NASA Conference Publication 3080

High Resolution, High Frame Rate Video Technology

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Vanderbilt University	William Hofmeister

Company	Technical Expert
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Ironics, Inc., Ithaca, New York	Saul Malamud
Megavision, Goleta, California	Ken Boyston
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Miltronics, Columbus, Indiana	John Binkley
Odetics, Inc., Anaheim, California	Ellie Kurrasch George Westrom
Perkin-Elmer, Pomona, California	Curt Solheim
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Storage Concepts, Irvine, California	Glen McKibben

Company	Technical Expert
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Government Agency	Engineer/Scientist
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NASA Headquarters (Bionetics)	James Kreer
NASA Johnson Space Center	Jeffrey Bye
NASA Langley Research Center	David Bowker Philip Hess Friedrich Huck
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High Resolution, High Frame Rate Video Technology

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PREFACE

The recording of optical imagery is the primary mode of data acquisition in many microgravity science experiments, particularly those in the combustion science, fluids, and transport disciplines. While the required spatial and temporal resolution of the imaging varies from experiment to experiment, there is in general a requirement for high speed, detailed optical data. Most current spaceflight experiments (developed or under development) requiring optical data rely on motion picture film photography to record the data. Available space qualified cameras have the ability to meet the high resolution and high speed recording requirements of these experiments, but the need for large amounts of film has caused serious payload design problems, or even constrained the amount of data that could be made available from a flight. In order to resolve this problem, the evolutionary development of a high resolution, high frame rate video system for microgravity science and applications investigators has been initiated at NASA Lewis Research Center. It is planned that this system will be used in the future on the Space Shuttle and Spacelab, and ultimately on Space Station Freedom.

The High Resolution, High Frame Rate Video (HHVT) Workshop was held at Lewis Research Center on May 11-12, 1988 for the dual purpose of (1) allowing potential scientific users to assess the utility of the proposed system for monitoring microgravity science experiments and (2) letting technical experts from industry recommend improvements to the proposed near-term HHVT system.

INTRODUCTION

The High Resolution, High Frame Rate Video (HHVT) Workshop was held at NASA Lewis Research Center on May 11-12, 1988. On the first day of the workshop members of the HHVT project team gave presentations on the conceptual design of the near-term HHVT system, the state of the art in video technology, the results of the Users' Requirements Survey that NASA has conducted previously, image enhancement methods, data compression, and data transmission networks. A text version of each presenter's vugraphs has been included in this Conference Proceedings. The second day of the workshop was reserved for two working group discussion sessions, followed by a joint discussion to review the findings and recommendations made by the two splinter groups. A summary of the comments made by the participants of the Users Working Group and the Technical Experts Working Group is included in this Conference Proceedings followed by a list of their findings and recommendations.

HHVT WORKSHOP ISSUES

In planning the topics to be discussed at the HHVT Workshop, the following list of issues was generated:

(1) How realistic are the requirements of the potential users of the HHVT system as expressed in their responses to the users' survey?

(2) Are the requirements driven by the nature of the science and, hence, unchangeable? Given that time constants impact frame rate, are the time constants of the experiment well understood? Given that spatial dynamics impact resolution, are the spatial dynamics of the experiment well understood?

(3) Which technologically limiting factors become apparent from the user survey? Can these imaging requirements be met by efficient and clever application of a video system with limited capability?

(4) The proposed near-term HHVT system represents the best we can do with near-term technology. Does its performance capability represent an advancement sufficient to justify its development at this time?

(5) Will the proposed near-term HHVT system be useful to the microgravity science experimenters?

(6) Is the proposed near-term HHVT system performance capability truly state of the art?

(7) Are there anticipated technological developments coming soon that would improve the near-term system?

(8) Are there any identifiable problems with the conceptual design of the near-term system?

(9) Do the users and the technical experts think the overall HHVT development project is headed in the right direction?

All of these topics were discussed at the workshop.

N91-14575

RESULTS OF THE USERS' REQUIREMENTS SURVEY

Robert L. Butcher
NASA Lewis Research Center

The objectives of the High Resolution, High Frame Rate Video Technology (HHVT) Users' Requirements Survey were the following:

(1) Document the requirements of potential users of the HHVT system
(2) Establish a database relating key video parameters to HHVT users
(3) Guide the development of a high resolution, high frame rate video system offering high data storage capacity and high data transmission rates
(4) Allow users to compare their requirements to those of other users and to state-of-the-art technology
(5) Allow users to reassess, if necessary, their requirements in light of existing and near-term technology

The Users' Requirements questionnaires were distributed to the following potential microgravity HHVT users:

Data Base ID Numbers		Potential Microgravity HHVT Users
100's	-----	LeRC project scientists of approved flight experiments
200's	-----	LeRC project scientists of ground-based science discipline areas which may lead to future microgravity flight experiments
300's	-----	Non-LeRC project scientists of ground-based science discipline areas which may lead to future microgravity flight experiments
400's	-----	Microgravity Science and Applications Division principal investigators
500's	-----	Microgravity Science and Applications Division discipline working groups
600's	-----	Miscellaneous
700's	-----	Private industry

The key video parameters solicited in the questionnaire for each experiment or ground-based research were

(1) Spatial resolution (in pixels/frame)
(2) Frame rate (in frames/sec)
(3) Gray scale resolution (up to 256 levels)
(4) Monochrome or color images
(5) Number of frames to be stored per experiment run
(6) Number of frames to be stored per flight
(7) Downlinking requirements

The first HHVT Users' Requirements Survey was issued in December 1986. Sixty-eight questionnaires were mailed. Seventeen of the thirty-nine completed questionnaires indicated video imaging requirements.

The same questionnaire was issued to 119 different investigators in May 1987. Eighteen of the twenty-eight completed questionnaires that were received indicated video imaging requirements.

In October 1987 the original questionnaire was mailed to fifteen more investigators. Both of the two completed questionnaires received indicated video imaging requirements. In November 1987 a different questionnaire that was written by engineers working on the HHVT project at Langley Research Center was mailed to all the investigators who had responded to the original questionnaire. This second questionnaire sought detailed information on the experimental images, image enhancement requirements, and real-time monitoring requirements. Fourteen investigators responded to the second questionnaire. Thirteen of these indicated a need for image enhancement.

The results of the HHVT Users' Requirements Survey have been tabulated and appear in Appendix I - HHVT Video Requirements Survey; Appendix II - HHVT Downlink Requirements; and Appendix III - Summary of Image-Processing Requirements appended to this report.

The formula used to calculate the downlink data rate requirement is as follows:

$$\begin{aligned}\text{Data rate (bytes/sec)} = {} & [\text{Spatial resolution (in pixels/frame)}] \\ & \times [\log_2 \text{(gray scale resolution in bits/pixel)}] \\ & \times [1 \text{ byte}/8 \text{ bits}] \times [\text{downlink frames/run}] \\ & \times [1 \text{ downlink time in sec}] \times [Y]\end{aligned}$$

where

$Y = 1$ (for monochrome), 3 (for color)

For example, User No. 102 in the HHVT Users' Requirements database has the following requirements for the Solid Surface Combustion Experiment:

Spatial resolution = 5000 × 2500 pixels = 1.25×10^7
Gray scale = 256
Frames per run to be downlinked = 23 040
Period during which downlinking must occur = 12 hr
Color images

$$
\begin{aligned}
\text{Data rate (bytes/sec)} &= [1.25\times10^7 \text{ pixels/frame}] \\
&\quad \times [8 \text{ bits/pixel}] \times [1 \text{ byte/8 bits}] \\
&\quad \times [23\,040 \text{ frames/run}] \times [1/12 \text{ hr}] \times [1 \text{ hr/3600 sec}] \\
&\quad \times [3] \\
&= 2.00\times10^7 \text{ bytes/sec}
\end{aligned}
$$

Currently, 37 potential microgravity HHVT users have submitted diverse video requirements. The requirements for spatial resolution range from 4100 pixels/frame to 100 000 000 pixels/frame (which is greater than the resolution achievable with 16 mm film). Framing rate requirements vary from four (4) per hour to 1 000 000 frames/sec. The results of the Users' Requirements Survey are as indicated in the attached appendixes (see pp. 6-17). The diversity of these requirements indicates a need for developing a video system with great flexibility. Further consideration has to be given to how the results of this survey correspond to plans being made for video systems to be installed onboard the Space Shuttle and Space Station Freedom.

APPENDIX I

HHVT VIDEO REQUIREMENTS SURVEY

--- HHVT Video Requirements Survey --- R. Ziemke 5/6/88

ID	NAME	EXPERIMENT/ ACTIVITY	COLOR B/W	GRAY SCALE	SP. RES. (PIXELS)	FRAME RATE	FRAMES/ RUN	FRAMES/ FLIGHT	EQ. ISO	SPECT. RESP.	NO. VIEWS
102	S. Olson (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Solid Surface Combustion	C	256	5000 X 2500 (1.25E7)	64	23040	69120	400	V-IR	2
103	S. Olson (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Gas Jet Diffusion Flames	C	256	4000 X 2000 (8.00E6)	400 100	5500	2.64E5	400	V-IR	1
104	H. Ross (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Particle Cloud Combustion	C	256	200 X 187 (3.75E4)	100	6000	48000	TBD	TBD	2
109	T. Jacobson (MS 500-205) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Surface Tension Driven Convection	BW	64	256 X 512 (1.31E5)	60	36000	5.40E5	1000	V	1
110	E. Winsa (MS 500-205) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Isothermal Dendritic Growth	BW	16	64 X 64 (4.10E3)	1/60	360	7200	100	V	2
111	J. Haggard (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Droplet Combustion	BW	TBD	600 X 600 (3.60E5)	100	3000	75000	160	.6328u	1
			C	TBD	200 X 200 (4.00E4)	100	3000	75000	400	V-IR	1
218	S. Olson (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Flame Spreading Over Solids in Forced Flows	C	256	7500 X 5000 (3.75E7)	100	36000	5.76E5	400	V-IR	2
225	R. Balasubramaniam (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Electro-hydrodynamics	BW	16	600 X 380 (2.28E5)	30	1800	1.00E5	TBD	V	2

ID	NAME	EXPERIMENT/ ACTIVITY	COLOR B/W	GRAY SCALE	SP. RES. (PIXELS)	FRAME RATE	FRAMES/ RUN	FRAMES/ FLIGHT	EQ. ISO	SPECT. RESP.	NO. VIEWS
228	J. McQuillen (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Mass Transport	BW	256	2000 X 2000 (4.00E6)	1,000 100 30	1.20E5	4.80E5	TBD	V	2
230	R. Vernon (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Nucleate Pool Boiling	BW	20	1000 X 500 (5.00E5)	1,000 100 10	7200	64800	TBD	TBD	1
234	J. Mcquillen (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Study of Forced Convection Boiling Under Reduced Gravity	BW	20	500 X 250 (1.25E5)	100 10	1800	16200	TBD	TBD	2
302	J. Baird Dept. of Physics Univ. of Alabama Huntsville, AL 35899	Extension of Ostwald Ripening Theory	BW	16	10000 X 10000 (1.00E8)	1 per 15 min	Continuous	400	100	V	1
304	A. Cezairliyan NBS Bldg. 236 Washington, DC 20234	Dynamic Thermo-physical Measure-ments in Space	BW	16	3000 X 1000 (3.00E6)	500 1000 2000	400	4000	300	V	1
305	P. Concus Lawrence Berkeley Lab Univ. of California Berkley, CA 94270	Free Surface Phenomena under Low and Zero Gravity Conditions	BW	64	200 X 200 (4.00E4)	30	2.16E4	6.55E5	10000	V-IR	3
307	R. Dressler Academic Bldg., Rm 715 George Washington Univ. Washington, DC 20052	Suppression of Marangoni Convection in Float Zones	BW	16	256 X 256 (6.55E4)	1 sec Time Exposure	1	100 (100 Time Exposures)	1000	V	1
310	P. Giarrantano NBS Boulder Laboratories Boulder, CO 80302	Transient Heat Transfer in Zero Gravity Environment	BW	256	256 X 256 (6.55E4)	2000	2000	70000	1000	V	1
312	W. Kaukler Univ of Alabama at Huntsville Huntsville, AL 35899	Direct Observation of Critical Point Wetting in Microgravity	BW	128	1024 X 1024 (1.05E6)	100	1600	1600	400	V	2
406	G. Borman Dept of Mech Eng Univ of Wisconsin Madison, WI 53706	Microgravity Combustion	BW	16	1000 X 1000 (1.00E6)	1000	100	2000	400	V	1

ID	NAME	EXPERIMENT/ ACTIVITY	COLOR B/W	GRAY SCALE	SP. RES. (PIXELS)	FRAME RATE	FRAMES/ RUN	FRAMES/ FLIGHT	EQ. ISO	SPECT. RESP.	NO. VIEWS
413	G. Debendetti Dept of Chem Eng Princeton Univ Princeton, NJ 08544	Disorder-order Transitions in Colloidall Suspensions	C	16	512 X 512 (2.62E5)	.0166	Cont.	10080	200	V	1
415	D. Elleman Jet Propulsion Lab Pasadena, CA	Protein Crystal Growth	C	16	256 X 256 (6.55E4)	.033	2880	20160	400	V	1
416	S. Feigelson Ctr for Materials Research Stanford Univ Stanford, CA 94305	Protein Crystal Growth	BW	32	410 X 246 (1.01E5)	.00167 30	48 8.64E5	480 8.64E6	3000	V	2
						1	1.21E6	1.21E7	3000	V	2
420	J. Hallett Desert Research Institute Univ of Nevada Reno, NV 89557	Crystallization of Spheres and Spherical Shells	BW	256	5000 X 5000 (2.50E7)	1000	1.50E4	7.50E4	100	V	1
424	P. Hrma Dept of Metallurgy & Materials Sciences Case Western Reserve Univ Cleveland, Ohio 44106	Foaming Glass Melts under Microgravity	BW	16	525 X 525 (2.76E5)	2	7200	7200	3200	V	1
427	D. Kassoy University of Colorado Boulder Engineering Center Boulder, CO 80309	Transient Effects in Combustion and Shock	C	16	512 X 512 (2.62E5)	1000	1000	1.00E4	25-1000	V	1
427A	D. Kassoy University of Colorado Boulder Engineering Center Boulder, CO 80309	Convective Diffusive Experiments	C	16	512 X 512 (2.62E5)	.01-1.0	1000	1000	25-1000	V	1
436	R. Nerem Mech Engineering Dept Univ of Houston Houston, TX 77004	Pool Boiling and External Flow Experiments	BW	16	200 X 266 (5.32E4)	200 to 6000	1000 to 8000	2.00E3 to 1.60E5	400	V	1
446	B. Singh Research & Develop Center Westinghouse Electric Corp Pittsburgh, PA	Electronic Materials	C	16	483 X 441 (2.13E5)	30	300	8.64E4	100	V	1
457	T. Wang Jet Propulsion Lab Pasadena, CA 91109	Drop Dynamics Module Upgrade	C	256	600 X 600 (3.60E5)	120	3600	3.60E6	TBD	V	1
			BW	256	300 X 300 (9.00E4	1000	5000	5.00E6	TBD	V	1

