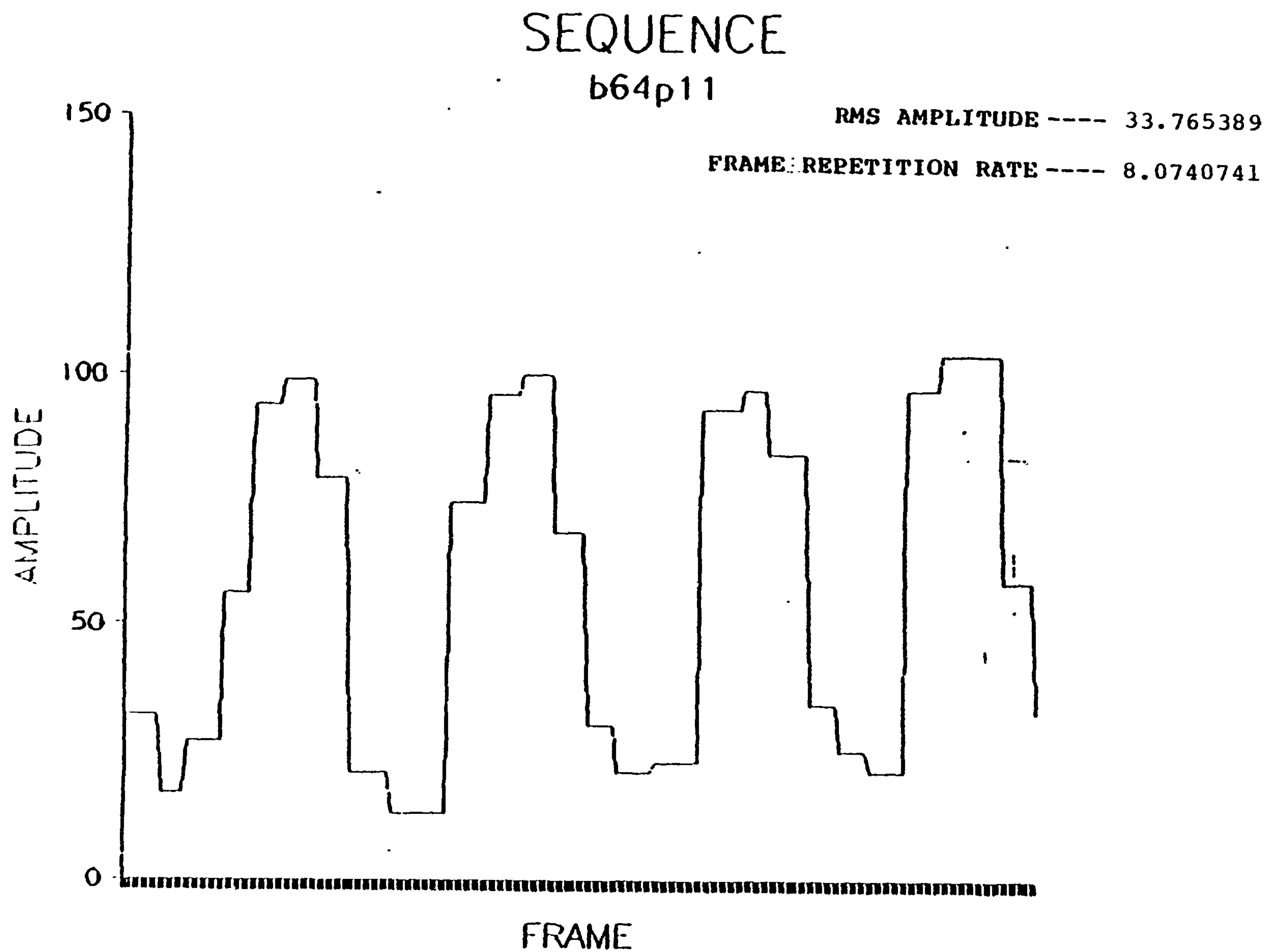


FIGURE 4.5
PRINTOUT OF WAVEFORM, RMS & FRAME REPETITION RATE

Numerical measurement results and discussions are contained in the following sections.