ID	NAME	EXPERIMENT/ ACTIVITY	COLOR B/W	GRAY SCALE	SP. RES. (PIXELS)	FRAME RATE	FRAMES/ RUN	FRAMES/ FLIGHT	EQ. ISO	SPECT. RESP.	NO. VIEWS
501	C. Bugg Univ of Alabama Birmingham, AL 3529	Protein Crystal Growth	C	128	120 X 120 (1.44E4)	.025	2160/ Day	1.30E4	200	V	1 (Movable)
504	D. Wolf Code SD4 Johnson Space Center Houston, TX 77058	Space Biotechnology	C	256	1024 X 1024 (1.05E6)	10s Time Exp	20	5400	200	.2-.9u	1
			BW	16	483 X 441 (2.13E5)	30 (Compressed Video OK)	5.40E4	4.86E6	200	.2-.9u	1
539	D. Day Materials Research Center Univ of Missouri, Rolla Rolla, MO 65401	Materials Processing in Space	C	256	300 X 500 (1.50E5)	2 10 30	9600	5.76E5	100	.45-1.0u	2
540	R. Doremus Materials Engineering Dept Rensselaer Polytech Tnst Troy, NY 12181	Melting & Crystallization of Fluoride Glasses	BW	16	100 X 100 (1.00E4)	.166	1200	1.20E4	400	V	1
558	R. Bayuzick Dept of Mech & Mat Engr Vanderbilt Univ Nashville, TN 37235	Containerless Processing	BW	256	10000 X 10000 (1.00E8)	1.00E6	2000	1.00E4	-	V-IR	1
559	G. Taylor Johnson Space Center Univ City Science Ctr Philadelphia, PA	Space Station Cytometer	C	32	128 X 128 (1.64E4)	100	5000	1.50E5	1000	.35-.80	1
601	D. Glover Mail Stop 500-207 Lewis Research Center Cleveland, Ohio 44135	COLDSAT Project	BW	64	200 X 200 (4.00E4)	4 1	3990	3.99E5	1000	V	4 per run (up to 6 available)
701	James Tegart Martin Marietta Corp. P.O. Box 179 Mail $8072 Denver, CO 80201	Storable Fluid Management Demonstration	C	TBD	483 X 441 (2.13E5)	30	5.40E4	5.40E5	TBD	V	2
702	James M. Caruthers School of Chem. Engr. Purdue University W. Lafayette, Ind. 47907	Elongational Viscosity of Polymer Solutions and Melts	BW	16	512 X 512 (2.62E5)	1000	1000	5.00E5	TBD	TBD	2

APPENDIX II

HHVT DOWNLINK REQUIREMENTS

--- HHVT Video Requirements Survey --- R. Ziemke 5/6/88 --- HHVT Video Requirements Survey --- R. Ziemke 5/6/88

ID	NAME	EXPERIMENT/ ACTIVITY	COLOR B/W	GRAY SCALE	SP. RES. (PIXELS)	NO. VIEWS	-----DOWNLINK REQUIREMENT----- FRAMES/ RUN	DOWNLINK TIME	REQUIRED DATA RATE
102	S. Olson (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Solid Surface Combustion	C	256	5000 X 2500 (1.25E7)	2	23040	12 hr	2.00E7 Byte/sec
103	S. Olson (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Gas Jet Diffusion Flames	C	256	4000 X 2000 (8.00E6)	1	5500	.5 hr	7.33E7 Byte/sec
104	H. Ross (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Particle Cloud Combustion	C	256	200 X 187 (3.75E4)	2	-------- NO REQUIREMENT ---------		
109	T. Jacobson (MS 500-205) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Surface Tension Driven Convection	BW	64	256 X 512 (1.31E5)	1	-------- NO REQUIREMENT ---------		
110	E. Winsa (MS 500-205) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Isothermal Dendritic Growth	BW	16	64 X 64 (4.10E3)	2	1 Frame/min. Continuously		6.83E1 Byte/sec
111	J. Haggard (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Droplet Combustion	BW	TBD	600 X 600 (3.60E5)	1	------------- TBD ---------------		
			C	TBD	200 X 200 (4.00E4)	1	------------- TBD ---------------		
218	S. Olson (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Flame Spreading Over Solids in Forced Flows	C	256	7500 X 5000 (3.75E7)	2	36000	12 hr	9.37E7 Byte/sec
225	R. Balasubramaniam (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Electro-hydrodynamics	BW	16	600 X 380 (2.28E5)	2	1800	15 min	2.28E5 Byte/sec

ID	NAME	EXPERIMENT/ ACTIVITY	COLOR B/W	GRAY SCALE	SP. RES. (PIXELS)	NO. VIEWS	-----DOWNLINK REQUIREMENT----- FRAMES/ RUN	DOWNLINK TIME	REQUIRED DATA RATE
228	J. McQuillen (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Mass Transport	BW	256	2000 X 2000 (4.00E6)	2	100	2 Min	3.33E6 Byte/sec
230	R. Vernon (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Nucleate Pool Boiling	BW	20	1000 X 500 (5.00E5)	1	--------	NO REQUIREMENT	---------
234	J. Mcquillen (MS 500-217) NASA-Lewis Research Center 21000 Brookpark Rd. Cleveland, Ohio 44135	Study of Forced Convection Boiling Under Reduced Gravity	BW	20	500 X 250 (1.25E5)	2	--------	NO REQUIREMENT	---------
302	J. Baird Dept. of Physics Univ. of Alabama Huntsville, AL 35899	Extension of Ostwald Ripening Theory	BW	16	10000 X 10000 (1.00E8)	1	4 Frame/hr. Continuously		5.55E4 Byte/sec
304	A. Cezairliyan NBS Bldg. 236 Washington, DC 20234	Dynamic Thermo-physical Measure-ments in Space	BW	16	3000 X 1000 (3.00E6)	1	100	10 min	2.50E5 Byte/sec
305	P. Concus Lawrence Berkeley Lab Univ. of California Berkley, CA 94270	Free Surface Phenomena under Low and Zero Gravity Conditions	BW	64	200 X 200 (4.00E4)	3	300	.5 hr	5.00E3 Byte/sec
307	R. Dressler Academic Bldg., Rm 715 George Washington Univ. Washington, DC 20052	Suppression of Marangoni Convection in Float Zones	BW	16	256 X 256 (6.55E4)	1	---------	NO REQUIREMENT	--------
310	P. Giarrantano NBS Boulder Laboratories Boulder, CO 80302	Transient Heat Transfer in Zero Gravity Environment	BW	256	256 X 256 (6.55E4)	1	---------	NO REQUIREMENT	--------
312	W. Kaukler Univ of Alabama at Huntsville Huntsville, AL 35899	Direct Observation of Critical Point Wetting in Microgravity	BW	128	1024 X 1024 (1.05E6)	2	---------	NO REQUIREMENT	--------
406	G. Borman Dept of Mech Eng Univ of Wisconsin Madison, WI 53706	Microgravity Combustion	BW	16	1000 X 1000 (1.00E6)	1	---------	NO REQUIREMENT	--------

ID	NAME	EXPERIMENT/ ACTIVITY	COLOR B/W	GRAY SCALE	SP. RES. (PIXELS)	NO. VIEWS	-----DOWNLINK REQUIREMENT----- FRAMES/ RUN	DOWNLINK TIME	REQUIRED DATA RATE
413	G. Debendetti Dept of Chem Eng Princeton Univ Princeton, NJ 08544	Disorder-order Transitions in Colloidall Suspensions	C	16	512 X 512 (2.62E5)	1	--------- NO REQUIREMENT --------		
415	D. Elleman Jet Propulsion Lab Pasadena, CA	Protein Crystal Growth	C	16	256 X 256 (6.55E4)	1	2880	20 min	2.36E5 Byte/sec
416	S. Feigelson Ctr for Materials Research Stanford Univ Stanford, CA 94305	Protein Crystal Growth	BW	32	410 X 246 (1.01E5)	4	2.07E6	2 hr	1.82E7 Byte/sec
420	J. Hallett Desert Research Institute Univ of Nevada Reno, NV 89557	Crystallization of Spheres and Spherical Shells	BW	256	5000 X 5000 (2.50E7)	1	1000	5 min	8.33E7 Byte/sec
424	P. Hrma Dept of Metallurgy & Materials Sciences Case Western Reserve Univ Cleveland, Ohio 44106	Foaming Glass Melts under Microgravity	BW	16	525 X 525 (2.76E5)	1	-------- NO REQUIREMENT ---------		
427	D. Kassoy University of Colorado Boulder Engineering Center Boulder, CO 80309	Transient Effects in Combustion and Shock	C	16	512 X 512 (2.62E5)	1	1000	30 min	2.18E5 Byte/sec
427A	D. Kassoy University of Colorado Boulder Engineering Center Boulder, CO 80309	Convective Diffusive Experiments	C	16	512 X 512 (2.62E5)	1	50	2 min	1.64E5 Byte/sec
436	R. Nerem Mech Engineering Dept Univ of Houston Houston, TX 77004	Pool Boiling and External Flow Experiments	BW	16	200 X 266 (5.32E4)	1	500	2 sec	6.65E6 Byte/sec
446	B. Singh Research & Develop Center Westinghouse Electric Corp Pittsburgh, PA	Electronic Materials	C	16	483 X 441 (2.13E5)	1	300	2 hr	1.33E4 Byte/sec
457	T. Wang Jet Propulsion Lab Pasadena, CA 91109	Drop Dynamics Module Upgrade	C	256	600 X 600 (3.60E5)	1	3600	10 min	6.48E6 Byte/sec
			BW	256	300 X 300 (9.00E4	1	5000	10 min	7.50E5 Byte/sec

ID	NAME	EXPERIMENT/ ACTIVITY	COLOR B/W	GRAY SCALE	SP. RES. (PIXELS)	NO. VIEWS	-----DOWNLINK REQUIREMENT----- FRAMES/ RUN	DOWNLINK TIME	REQUIRED DATA RATE
501	C. Bugg Univ of Alabama Birmingham, AL 3529	Protein Crystal Growth	C	128	120 X 120 (1.44E4)	1	20	12 hr	1.75E1 Byte/sec
504	D. Wolf Code SD4 Johnson Space Center Houston, TX 77058	Space Biotechnology	C	256	1024 X 1024 (1.05E6)	1	10	2hr	4.37E3 Bytes/sec
			BW	16	483 X 441 (2.13E5)	1	(Compressed RS170, 0.5hr per run, Real Time)		--- TBD ---
539	D. Day Materials Research Center Univ of Missouri, Rolla Rolla, MO 65401	Materials Processing in Space	C	256	300 X 500 (1.50E5)	2	(2 f/sec, 10 min per run, Real Time)		9.00E5 Bytes/sec
540	R. Doremus Materials Engineering Dept Rensselaer Polytech Tnst Troy, NY 12181	Melting & Crystallization of Fluoride Glasses	BW	16	100 X 100 (1.00E4)	1	1200	2 hr	8.33E2 Byte/sec
558	R. Bayuzick Dept of Mech & Mat Engr Vanderbilt Univ Nashville, TN 37235	Containerless Processing	BW	256	10000 X 10000 (1.00E8)	1	200	30 min	1.11E7 Byte/sec
559	G. Taylor Johnson Space Center Univ City Science Ctr Philadelphia, PA	Space Station Cytometer	C	32	128 X 128 (1.64E4)	1	-------------- TBD --------------		
601	D. Glover Mail Stop 500-207 Lewis Research Center Cleveland, Ohio 44135	COLDSAT Project	BW	64	200 X 200 (4.00E4)	6	3000	24 hr	1.04E3 Byte/sec
701	James Tegart Martin Marietta Corp. P.O. Box 179 Mail $8072 Denver, CO 80201	Storable Fluid Management Demonstration	C	TBD	483 X 441 (2.13E5)	2	-------- NO REQUIREMENT ---------		
702	James M. Caruthers School of Chem. Engr. Purdue University W. Lafayette, Ind. 47907	Elongational Viscosity of Polymer Solutions and Melts	BW	16	512 X 512 (2.62E5)	2	-------------- TBD --------------		

APPENDIX III

SUMMARY OF IMAGE-PROCESSING REQUIREMENTS

(SURVEY RESPONSE TO LANGLEY RESEARCH CENTER REQUEST TO OBTAIN DETAILED IMAGE INFORMATION, IMAGE ENHANCEMENT REQUIREMENTS, AND REAL-TIME MONITORING REQUIREMENTS)

SUMMARY OF IMAGE-PROCESSING REQUIREMENTS

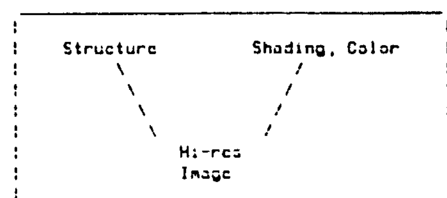
NO.	P.I.	EXPERIMENT	FEATURE	SIZE	ACCUR.	FPS	REAL-TIME NEED	R-T, LO-RES STRUCT.	IMAGE ENHANCING
1	G. Borman	Droplets	Size & Shape	100um-100mm	<5% dia.	1000	Not realistic	Yes	Structure
2	S. Olson	Flames	Edge of flame color	approx. 0.2cm	0.05mm	12-100	No	n/a	Structure & color
3	A. Dukler	Gas-liquid	Gas-liq. interface	<10in wide	0.5mm	1000	No	Yes, if R-T needed	Structure
4	R. Doremus	Crystals	Crystal form.	>100um	-	<1	Yes/essential	Not desir./better than nothing	Very helpful/to be examined
5	D. Glover	Liquid-vapor	Interface motion	-	-	-	No/but some insight useful	Same	3-D Structure
6	D. Saville	Droplets	Shape & position	1mm	-	-	Not anticipated	Yes	Structure
7	P. Giarratano	Liquid Mixtures	Spatial boundaries	Mach Zehnder interfer.	-	30	Yes	Yes	Structure
8	P. Hrma	Foaming	Cells & boundaries	2-4mm	-	-	No	No	Structure & shading
9	K. DeWitt	Bubbles/gases	Bubbles	500um	1um	1-1000	Yes	Not satisfactory	Structure & center location
10	A. Cezairliyan	Thermophysical melting	Spatial boundaries	-	<0.5%	1000	No	Yes	Structure
11	D. Day	Glass melt	Spatial boundaries	-	-	30	Yes	Yes	Structure
12	W. Kaukler	Liquid-vapor	Interface profile	-	Hi-res	>30	Yes/or sub. evaluation	No	Structure
13	C. Bugg	Crystals	Spatial boundaries	0.1-1.0mm	Hi-res	-	Yes/anticipated for the future	Yes	Structure & shading
14	S. Feigelson	Crystals	Spatial boundaries	-	0.03mm	30-120	Yes/brief inter.	No	Structure

Definitions for image coding and processing.

Structure: Edges, creases, scratches and marks that can be delineated as sharp boundaries. We can draw these boundaries as <u>primal sketches</u>.

Shading: We can delineate shading by intensity terracing.

Color: We can delineate color(or temperature) by intensity terracing.



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N91-14576

DATA TRANSMISSION NETWORKS

Robert Alexovich
Analex Corporation
NASA Lewis Research Center

The High Resolution, High Frame Rate Video Technology (HHVT) project engineers wrote a task order to Analex Corporation to investigate data compression techniques that could be applied to the HHVT system, and both existing and planned downlink/uplink capabilities of the Space Shuttle and Space Station Freedom. Specifically, Analex Corporation was directed to do the following:

(1) Investigate signal channel availability and determine both the maximum possible data rate and the average data rate
(2) Identify time blocks for HHVT video transmission assuming time sharing and interruptions in the communications links
(3) Determine the bit error rates to be expected
(4) Define the transmit and receive interfaces

The formula used to determine the bit rate is as follows:

$$\text{Bit rate} = (HR)(VR)(IR)(FR)(C)(V)$$

where

HR horizontal resolution in pixels
VR vertical resolution in pixels
IR intensity resolution in bits
FR frame rate in frames/sec
C 3 (for color), 1 (for monochrome)
V number of views

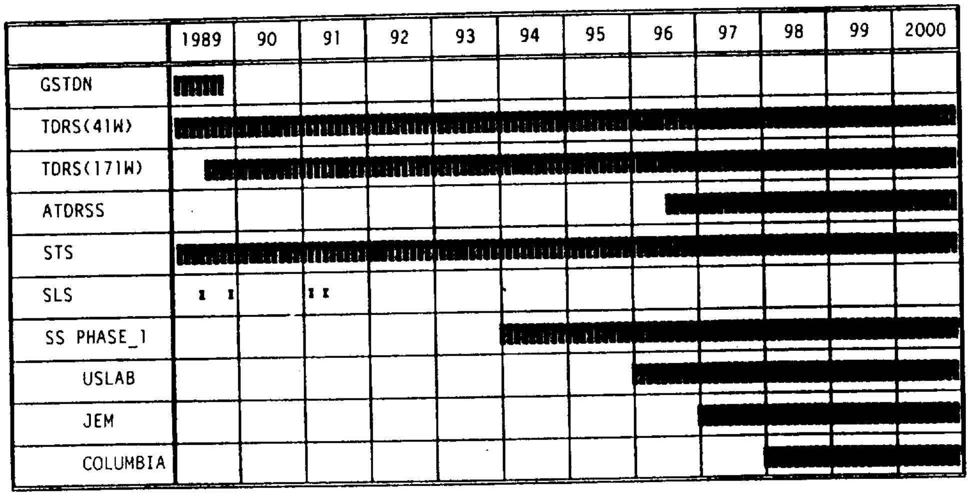
For example, with HR = VR = 512 pixels, IR = 8 bits (which corresponds to 256 level resolution), FR = 30 frames/sec, C = 3 for color, and V = 1,

$$\text{Bit rate} = 512 \times 512 \times 8 \times 30 \times 3 \times 1 = 190 \text{ Mbits/sec}$$

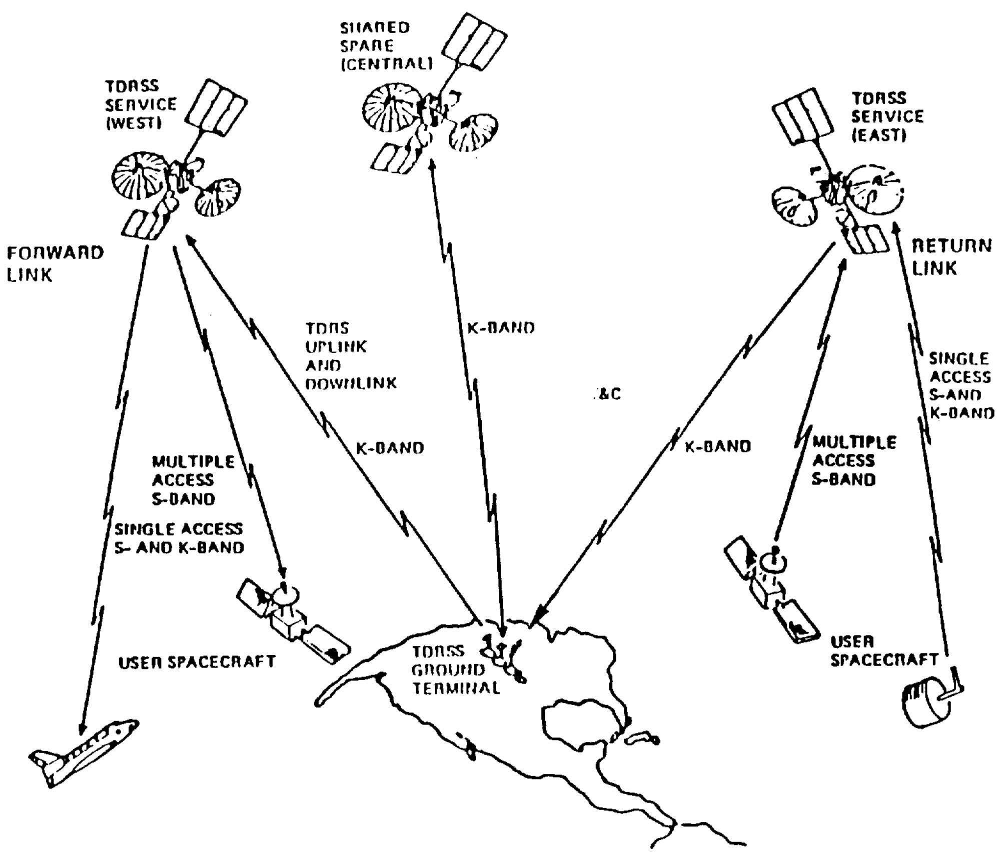
There are several constraints on the amount of data that can be downlinked at any given time. These constraints include the maximum possible data downlinking rate, geometric coverage, antenna blockage, data acquisition, and the fact that the data transmission network is a multiuser shared resource.

A summary chart of the data transmission capabilities for TRSS, the Space Shuttle, Space Station Freedom, Spacelab, and USLab is attached.