5.0 TEST RESULTS

5.1 Temporal Response

The rotating wheel patterns the details of which are given on Table 4-2 were processed through 3 different codecs and recorded on 3/4" video tape. The codecs are designated H, L, and P. Codec H covers the range of 384 to 1544 Kbps while codecs L and P operate over the range of 64 to 384 Kbps. The operating bit rates were selected from the P x 64 hierarchy and are 64, 128, 256, and 384 Kbps for codecs L and P, and 384, 768, and 1536 Kbps for codec H.

Initial visual inspection showed that due to the wide range of bit rates not all test patterns produced significant and usable results. Patterns with wide spokes and low speeds do not provide sufficient challenge at high bit rates while narrow spokes and high speeds generally far exceed the capability of low bit rate codecs. Therefore, specific groups of patterns were selected for numerical evaluation of each bit rate and codec. A sample of such a selection is shown on Table 5-1 which is simply a marked-up copy of Table 4-2.

Using the test setup of Figure 4.1, an amplitude measurement is made following each test pattern advance. The results are recorded on a data sheet, a filled-in sample of which is shown on Table 5-2. The frame numbers and amplitudes are processed in a computer, resulting in the previously mentioned printout, a sample of which is shown on Figure 4.5. The RMS amplitude number on this figure represents one value of temporal response. Analyzing various rotation speeds of the same test pattern under identical test conditions results in a series of points on a temporal response curve. As indicated on Table 5-1, portions of two different spoke width patterns were analyzed for every bit rate on every codec. Thus, as shown on Figure 5.1, two temporal response curves can be

ROTATION SPEED

TEST PATTERN NO.	SPOKE WIDTH (DEGREES)	FRAMES/ REVOLUTION	DEGREES/ SECOND	TEMPORAL FREQUENCY (CPS)	FRAMES/ SPOKE	% PIXEL CHANGE/ FRAME	% BLOCK CHANGE/ FRAME
1	30	540	20	0.33	45	2.2	18
2	30	360	30	0.50	30	3.3	
3	30	240	45	0.75	20	5.0	
4	30	180	60	1.00	15	6.7	22
5	30	144	75	1.25	12	8.3	
6	30	120	90	1.50	10	10.0	
7	30	90	120	2.00	7.5	13.3	34
8	30	72	150	2.50	6	16.7	
9	30	60	180	3.00	5	20.0	43
10	18	720	15	0.42	36	2.8	31
11	18	540	20	0.55	27	3.7	
12	18	360	30	0.85	18	5.6	
13	18	240	45	1.25	12	8.3	
14	18	180	60	1.67	9	11.1	42
15	18	144	75	2.10	7.2	13.9	
16	18	120	90	2.50	6	16.7	
17	18	90	120	3.33	4.5	22.2	57
18	10	720	15	0.75	20	5.0	50
19	10	540	20	1.00	15	6.7	54
20	10	360	30	1.50	10	10	
21	10	240	45	2.25	6.7	15	
22	10	180	60	3.00	5	20	70
23	10	144	75	3.75	4	25	75

TABLE 5 - 1
ROTATING WHEEL PATTERNS SELECTED
FOR CODEC L AT 128 KBPS

CODEC: L RATE: 128 PATTERN: 3 LINE: 70 POS: 36/MICROSEC

FR	AMP	FR	AMP	FR	AMP	FR	AMP	FR	AMP	FR	AMP
1	96	71	99	142	20						
4	90	74	99	144	54						
8	28	78	97	148	97						
12	14	82	90	152	100						
17	15	86	57	155	99						
20	18	88	17	158	97						
24	27	93	16	161	82						
28	94	97	17	165	32						
32	102	101	18	170	14						
38	100	105	50	174	12						
40	102	109	99	178	15						
43	89	113	99	182	22						
47	48	117	98								
51	15	120	99								
55	15	124	54								
59	16	128	20								
63	21	132	15								
67	69	137	20								