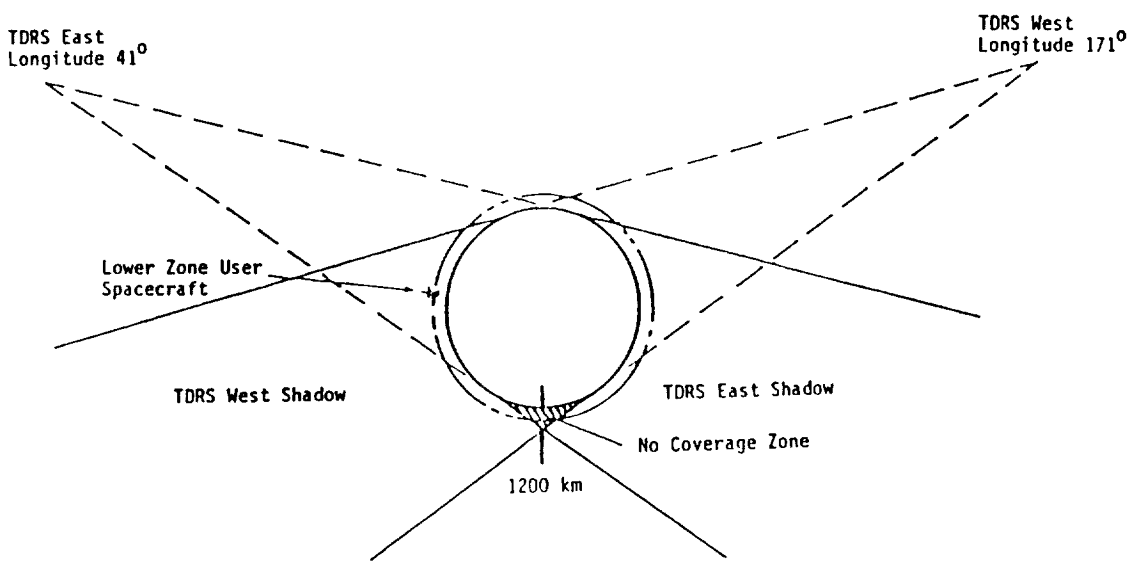
SCHEDULE OF RELATED SYSTEMS



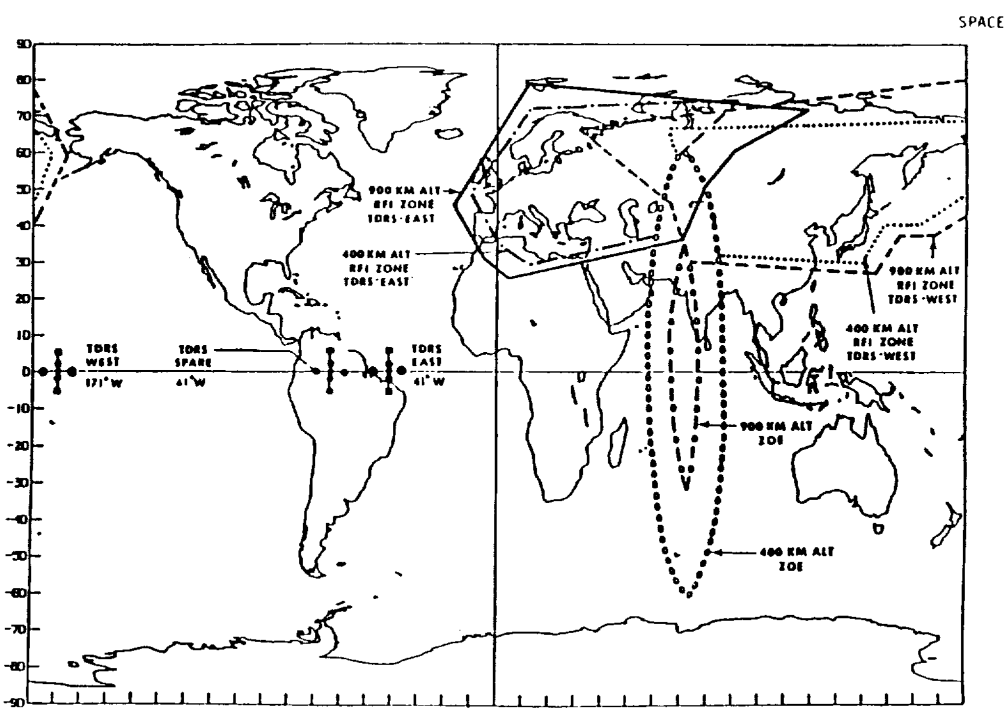
TDRSS SPACE SEGMENT



TDRSS COVERAGE GEOMETRY



TDRSS COVERAGE ZONE



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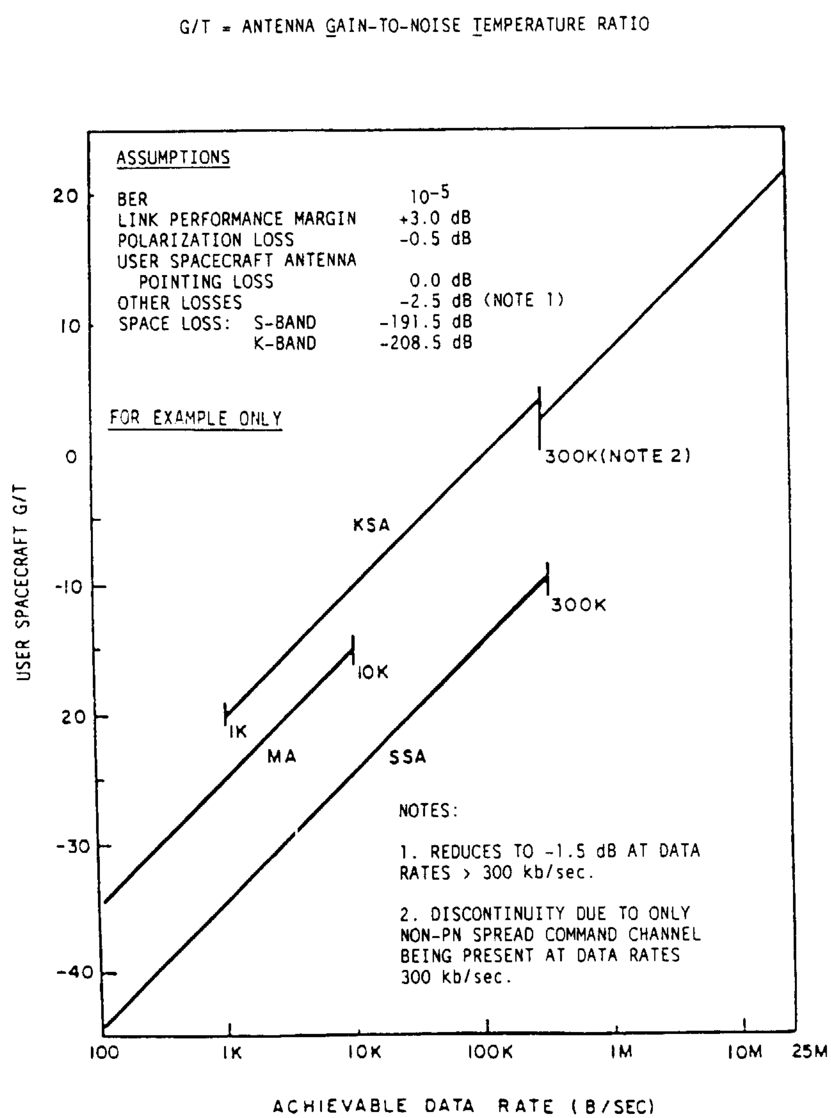
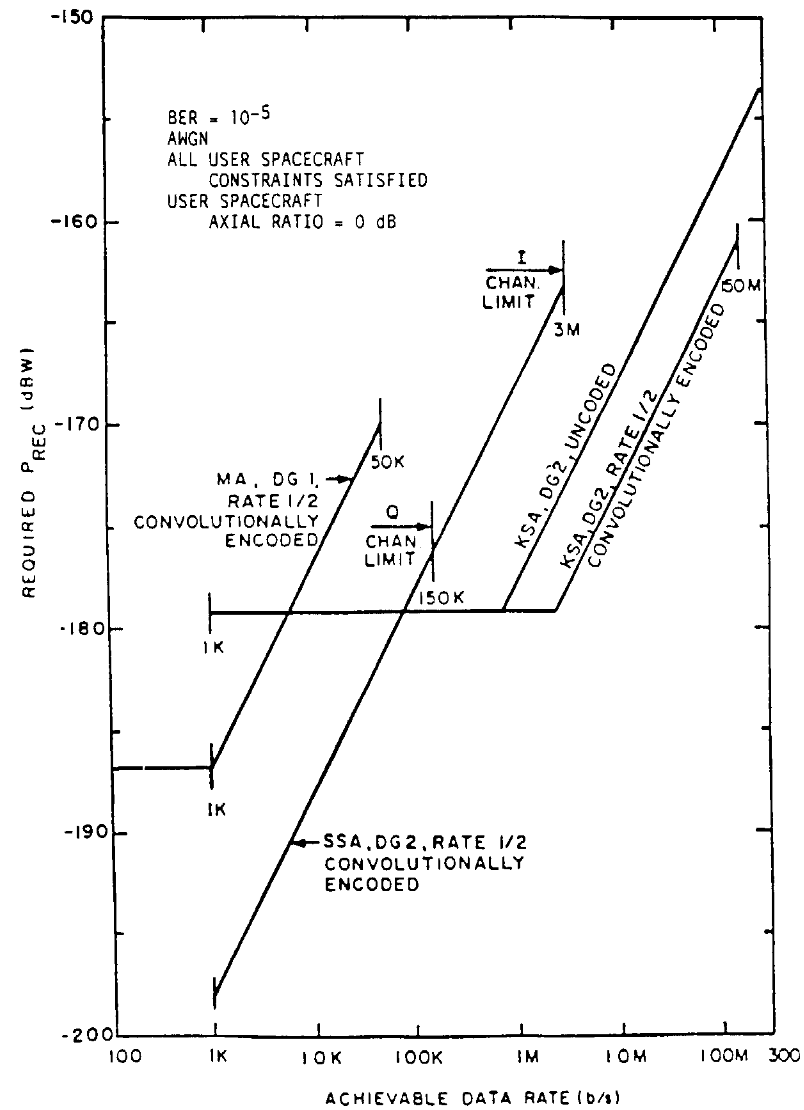
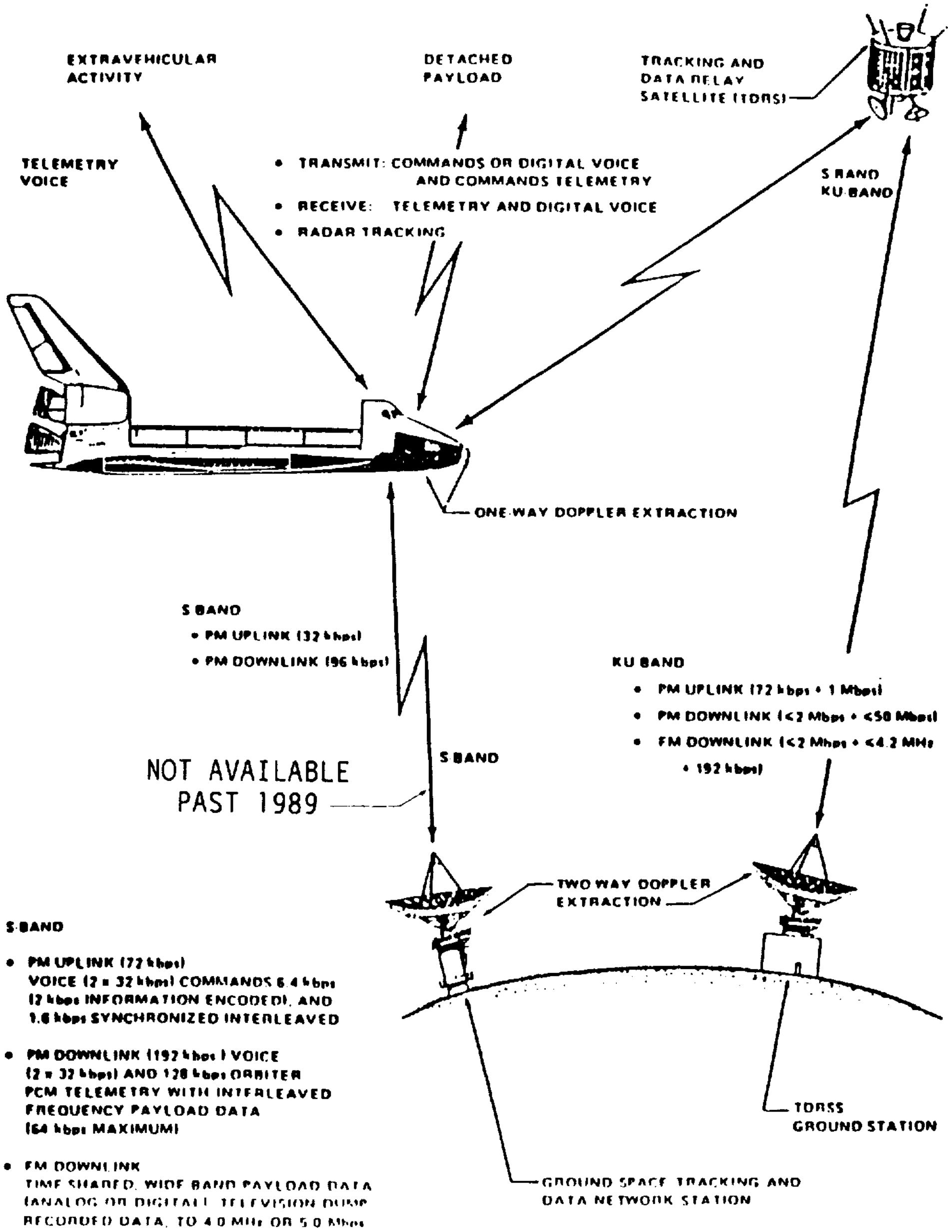

G/T = ANTENNA GAIN-TO-NOISE TEMPERATURE RATIO
ASSUMPTIONS
BER 10-5
LINK PERFORMANCE MARGIN +3.0 dB
POLARIZATION LOSS -0.5 dB
USER SPACECRAFT ANTENNA POINTING LOSS 0.0 dB
OTHER LOSSES -2.5 dB (NOTE 1)
SPACE LOSS: S-BAND -191.5 dB
K-BAND -208.5 dB
FOR EXAMPLE ONLY
KSA
MA
SSA
1K
10K
300K(NOTE 2)
300K
NOTES:
1. REDUCES TO -1.5 dB AT DATA RATES > 300 kb/sec.
2. DISCONTINUITY DUE TO ONLY NON-PN SPREAD COMMAND CHANNEL BEING PRESENT AT DATA RATES 300 kb/sec.
USER SPACECRAFT G/T
20
10
0
-10
20
-30
-40
100
1K
10K
100K
1M
10M
25M
ACHIEVABLE DATA RATE (B/SEC)

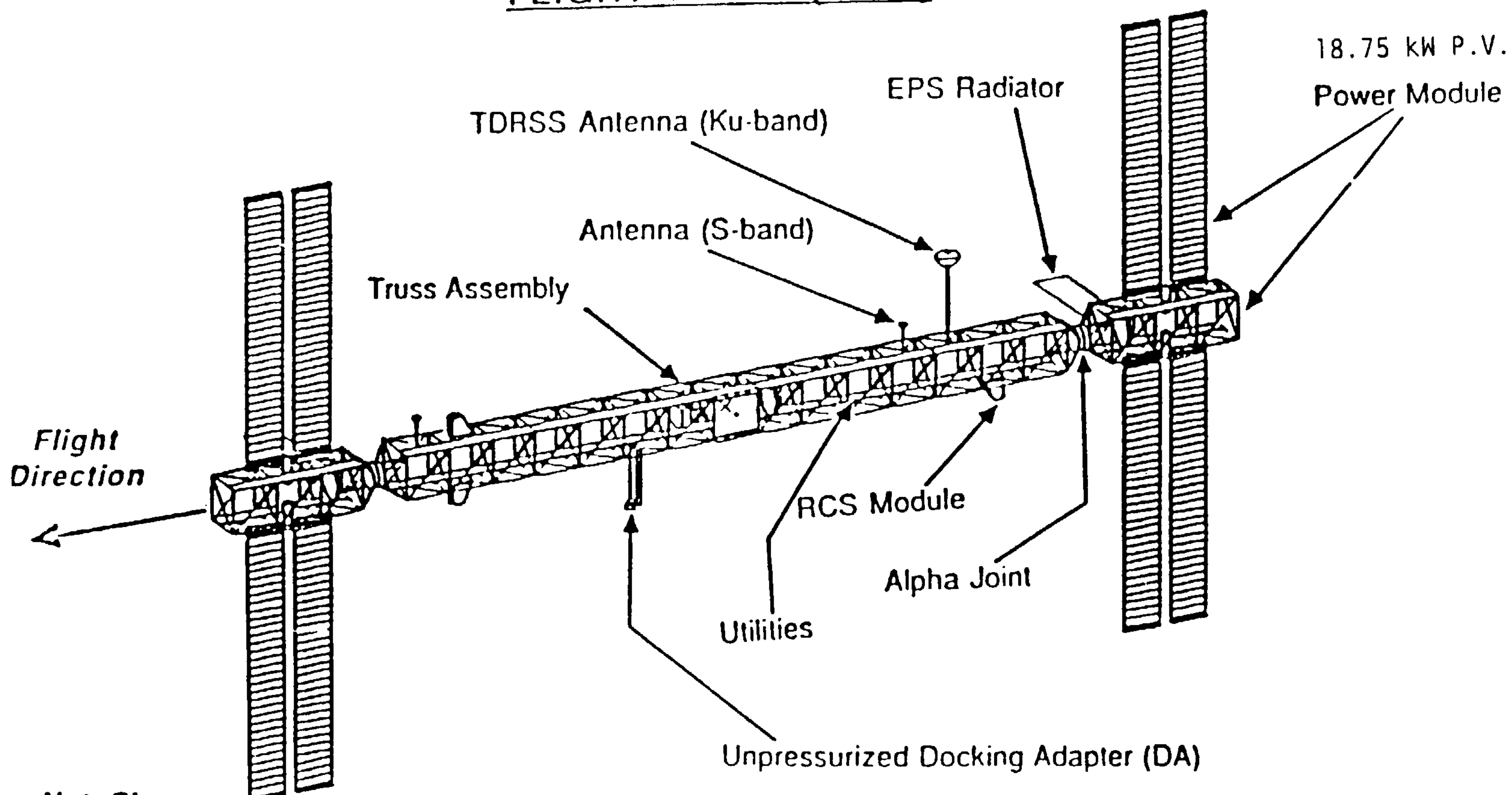

BER = 10-5
AWGN
ALL USER SPACECRAFT CONSTRAINTS SATISFIED
USER SPACECRAFT AXIAL RATIO = 0 dB
I CHAN. LIMIT
Q CHAN LIMIT
MA, DG 1, RATE 1/2 CONVOLUTIONALLY ENCODED
KSA, DG2, UNCODED
KSA, DG2, RATE 1/2 CONVOLUTIONALLY ENCODED
SSA, DG2, RATE 1/2 CONVOLUTIONALLY ENCODED
1K
50K
150K
3M
50M
REQUIRED P REC (dBW)
-150
-160
-170
-180
-190
-200
100
1K
10K
100K
1M
10M
100M
300M
ACHIEVABLE DATA RATE (b/s)