TABLE 5-2

AMPLITUDE MEASUREMENT DATA SHEET

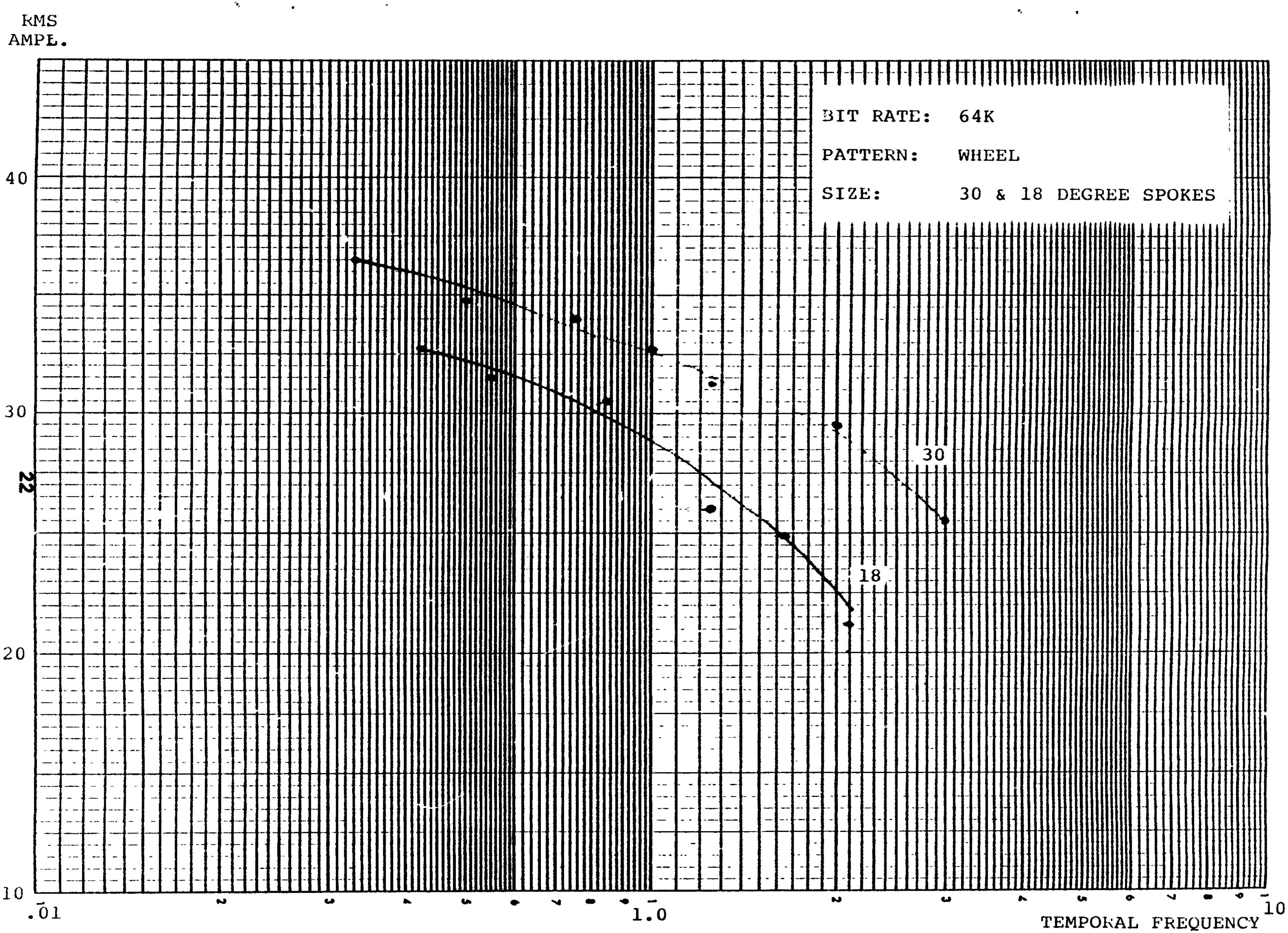

RMS
AMPL.
BIT RATE: 64K
PATTERN: WHEEL
SIZE: 30 & 18 DEGREE SPOKES
40
30
20
10
30
18
.01
1.0
10
TEMPORAL FREQUENCY

FIGURE 5.1

drawn for every codec/bit rate combination. This not only demonstrates the dependence of the results on the test pattern, but helps in verification of the validity of the test method. It does not seem necessary to draw all such possible curves but the range of results is summarized on Tables 5-3, 5-4, and 5-5.

Codec H at 384 Kbps visually shows considerable deterioration at higher temporal frequencies, particularly in the bottom of the picture. Figure 5.2 shows the resulting two branches of the temporal response curve.

The printout of the frame repetition rate gives the average of the spacing of the points of temporal advance of the test pattern. This number is always essentially 2 for codec H but has higher values at the other codecs, increasing at lower bit rates and with the challenge of the test pattern. The frame repetition rate which is adaptive for most low bit rate codecs is significant for two reasons. When it becomes high enough to approach the number of frames per spoke as given on Table 4-2, the measured amplitudes will be distorted, and it is possible that one spoke (either black or white) may be skipped in the analysis. This phenomenon may be called temporal aliasing and gives false results beyond the limit where the two parameters are approximately equal. Another application of frame repetition rate is covered in the subsequent paragraph.