SHUTTLE ORBITAL COMMUNICATIONS LINKS



SPACE STATION POWER MODULE AND TRUSS

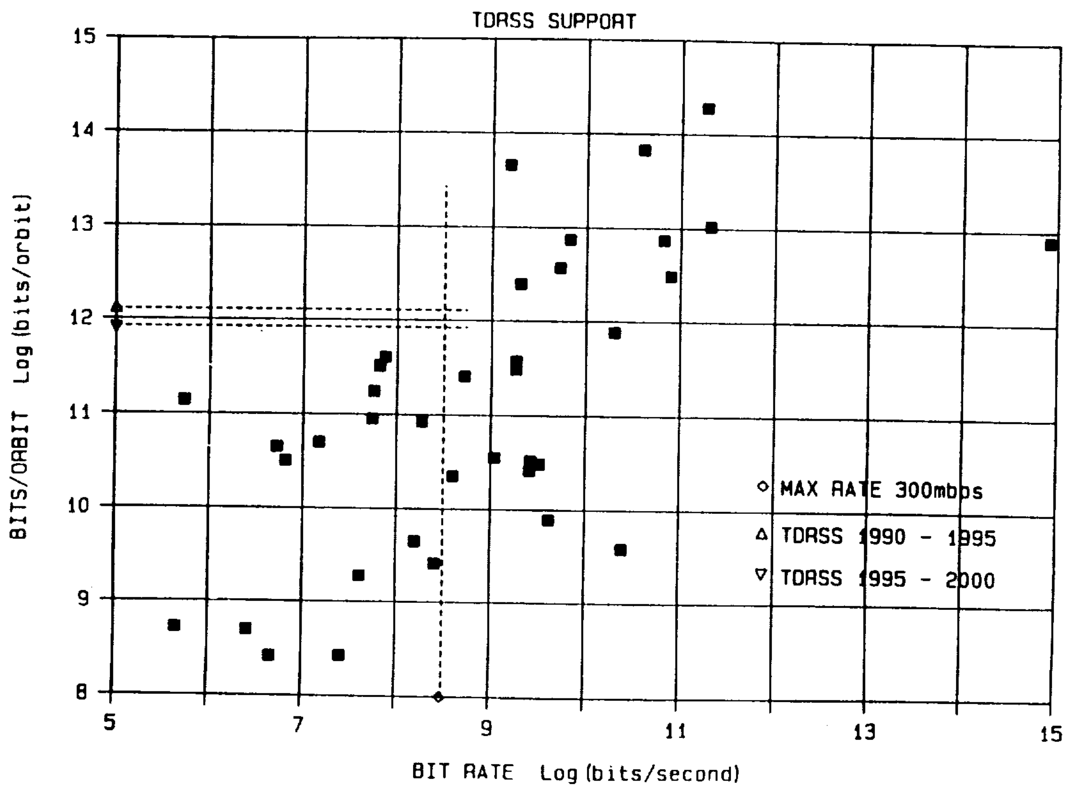
FLIGHT No. 2 (MB-2)



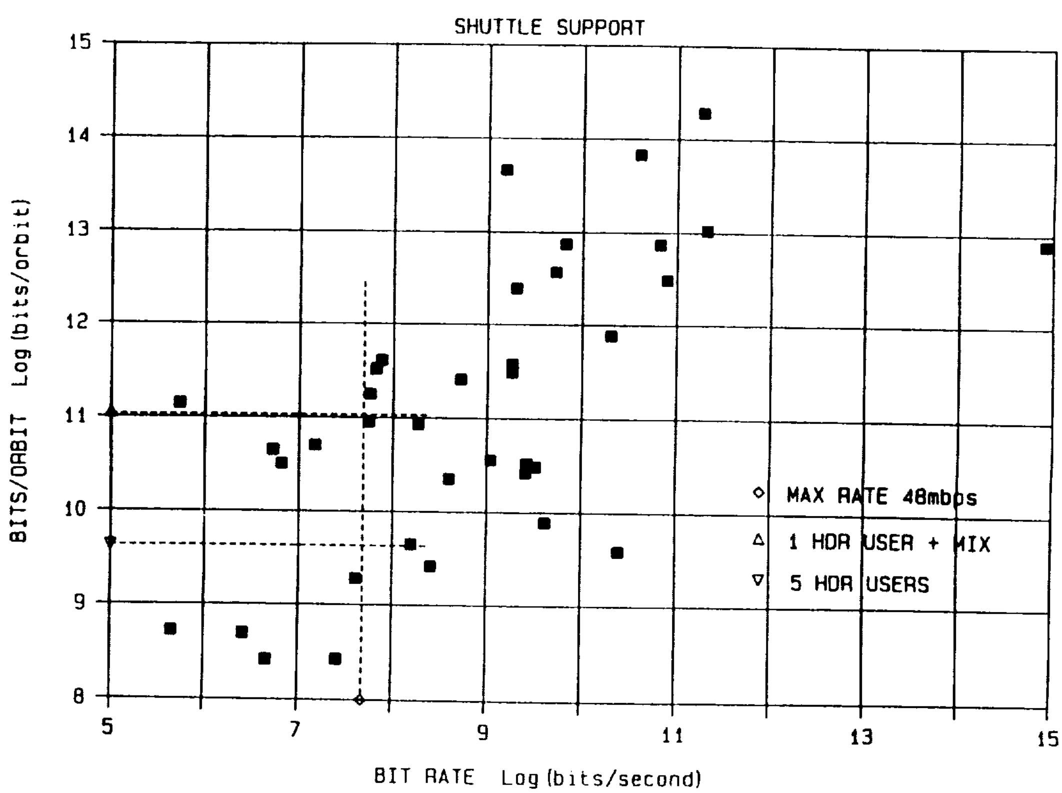
Not Shown
- CMG's
- Tank Farm
- EPS Equipment

Flight Mode
- Arrow
- P.V. Arrays Feathered

USER REQUIREMENTS

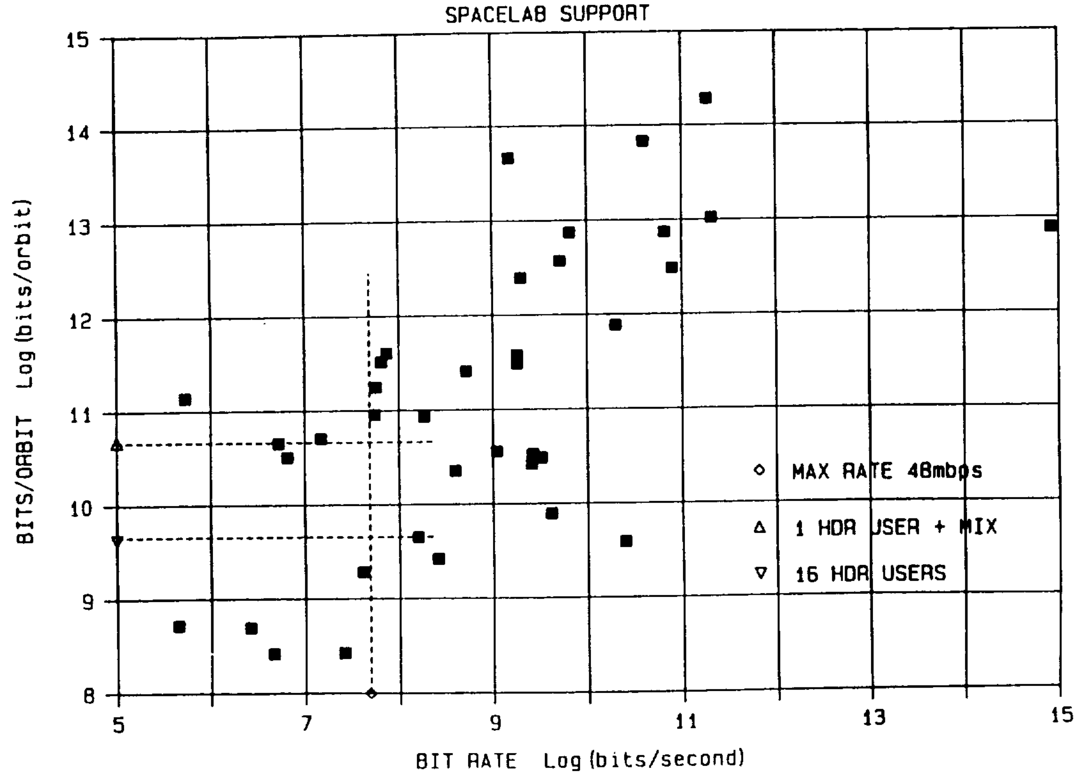


USER REQUIREMENTS



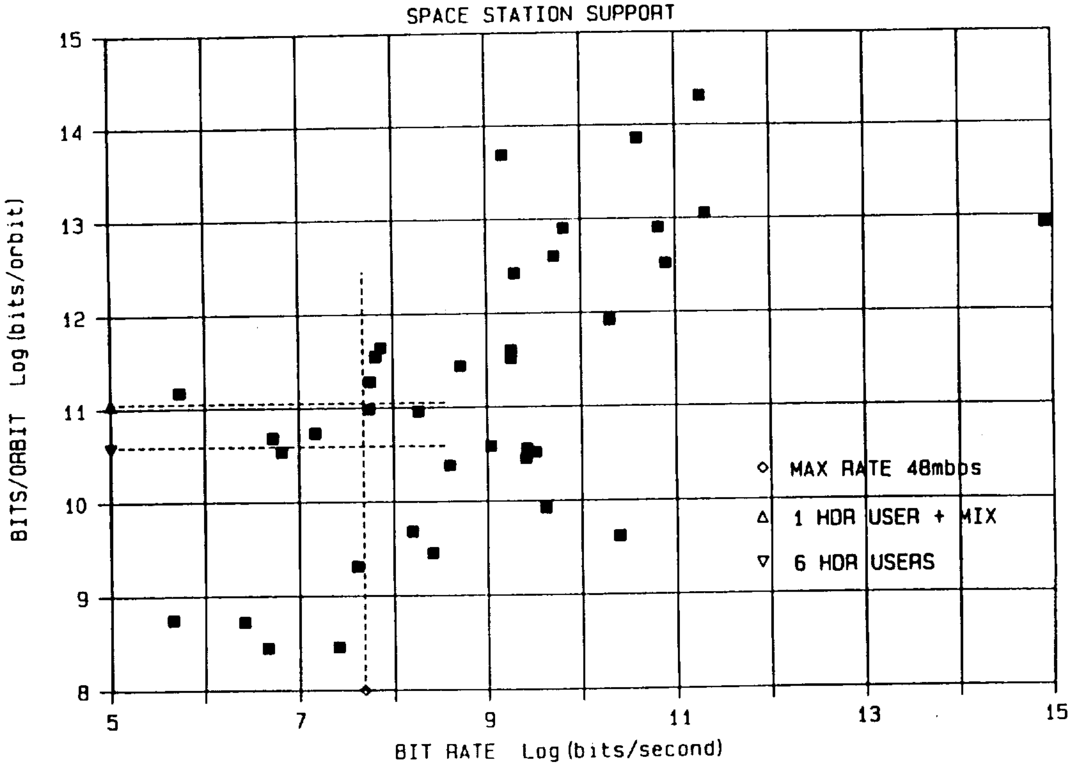
USER REQUIREMENTS

SPACELAB SUPPORT

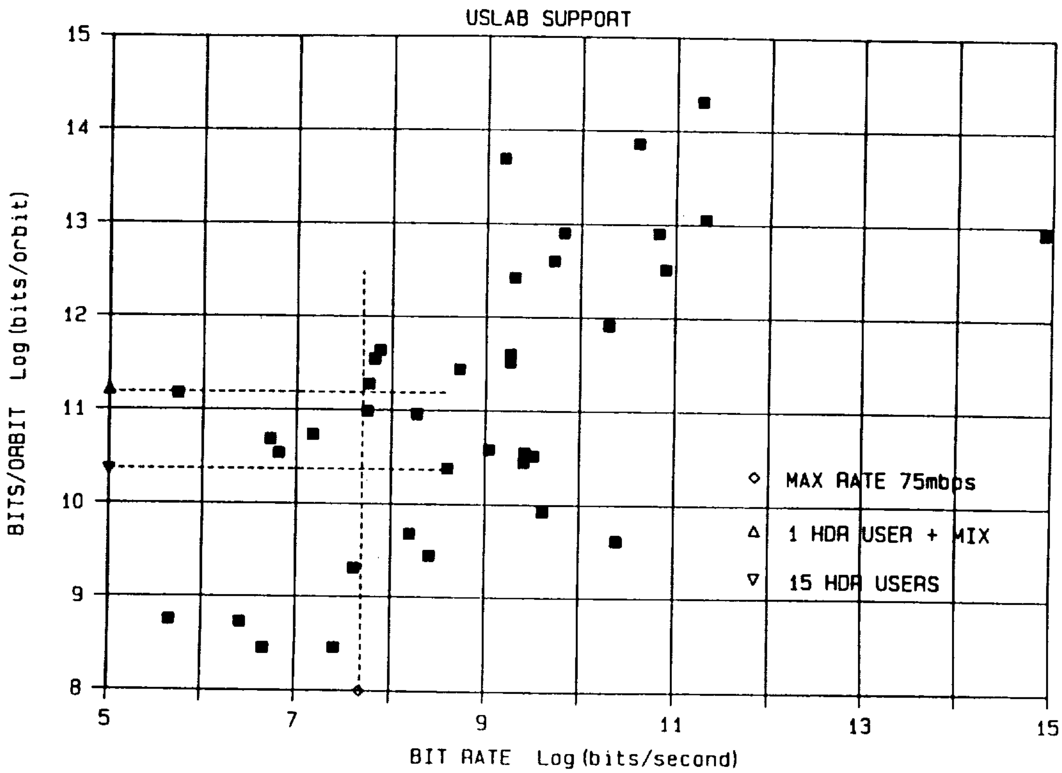


USER REQUIREMENTS

SPACE STATION SUPPORT



USER REQUIREMENTS



DATA SUPPORT SUMMARY

	MAX RATE mbps	PROB UPPER BOUND bits/orbit	LOWER BOUND bits/orbit
TDRSS	300	1.3E12	7.9E11
SHUTTLE	48	1.0E11	4.3E9
SPACELAB	48	4.8E10	3.OE9
SPACE STATION	48	1.1E11	3.7E10
USLAB	75	1.7E11	2.2E10

N91-14577

DATA COMPRESSION APPLIED TO HHVT

William K. Thompson
Analex Corporation
NASA Lewis Research Center

The High Resolution, High Frame Rate Video Technology (HHVT) project engineers wrote a task order to Analex Corporation to study data compression techniques that could be applied to the HHVT system. Specifically, the goals of the HHVT data compression study are to accomplish the following:

(1) Determine the downlink capabilities of the Space Shuttle and Space Station Freedom to support HHVT data (i.e., determine the maximum data rates and link availability)

(2) Determine current and projected capabilities of high speed storage media to support HHVT data by determining their maximum data acquisition/transmission rates and volumes

(3) Identify which experiments in the HHVT Users' Requirements database need data compression, based on the experiments' imaging requirements

(4) Select the best data compression technique for each of these users by identifying a technique that provides compression but minimizes distortion

(5) Investigate state-of-the-art technologies for possible implementation of selected data compression techniques

Data compression will be needed because of the high data rates and large volumes of data that will result from the use of digitized video onboard the Space Shuttle and Space Station Freedom. For example, the data rates and volumes stemming from the use of standard RGB video and HHVT RGB video are compared in the following table:

	Standard RGB Video	HHVT RGB Video
Spatial resolution, pixels	512 × 512	1024 × 1024
Color components	3 (Red, green, blue)	3 (Red, green, blue)
Quantization, levels (8 bits)/component	256	256
Frame rate, frames/sec	30 (interlaced scan)	1000 (no interlacing)
Duration, frames	10 000	10 000
Resultant data rate	190 Mbits/sec	26 Gbits/sec
Required storage volume, Gbits	63	520

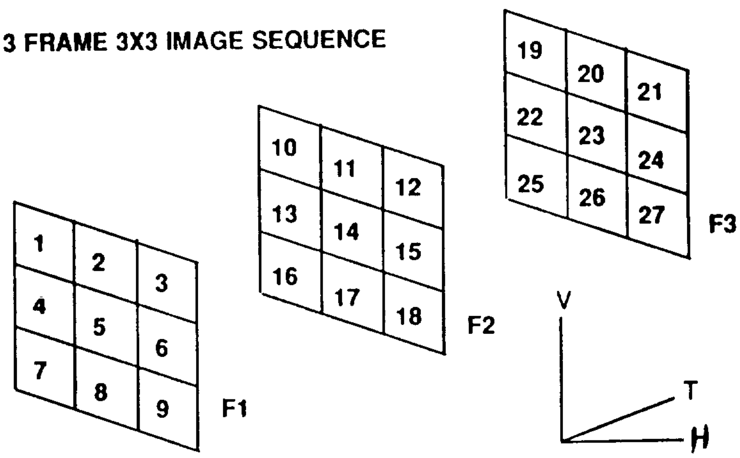
Existing high speed data storage systems and those expected to be commercially available within the next few years cannot support the very high data rates that are generated by some potential users of the HHVT system. Many of these experiments will require data compression during their data acquisition cycles just to be compatible with existing data storage devices.

The downlink capabilities of the Space Shuttle and Space Station Freedom cannot support the large volumes of HHVT data due to limited link availability. For example, the link will be available to the USLab on Space Station Freedom for 74 min/orbit. With a maximum downlink rate of 75 Mbits/sec, the maximum volume of data that can be downlinked per orbit is 333 Gbits. Assuming the data must be downlinked before the next orbit, data compression needs to be applied after the data has been acquired but prior to downlink. Nonreal-time processing could be used since the data is not necessarily required immediately after it has been acquired.

II. THEORETICAL APPROACHES TO DATA COMPRESSION

- *FIRST GENERATION APPROACH*
  - BASED ON INFORMATION THEORY AND STATISTICS
  - IMAGES TREATED AS 2-D OR 3-D RANDOM FIELDS (V,H,T)
  - EXPLOITS CORRELATION OF A PEL WITH ITS SPATIAL AND TEMPORAL NEIGHBORS

3 FRAME 3X3 IMAGE SEQUENCE



- DATA COMPRESSION BY STATISTICAL REDUNDANCY REDUCTION

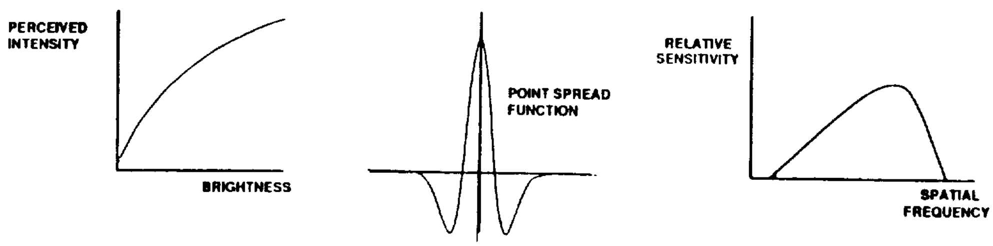
II. THEORETICAL APPROACHES TO DATA COMPRESSION

- *FIRST GENERATION APPROACH*

  - CORRELATION BETWEEN PELS DECREASES WITH INCREASING SPATIAL OR TEMPORAL DISTANCE BETWEEN PELS
  - CAUSAL APPROACHES ONLY REDUCE CORRELATION OF PEL 14 WITH PELS 1-13 SINCE PELS 1-13 ARE SCANNED PRIOR TO PEL 14
  - INTRAFRAME APPROACHES ONLY REDUCE CORRELATION OF PEL 14 WITH OTHER PELS IN F2
  - ADAPTIVE TECHNIQUES VARY THEIR CODING EFFICIENCY BASED ON SCENE ACTIVITY

II. THEORETICAL APPROACHES TO DATA COMPRESSION

- ***SECOND GENERATION APPROACH***
  - EXTENDS INFORMATION THEORY TO INCLUDE VISION AND IMAGE GATHERING MODELS
  - MOST IMPORTANT INFORMATION IS EXTRACTED FROM THE IMAGE
  - INSPIRED BY PROPERTIES OF THE HUMAN VISUAL SYSTEM (HVS)



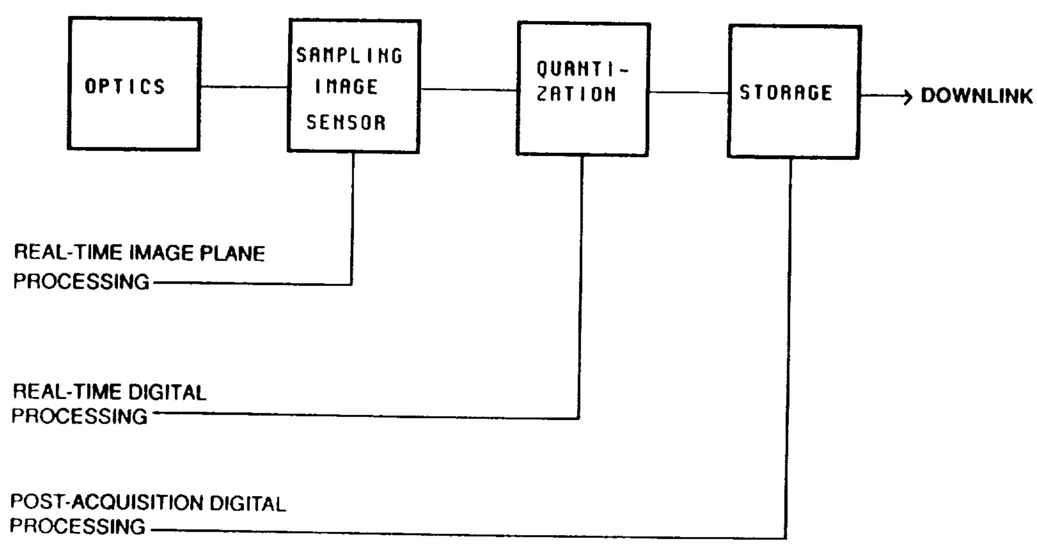
1. WEBER'S LAW **2. LATERAL INHIBITION** **3. BAND PASS SFR**

4. **LOW PASS TEMPORAL FREQUENCY RESPONSE, INTEGRATING FOR .1 SEC**
5. **CONTOUR PERCEPTION**
6. **MOTION DEPENDENT SPATIAL RESPONSE**
7. **DIRECTIONAL SENSITIVITY - MORE SENSITIVE TO VERTICAL AND HORIZONTAL**

- **DATA COMPRESSION BY FEATURE EXTRACTION**

II. THEORETICAL APPROACHES TO DATA COMPRESSION

- **OPPORTUNITIES FOR DATA COMPRESSION IN DATA PATH**



- **DATA COMPRESSION FOR LONG TERM HHVT SYSTEM MAY BE PERFORMED AT MULTIPLE LOCATIONS IN THE DATA PATH**

II. THEORETICAL APPROACHES TO DATA COMPRESSION

COLOR

- COMPOSITE SIGNAL CODING VS. COMPONENT CODING
- COMPONENT CODING HAS GIVEN BEST RESULTS IN THE LITERATURE
- BEST RESULTS WHEN YIQ COMPONENTS ARE USED INSTEAD OF RGB
  Y = LUMINANCE SIGNAL   I,Q = CHROMINANCE SIGNALS
- RGB TO YIQ CONVERSION IS STRAIGHTFORWARD AND LINEAR
- YIQ COMPONENTS ARE NEARLY UNCORRELATED, RGB ARE HIGHLY CORRELATED

III. PERFORMANCE CRITERIA

- PERFORMANCE IS HIGH CODING EFFICIENCY WITH HIGH FIDELITY
- WAYS OF EVALUATING CODING EFFICIENY
  1. ACHIEVABLE COMPRESSION RATIO AT A GIVEN FIDELITY CRITERION
  2. UNCORRELATED DATA (FIRST GENERATION)
  3. MINIMAL DATA REPRESENTATION OF DESIRED FEATURE (SECOND GENERATION)
- WAYS OF EVALUATING FIDELITY
  1. **SUBJECTIVE OBSERVER**
     IS THE OUTPUT IMAGE AESTHETICALLY PLEASING?
  2. **QUANTITATIVE**
     IS THE ERROR MATHEMATICALLY MINIMIZED?
     - MEAN SQUARE $E = (f' - f)^2$
     - MAGNITUDE $E = |f' - f|$
  3. **FEATURE SPECIFIC**
     ARE IMPORTANT FEATURES IN THE OUTPUT PROPERLY REPRESENTED?
     - EDGE AND CONTOUR INFORMATION
     - LUMINANCE / REFLECTANCE INFORMATION
     - COLOR INFORMATION
     - MOTION SEQUENCES

IV. COMPRESSION ALGORITHMS FOR HHVT

- **QUANTIFICATION OF USER REQUIREMENTS**

- **EACH USER'S VIDEO REQUIREMENTS CHARACTERIZED IN TERMS OF SIX PARAMETERS AND THEIR IMPORTANCE TO THE USER'S REQUIREMENTS**

- **SCORED FROM 0** (NOT IMPORTANT) **TO 5** (VERY IMPORTANT)

- **PARAMETERS CONSIDERED**
  1. **SPATIAL INFORMATION**
     - PLACEMENT AND SHARPNESS OF EDGES, CONTOURS
     - TEXTURE INFORMATION
  2. **TEMPORAL INFORMATION**
     - ACCURATE REPRESENTATION OF MOTION: SPEED AND DIRECTION
  3. **AESTHETIC APPEARANCE**
     - SUBJECTIVE EVALUATION BY HUMAN OBSERVER
  4. **LUMINANCE / REFLECTANCE INFORMATION**
     - CONTRAST
     - INTENSITY
  5. **SPECTRAL INFORMATION**
     - COLOR
  6. **IMAGE DYNAMICS**
     - ADAPTABILITY
     - NEED FOR COMPRESSION ALGORITHM TO VARY PERFORMANCE BASED ON SCENE ACTIVITY

IV. COMPRESSION ALGORITHMS FOR HHVT

- **QUANTIFICATION OF COMPRESSION TECHNIQUE PERFORMANCE**
  - EACH TECHNIQUE SCORED FOR EACH PARAMTER BASED ON HOW WELL IT PRESERVES THE PARAMETER WITHOUT INTRODUCING DEGRADATION

- **EACH TECHNIQUE SCORED AT COMPRESSION RATIO REQUIRED BY EXPERIMENT**
  0 = POOR PERFORMANCE
  5 = EXCELLENT PERFORMANCE

- **EVALUATING A GIVEN TECHNIQUE FOR A GIVEN EXPERIMENT**
  - FORM A REQUIREMENTS VECTOR (SIX ELEMENTS)
  - FORM A PERFORMANCE VECTOR (SIX ELEMENTS)
  - TAKE A DOT PRODUCT AND NORMALIZE

$\boxed{\text{EXAMPLE:}}$

$$[5\ 3\ 3\ 2\ 0\ 1] \begin{bmatrix} 5 \\ 2 \\ 2 \\ 1 \\ 1 \\ 5 \end{bmatrix} = 5(5) + 3(2) + 3(2) + 2(1) + 0(1) + 1(5) = 44$$

MAX = 70

44/70 = 63%
SCORE

- **THOSE COMBINATIONS** RECEIVING HIGHEST SCORES WILL BE EVALUATED FURTHER

IV. COMPRESSION ALGORITHMS FOR HHVT

- OTHER CONSIDERATIONS OF IMPORTANCE

  1. TECHNIQUE COMPLEXITY
     - SPEED
     - WEIGHT
     - COST
     - DEVELOPMENT TIME
     - POWER

  2. SUSCEPTIBILITY TO CHANNEL ERRORS
     - AFFECT ON IMPORTANT PARAMETERS
     - LOCAL EFFECTS VS. AVERAGED EFFECTS
     - RESTORABILITY

V. DATA COMPRESSION OVERVIEW

LOSSLESS CODING METHODS

- IMAGE IS FULLY RECOVERABLE GIVEN ERROR-FREE TRANSMISSION

EXAMPLES:

RICE ALGORITHMS (CODED DIFFERENCES)

RUN -LENGTH CODING

BIT PLANE CODING

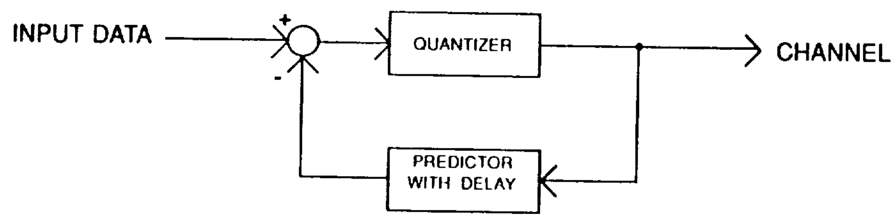
CONDITIONAL REPLENISHMENT

V. DATA COMPRESSION OVERVIEW

- LOSSY PREDICTIVE CODING

  - IMAGES ENCODED BY QUANTIZING THE ERROR BETWEEN THE PREDICTED VALUE OF A SUBPICTURE AND THE ACTUAL VALUE

  - SUBPICTURES MAY BE INDIVIDUAL PELS OR VECTORS



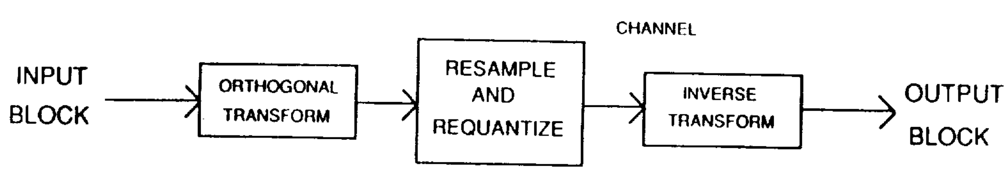
  - EXAMPLES
    - DPCM, VECTOR DPCM
    - DELTA MODULATION

  - MADE ADAPTIVE BY VARYING QUANTIZATION OR PREDICTION PARAMETERS WITH SCENE ACTIVITY

V. DATA COMPRESSION OVERVIEW

- TRANSFORM CODING

  - LINEAR TRANSFORM (ORTHOGONAL BASIS SET) DESCRIBES SPATIAL "FREQUENCY" DOMAIN BEHAVIOR OF IMAGE

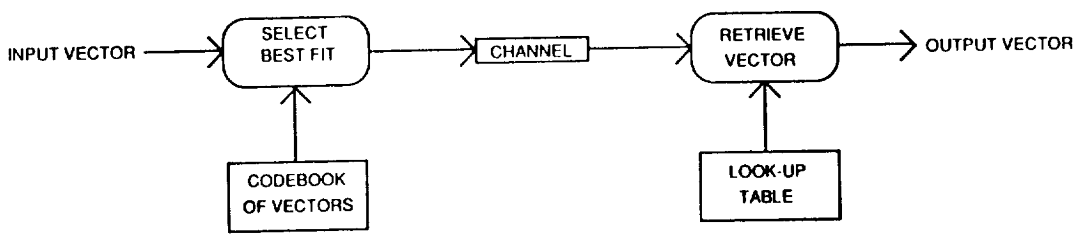


  - LOW MAGNITUDE COEFFICIENTS IN "FREQUENCY DOMAIN" ARE UNDER QUANTIZED OR OMITTED DURING RESAMPLING AND REQUANTIZATION
    - THRESHOLD SAMPLING: SELECTIVE TRANSMISSION BASED ON COEFFICIENT MAGNITUDE (ADAPTIVE)
    - ZONAL SAMPLING: FIXED SAMPLING AND QUANTIZATION PATTERN DETERMINED A PRIORI FROM ANTICIPATED IMAGE STATISTICS (NON-ADAPTIVE)
    - ZONAL SAMPLING IS OFTEN MADE "CLASS-ADAPTIVE"

  - EXAMPLES OF COMMONLY USED BASIS FUNCTIONS
    - KARHUNEN-LOEVE: OPTIMAL BUT VERYDIFFICULT TO IMPLEMENT
    - COSINE, FOURIER, SLANT, HADAMARD, HAAR: SUBOPTIMAL BUT EASIER TO IMPLEMENT

V. DATA COMPRESSION OVERVIEW

- VECTOR QUANTIZATION
  - PARTITION THE IMAGE INTO BLOCKS TO BE TREATED AS VECTORS



  - CODEBOOK DESIGNED A PRIORI WITH TRAINING DATA OR ADAPTIVELY TO MINIMIZE MEAN-SQUARE ERROR
  - SEARCH ALGORITHMS FOR BEST FIT IN CODEBOOK CAN BE FULL (OPTIMAL) OR TREE-STRUCTURED (SUBOPTIMAL, BUT FASTER)
  - DECODER IS A SIMPLE LOOK-UP TABLE
  - LARGE CODEBOOKS GIVE BETTER OUTPUT, BUT COMPLEXITY RISES SHARPLY WITH CODEBOOK SIZE

V. DATA COMPRESSION OVERVIEW

- FEATURE EXTRACTION
- DETERMINE A PRIORI WHAT INFORMATION IS IMPORTANT IN THE IMAGE
- EXTRACT THIS INFORMATION UP FRONT AND DISCARD THE REST
- *EXAMPLES:*
  - CONTOUR CODING
  - SYNTHETIC HIGHS
  - IDS
  - DIRECTIONAL DECOMPOSITION
  - CONTOUR TEXTURE CODING
- THESE TECHNIQUES OFFER THE HIGHEST COMPRESSION RATIOS

DATA COMPRESSION OVERVIEW

CATEGORY	LOSSLESS	LOSSY PREDICTIVE	TRANSFORM	VQ	FEATURE EXTRACTION
COMPRESSION FACTOR	2	8	16	20	100
LEAD TIME	NOW	NOW	NOW	1 YR	5 YRS
COMPLEXITY	LOW	LOW TO MODERATE	MODERATE TO HIGH	MODERATE TO HIGH	HIGH
DISTORTION EFFECTS	NONE	QUANTI- ZATION NOISE, LOSS OF DETAIL	LOSS OF DETAIL, BLOCKING	BLOCKING, ARTIFACTS	LOSS OF UNEXTRACTED INFORMATION
SENSITIVITY TO CHANNEL ERRORS	MODERATE TO HIGH	HIGH	MODERATE	MODERATE	VERY HIGH
CHANNEL DELAY	LOW	LOW	MODERATE	MODERATE	LOW
FLEXIBILITY	HIGH	MODERATE TO HIGH	HIGH	HIGH	LOW

N91-14578

STATE OF THE ART IN VIDEO SYSTEM PERFORMANCE

Michael J. Lewis
NASA Lewis Research Center

The closed circuit television (CCTV) system that is onboard the Space Shuttle has the following capabilities:

Camera

- based on a silicon intensified target (SIT) image tube
- has approximately 300 TV lines of horizontal resolution
- the full frame rate is 30/sec for monochrome images, 20 frames/sec for field sequential color format
- mates to a commandable pan and tilt unit
- has a commandable zoom lens assembly
- has operating settings for the iris, gamma, shading correction, etc.

Video signal switching and routing unit (VSU)

- accepts up to 14 input video signals, including up to 3 from cargo bay payloads and up to 4 from the crew compartment (which includes the middeck)
- routes video signals to 12 output ports, including two TV monitors, the Space Shuttle video tape recorder (VTR), and one KU or S band downlink channel
- allows two camera views to be multiplexed onto one composite signal which can then be recorded, displayed, or downlinked
- provides time tags to the video signals

Space Shuttle video tape recorder (VTR)

- records monochrome or color format video and audio from the VSU
- the playback video signal can be routed to the VSU or directly to the No. 2 TV monitor
- one 3/4 in. cassette can record for 30 min

Useful as it is, the Space Shuttle CCTV system is inadequate for use with many experiments that require video imaging. Some of these shortcomings are

(1) The CCTV camera cannot frame at more than 30 frames/sec.

(2) The camera does not have high resolution.

(3) The CCTV system lacks the ability to trade off resolution and frame rate in order to accommodate experiments with different imaging requirements.

(4) The camera lens has to be changed in order to switch from monochrome to color imaging.

(5) The CCTV camera captures color images in field sequential format which produces an image flicker effect on the Space Shuttle monitors. Only monochrome images can be displayed on Shuttle monitors because of this flickering. Also, the image data in field sequential format must be converted to NTSC format before it can be distributed on ground.

(6) The video tape recorder's 30-min maximum recording time is insufficient for experiments that require more than 30 min to run their course.

NASA does have a contract underway to build a 3-chip CCD color/monochrome camera using NTSC format to replace the existing SIT Shuttle cameras.

In order to assess the state of the art in video technology and data storage systems, NASA Lewis Research Center has been conducting a survey of manufacturers. The HHVT project engineers have searched the technical literature on state-of-the-art imaging components and data handling systems, as well as meeting with vendors and/or discussing their products via the telephone. The project engineers have investigated the state of the art in commercially available high frame rate video systems, image sensors and cameras, high speed data storage systems, and mass storage data systems. The database generated will be updated throughout the duration of the HHVT development project.

The performance of state-of-the-art solid state cameras and image sensors, video recording systems, data transmission devices, and data storage systems versus users' requirements are shown graphically on the attached charts (see Figs. 1 to 4). Figure 3 shows maximum data transfer rates versus users' requirements. In order to plot the transfer rate in terms of the highest possible frame rate versus resolution for a given data storage system, 1 byte/pixel was assumed to be sufficient. It is important to note that this graph assumes that the overall video system is not limited by the capabilities of the image sensor.

In comparing the various available data acquisition/transmission/storage systems, the dynamic random access memory (RAM) has numerous advantages. These advantages are

(1) Very high speed data acquisition
(2) Slower speed random access transfers
(3) Error correction
(4) Varying input data rates are acceptable
(5) Compatiblity with various control busses
(6) Compactness

One disadvantage of the dynamic RAM is that it has a relatively low storage capacity for extended high frame rate imaging.

The advantages of random file access systems such as PDT, NPDT, and optical disks are

(1) Large data capacity for extended imaging times
(2) Compatibility with various control busses
(3) Replaceable disks for greater storage capacity

Their disadvantages include

(1) Relatively slow data acquisition rates for high frame rate imaging
(2) Little or no error correction
(3) Questionable ruggedization of disks and disk drives
(4) Large volume requirements for most magnetic disk systems

Magnetic tape recorders have numerous advantages including

(1) Very large data capacity for extended imaging times
(2) Variable data acquisition/transmission rates for recording and playback
(3) Relatively high data transfer rates
(4) Error correction
(5) Replaceable tape cartridges for greater storage capacity
(6) Ruggedness
(7) Compactness

Their disadvantages are

(1) Relatively slow data transfer rates for direct recording of high frame rate images
(2) Incompatibility with various control busses
(3) Possible file access delay

Sixteen millimeter film has been used reliably in the past because there are numerous film cameras which allow very high frame rates with high resolution and the cameras have been ruggedized for flight. But their disadvantages are that images can only be acquired for very short durations at high frame rates because the film magazines run out so fast, and longer imaging times even at moderate frame rates require large amounts of film to be used. Also, astronauts are needed to replace the film magazines, adding extra work to their already busy schedules. On Space Station Freedom replenishment of film magazines will only occur every 3 months.

The conclusions that have been drawn from this survey of state-of-the-art video technology and memory systems are as follows:

(1) Current imaging systems and solid state sensors fall short of achieving a major portion of the users' requirements.

(2) Custom CID or CCD sensors could accommodate more of the users' requirements.

(3) Some data storage systems have the potential to satisfy a major portion of the users' requirements.

SOLID STATE IMAGE SENSORS AND CAMERA DATA

O TEKTRONICS TK128PR	- RESOLUTION - 64 X 128 PIXELS - FRAME RATE - > 5000 FRAMES/SEC. - PIXEL RATE - 5 MHz (MAX.)/CHANNEL - VIDEO CHANNELS - 64
O RETICON RA2566N	- RESOLUTION - 256 X 256 PIXELS - FRAME RATE - 500 FRAMES/SEC. - PIXEL RATE - 5 MHz/CHANNEL - VIDEO CHANNELS - 8
O GENERAL ELECTRIC CID512 CAMERA	- RESOLUTION - 256 X 256 PIXELS - FRAME RATE - 500 FRAMES/SEC. (SKIP SCAN) - PIXEL RATE - 7.8 MHz - VIDEO CHANNELS - 1
O GENERAL ELECTRIC CID 256E SENSOR	- RESOLUTION - 256 X 256 - FRAME RATE - 150 FRAMES/SEC. - PIXEL RATE - 2.5 MHz/CHANNEL - VIDEO CHANNELS - 4
O KODAK VIDEK MEGA PLUS	- RESOLUTION - 1320 X 1032 - FRAME RATE - 10 FRAMES/SEC. - PIXEL RATE - 14 MHz (MAX) - VIDEO CHANNELS - 1
O TEKTRONICS TK2048M	- RESOLUTION - 2048 X 2048 - FRAME RATE - 4 FRAMES/SEC. - PIXEL RATE - 1 MHz (MAX) - VIDEO CHANNELS - 1