Though families of curves like the ones on Figure 5.1 are descriptive of the motion rendition capabilities of a codec, a reference is necessary to put the plotted values in perspective and establish numerical limits of acceptable performance. Therefore the RMS values for all 23 test patterns before processing through a codec were computed in the same fashion as above. For an ideal static square wave extending between 10 and 100 IRE units this value theoretically should be 45 but limitations in dynamic response and minor random deviations produce lower numbers. The mean values for the 3 spoke widths are as follows:

CODEC MODEL	H					
BIT RATE (KBPS)	384		768		1544	
SPOKE WIDTH (DEGREES)	18	10	18	10	18	10
TEMPORAL FREQ. RANGE (CPS)	0.42 TO 3.3	1.0 TO 2.25	1.67 TO 3.3	0.75 TO 3.0	2.1 TO 3.3	0.75 TO 3.75
TEMPORAL RESPONSE RANGE (IRE/RMS)	37.2 TO 28.9	27.8 TO 23.0	29.4 TO 27.7	24.9 TO 19.9	29.7 TO 28.7	29.5 TO 24.9

TABLE 5-3

TEMPORAL RESPONSE SUMMARY - CODEC H

CODEC MODEL	L							
BIT RATE (KBPS)	64		128		256		384	
SPOKE WIDTH (DEGREES)	30	18	30	18	30	18	18	10
TEMPORAL FREQ. RANGE (CPS)	0.33 TO 2.0	0.42 TO 2.1	0.75 TO 2.5	0.55 TO 3.3	1.5 TO 3.0	1.25 TO 3.3	1.67 TO 3.3	0.75 TO 3.75
TEMPORAL RESPONSE RANGE (IRE/RMS)	36.6 TO 25.4	32.6 TO 20.6	37.1 TO 31.0	35.0 TO 23.8	30.4 TO 26.9	28.0 TO 24.3	36.0 TO 30.8	29.3 TO 26.5

TABLE 5-4

TEMPORAL RESPONSE SUMMARY - CODEC L

CODEC MODEL	P							
BIT RATE (KBPS)	64		128		256		384	
SPOKE WIDTH (DEGREES)	30	18	30	18	18	10	18	10
TEMPORAL FREQ. RANGE (CPS)	0.33 TO 1.5	0.42 TO 1.25	1.0 TO 2.5	0.55 TO 2.5	1.25 TO 3.3	0.75 TO 3.0	1.25 TO 3.3	0.75 TO 3.75
TEMPORAL RESPONSE RANGE (IRE/RMS)	40.3 TO 36.9	34.5 TO 28.9	40.8 TO 23.7	36.0 TO 23.0	38.8 TO 32.2	30.5 TO 18.4	35.8 TO 17.9	30.2 TO 7.0

TABLE 5-5

TEMPORAL RESPONSE SUMMARY - CODEC P

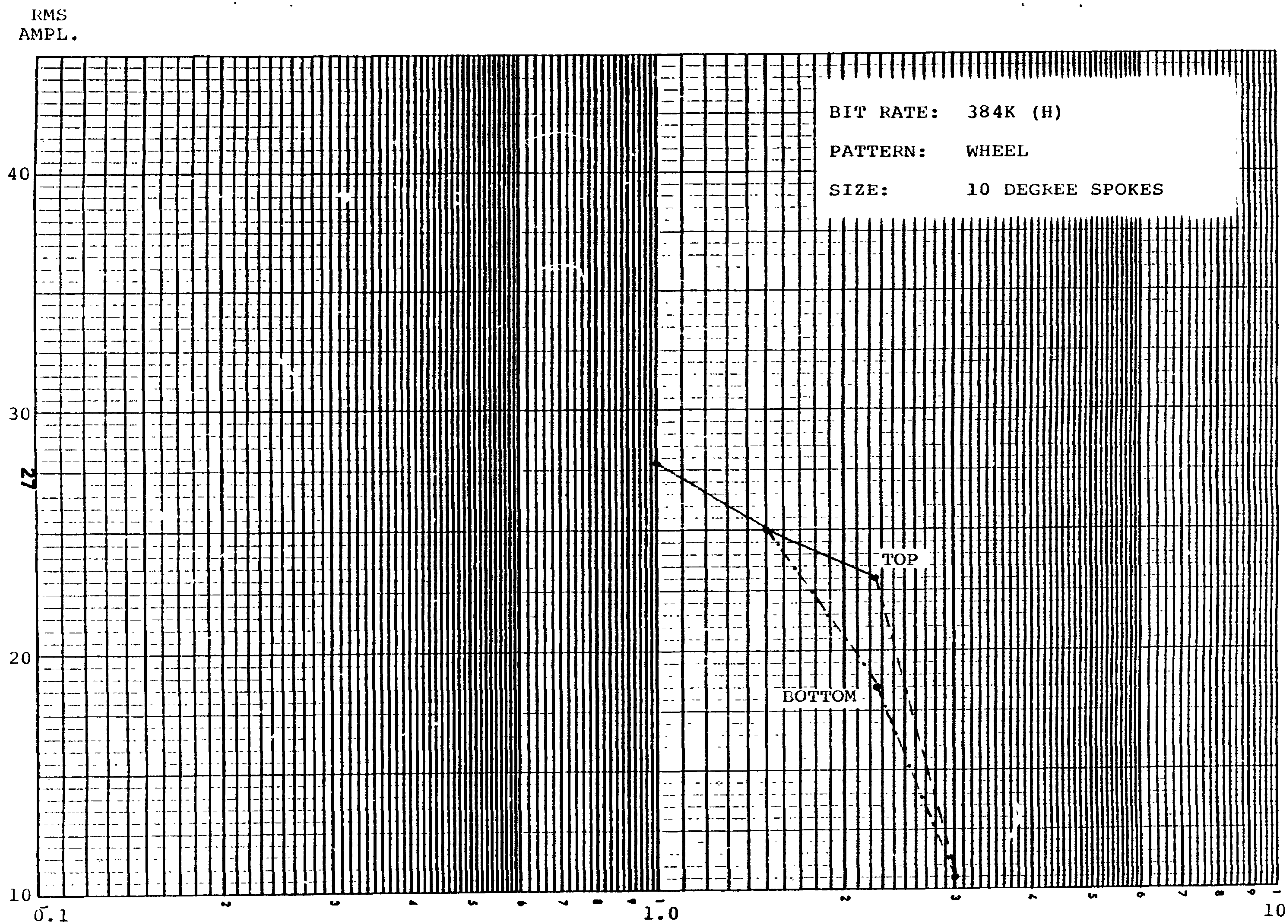

RMS
AMPL.
BIT RATE: 384K (H)
PATTERN: WHEEL
SIZE: 10 DEGREE SPOKES
TOP
BOTTOM
40
30
20
10
0.1
1.0
10

FIGURE 5.2

30 Degree Spokes: 41.3

18 Degree Spokes: 39.9

10 Degree Spokes: 35.4

The difference between these values and the RMS amplitudes at the codec output provides a measure of motion performance degradation produced by the codecs.

5.2 Related Motion Parameters

5.2.1 Jerkiness

All codecs reduce the transmission bit rate requirement by reducing the transmitted frame rate and repeat frames at the receiver. This produces jerkiness in the received picture which becomes more pronounced as the transmitted frame rate decreases and the number of repeated frames increases. Since the frame repetition rate is one of the results of the analysis of the motion test patterns a direct measure of jerkiness is obtained as a by-product of the temporal frequency response measurement. Due to the adaptive frame repetition feature of most low bit rate codecs, jerkiness increases as the bit rate is reduced and the test pattern becomes more challenging. Though each frame repetition must be a whole number, averaging over several frames generally produces a fractional value. The transmitted frame rate is obtained by dividing 30 by the frame repetition rate.

The results of the jerkiness measurements for codecs L and P are given in Tables 5-6 and 5-7. Codec H has a fixed frame repetition rate of 2 (transmitted frame rate of 15 FR/sec) which is part of the equipment specification, therefore the measurement result would be trivial. All adaptive frame repetition rates of codecs L and P are averages rounded to the nearest whole number. The values decrease with increasing bit rate and increase only somewhat with more challenging test patterns. The values for the two codecs are noticeably different due to different design trade-offs used by the manufacturers. Examination of Tables 5-4 and 5-6 versus 5-5 and 5-7 shows that codec L is designed for less jerkiness at some sacrifice of temporal frequency response when compared with codec P.

BIT RATE (KBPS)	64		128		256		384	
SPOKE WIDTH (DEGREES)	30	18	30	18	30	18	18	10
FRAME REPETITION RATE RANGE	7 TO --	8 TO 10	4 TO --	5 TO 6	2 TO --	3 TO --	2 TO --	2 TO 3
TRANSMITTED FRAME RATE RANGE	4.3 TO --	3.75 TO 3	7.5 TO --	6 TO 5	15 TO --	10 TO --	15 TO --	15 TO 10

TABLE 5-6

JERKINESS SUMMARY - CODEC L

BIT RATE (KBPS)	64		128		256		384	
SPOKE WIDTH (DEGREES)	30	18	30	18	18	10	18	10
FRAME REPETITION RATE RANGE	7 TO 12	8 TO 12	3 TO 6	3 TO 6	3 TO 5	6 TO --	3 TO 5	3 TO 6
TRANSMISSTED FRAME RATE RANGE	4.3 TO 2.5	3.75 TO 2.5	10 TO 5	10 TO 5	10 TO 6	5 TO --	10 TO 6	10 TO 5

TABLE 5-7

JERKINESS SUMMARY - CODEC P

5.2.2 Image Update Time

In videoconferencing and videophone systems there is typically an "update" mode of operation when the output image must change to a totally new picture as rapidly as possible. For example, this mode occurs when a scene cut is introduced. In this case, an artifact appears which is particularly visible at low bit rates. The artifact may take the form of blocking, blurring, retention of the previous picture, etc.

Measurements of image update time were performed on codecs H and L using the scene cut patterns A-1, A-13, and A-25 as shown on Table 4-1 and the test setup of Figure 4.1. Switching from an all black screen to the white circle pattern with a switching interval of 4 seconds (120 frames) gave the best results. Update of the image occurs usually in 2 or 3 discrete steps, and in some cases there are distinct differences between top and bottom of the picture. Therefore, measurements were made on lines No. 25, 150, and 255 whenever needed.

The measurement results are summarized in the six simple graphs on Figure 5.3. The update time is defined as the number of frames necessary after switching to achieve 100% output level. This definition gives the widest range of useful data which are fully consistent in their relation to other system parameters. As expected, the update time increases at lower data rates and with increasing challenge on the codec algorithm produced by smaller circles. Each codec has almost perfect performance at its highest data rate.

A comparison of the two tested codecs is possible at the common data rate of 384 Kbps. This was done subjectively during equipment demonstrations when both codecs were operating side-by-side. The unanimous opinion of the observers was that at 384 Kbps codec L (with its algorithm optimized for low data rates) gave superior performance. The same is brought out clearly in the graphs of Figure 5.3 This shows full correlation between the update time measurement and subjective evaluation.

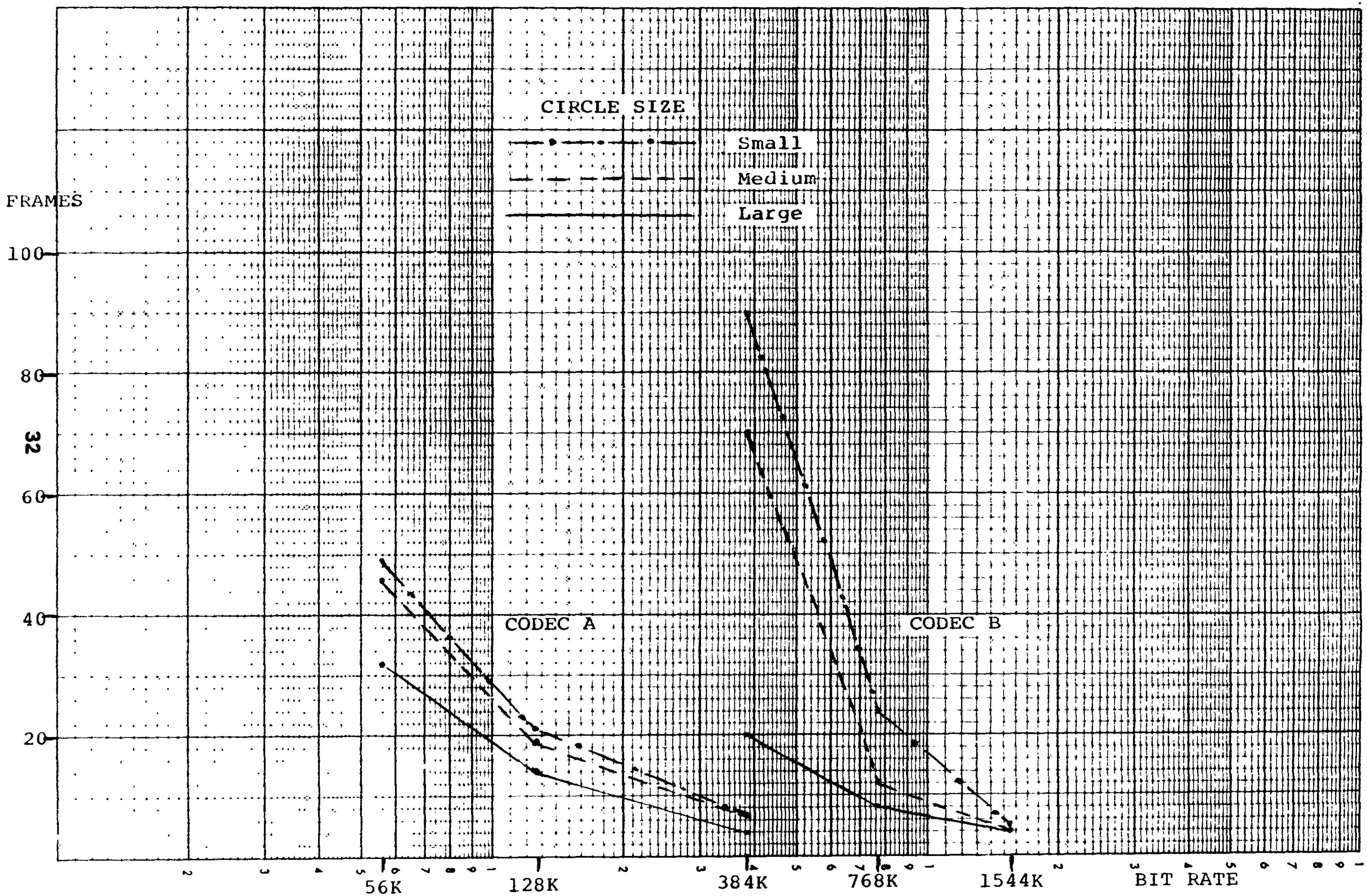

FRAMES
100
80
60
40
20
CIRCLE SIZE
Small
Medium
Large
CODEC A
CODEC B
56K
128K
384K
768K
1544K
BIT RATE

FIGURE 5.3

6.0 DISCUSSION

The results summarized in Section 5.0 show that the requirements postulated in Paragraph 3.2 have been satisfied by the performed measurements of temporal frequency response. All measurements were performed using the taped processed picture only. The test signals are firmly defined and computer generated. Evaluation of the processed signal waveforms is straightforward andrequires only standard video test equipment and a simple computer program to achieve numerical results. Correlation with subjective evaluation will make it possible to establish numerical limits of acceptability for many different applications of digital video technology. Since a large number of motion artifacts produce distortions in video amplitude, temporal frequency response provides a measure of the combined effect of these artifacts.

A review of the consolidated test results shows the following relations between the various operation and test parameters:

- o Temporal response decreases with increasing temporal frequency
- o Temporal response decreases at lower bit rates
- o Temporal response decreases with a "busier" test pattern, meaning narrower spokes or smaller and denser white circles.

These results are logical and exactly according to expectations. Limited subjective observations also have shown good agreement. These facts verify not only the methodology of measuring temporal frequency response but primarily the validity of this parameter as descriptive of the overall performance of a digital video system. One single parameter, temporal frequency response which is descriptive of the overall visual impression on an average viewer is the most useful tool for objectively evaluating the motion performance of a digital video system. This will be confirmed by correlation of subjective and objective test results which will be performed on a later program.

7.0 CONCLUSION AND RECOMMENDATIONS

The effort described in this report has proved that Temporal Frequency Response is a valid practical parameter to describe the effect of most of the motion artifacts of a digital video codec. The proposed measurement methodology yields additional parameters as by-products. It was shown that the previously designed test patterns were adequate to test codecs over the full range of bit rates from 64 to 1536 Kbps. The convenience of measurement and accuracy of the results were improved by choosing a different location of the measurement point. A survey of the latest available test equipment and procurement of the applicable items made it possible to use 3/4" video tape instead of the previously needed 1" tape. This resulted in a considerable simplification and reduced cost of the test procedures.

The test results show excellent consistency with anticipations and logical interdependency of the various parameters. There also is good correlation with limited informal subjective impressions but final verification of the methodology must await correlation with the results of formal subjective tests which are being initiated under a concurrent program.

The measurement results show that the status of objective motion testing is well advanced. Though some refinements of the existing methodology are expected to be possible, the next big progress should result in the elimination of the requirement for a test tape and the partly manual evaluation. An electronic pattern generator with a wide variety of selectable motion test patterns can and should be designed. Similarly, the evaluation of the processed patterns can be automated, eliminating the need for taking and recording visual readings from the VM-700 display. Both these projects will require a considerable design effort.