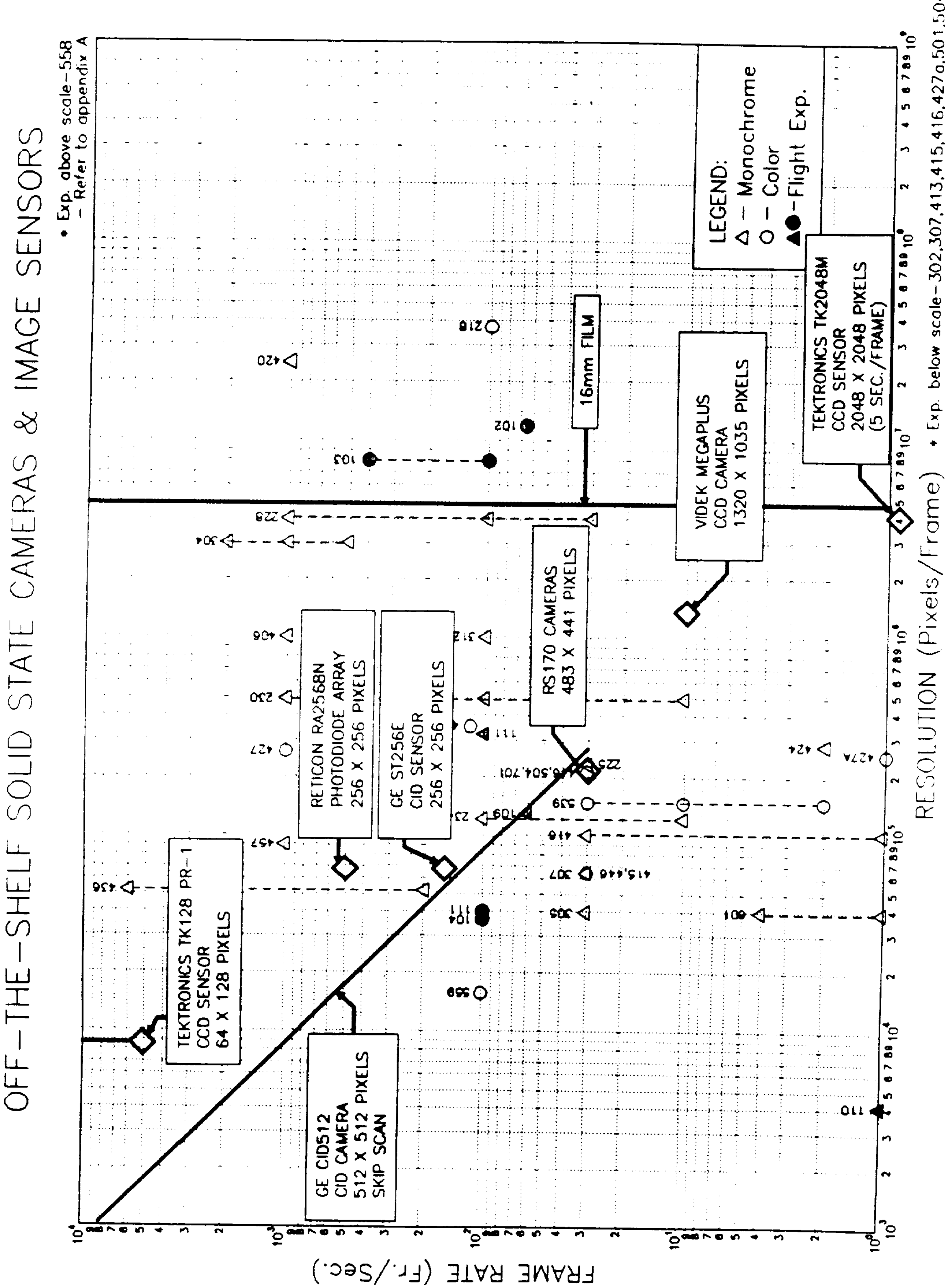


Figure 1

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PRESENTLY AVAILABLE VIDEO SYSTEM DATA

- O SPIN PHYSICS SP 2000
  - FULL FRAME RATE - 2000, 1000, 500, 200, 60
  - SENSOR
    - MOS ARRAY
    - RESOLUTION - 192 X 240 PIXELS
    - 32 PARALLEL CHANNELS
    - PIXEL RATE - 3.0 MHz
  - RECORDER
    - FULL RESOLUTION
    - 64 GRAY LEVELS
    - 34 TRACKS
    - 1/2" HIGH DENSITY CASSETTE

- O NAC HVRB-200SS
  - FULL FRAME RATE - 200, 60
  - SENSOR
    - MOS CCD ARRAY
    - RESOLUTION - 244 X 280 PIXELS
  - RECORDER
    - 200 + HORZ. LINES
    - 1/2" VHS TAPE

- O RS170 CAMERA & VHS VCR
  - FULL FRAME RATE - 30
  - SENSOR
    - CCD, CID, PHOTO-CAPACITOR, TUBE
    - RESOLUTION - 483 X 441 PIXELS
  - RECORDER
    - FULL FRAME RATE - 30
    - RESOLUTION - 483 X 320

- O 16MM FILM
  - RAR 2498 FILM
  - ASA 125
  - FULL FRAME RATE - NO LIMIT
  - RESOLUTION - 1920 X 2400 PIXELS

OFF-THE-SHELF VIDEO RECORDING SYSTEM PERFORMANCE

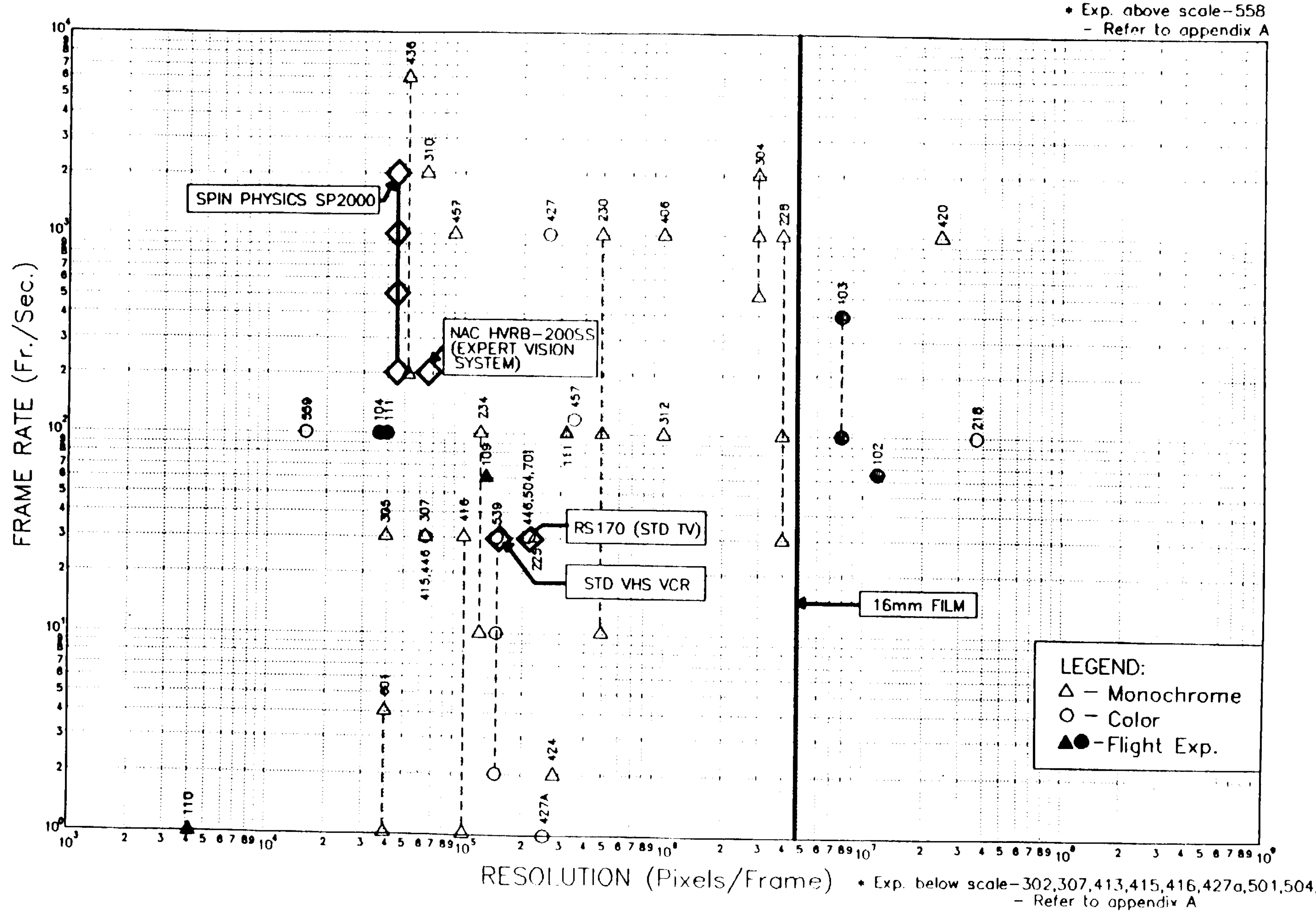

Figure 2

GENERAL COMPONENT DATA FOR DATA TRANSFER RATE AND STORAGE

O DYNAMIC RAM	- ZITEL 93+ SPLIT - TRANSFER RATE - 640 MBYTES/SEC. - STORAGE CAPACITY - 512 MBYTES - DATA WORD SIZE - 256 PARALLEL CHANNELS - HIGH SPEED SEQUENTIAL BLOCK TRANSFER - SLOWER SPEED RANDOM WORD READ/WRITE - SIZE - 14" X 19" X 21.2" - AVAILABILITY - LATE '88
O NON-PARALLEL MAG. DISK TRANSFER	- RECOGNITION CONCEPTS INC. VISISTORE - TRANSFER RATE - 74 MBYTES/SEC. (SUSTAINTED) - STORAGE CAPACITY - 25 GBYTES - DATA WORD SIZE - 64 PARALLEL CHANNELS - RANDOM FILE READ/WRITE - SIZE - 60" X 19" X 27" (2) - AVAILABILITY - MID TO LATE '88
O MAG. TAPE REC.	- MIL. STANDARD 21-79AS - TRANSFER RATE - 30 MBYTES/SEC. - STORAGE CAPACITY - 99 GBYTES - DATA WORD SIZE - 8 PARALLEL CHANNELS - SEQUENTIAL DATA READ/WRITE - SIZE -170" X 16" X 16" - AVAILABILITY - MID '89
O PARALLEL MAG. DISK TRANSFER	- APPLIED MEMORY TECHNOLOGY MODEL 8300 - TRANSFER RATE - 7.8 MBYTES/SEC. (SUSTAINED) - STORAGE CAPACITY - 1.0 GBYTES - DATA WORD SIZE - 16 PARALLEL CHANNELS - RANDOM FILE READ/WRITE - SIZE - 8.75" X 17" X 26" - AVAILABILITY - LATE '88

GENERAL COMPONENT DATA FOR DATA TRANSFER RATE AND STORAGE

(CONTINUED)

O OPTICAL DISK	- KODAK - TRANSFER RATE - 1 MBYTES/SEC. * - STORAGE CAPACITY - 6.8 GBYTES - DATA WORD SIZE - 16 PARALLEL CHANNELS - RANDOM FILE READ/WRITE - SIZE - - AVAILABILITY -
O SHUTTLE KU BAND DOWNLINK	- VIA TDRSS - TRANSFER RATE - 6.0 MBYTES/SEC. ** - FULL USE OF SHUTTLE HIGH SPEED DIGITAL DATA CHANNEL

* INTERFACE LIMITED VIA SCSI

** DATA RATE FROM WHITE SANDS

NEAR-TERM TECHNOLOGY DATA TRANSFER RATE vs. USER REQUIREMENTS

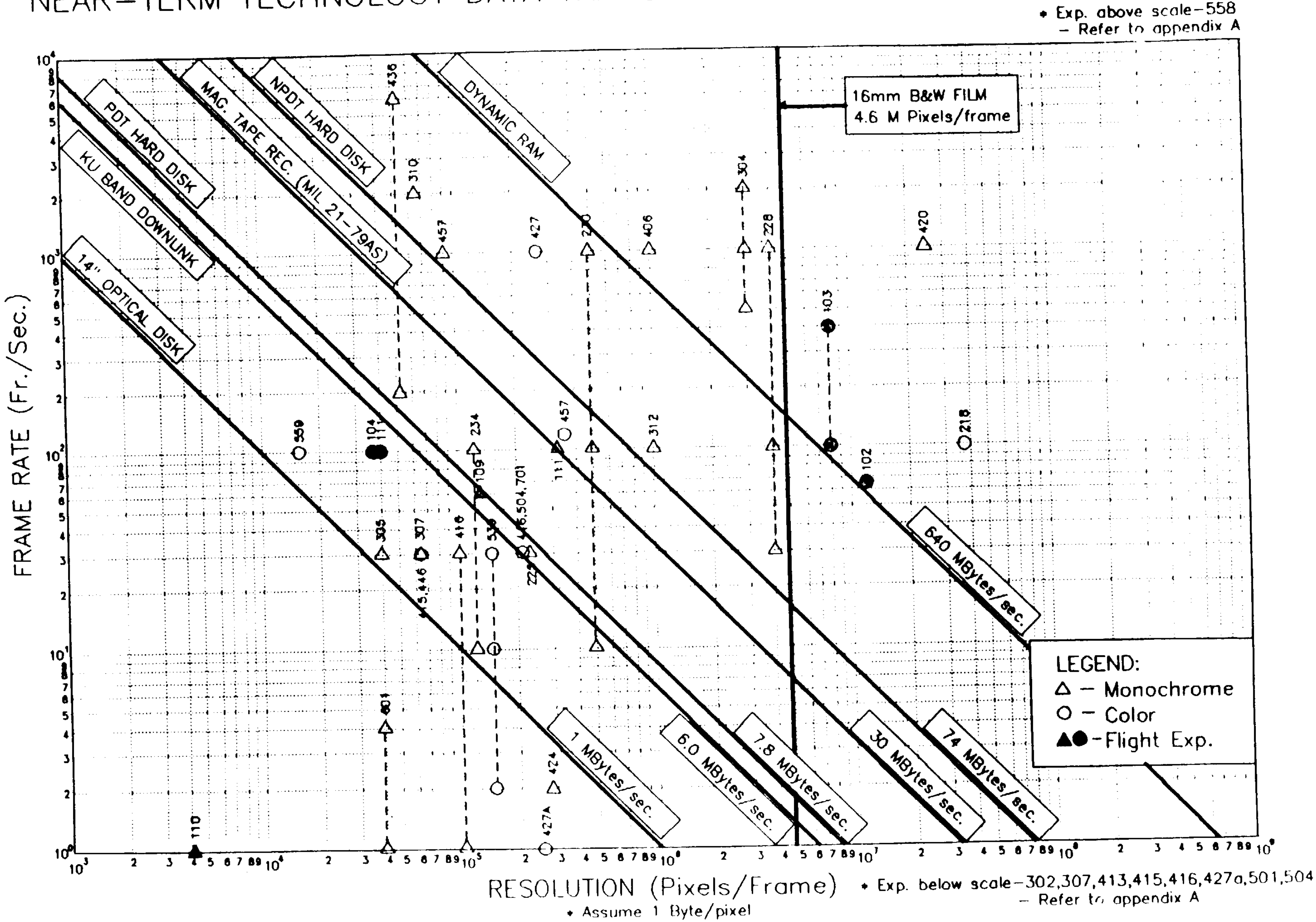

Figure 3

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NEAR-TERM TECHNOLOGY STORAGE CAPACITY vs. USER REQUIREMENTS PER RUN

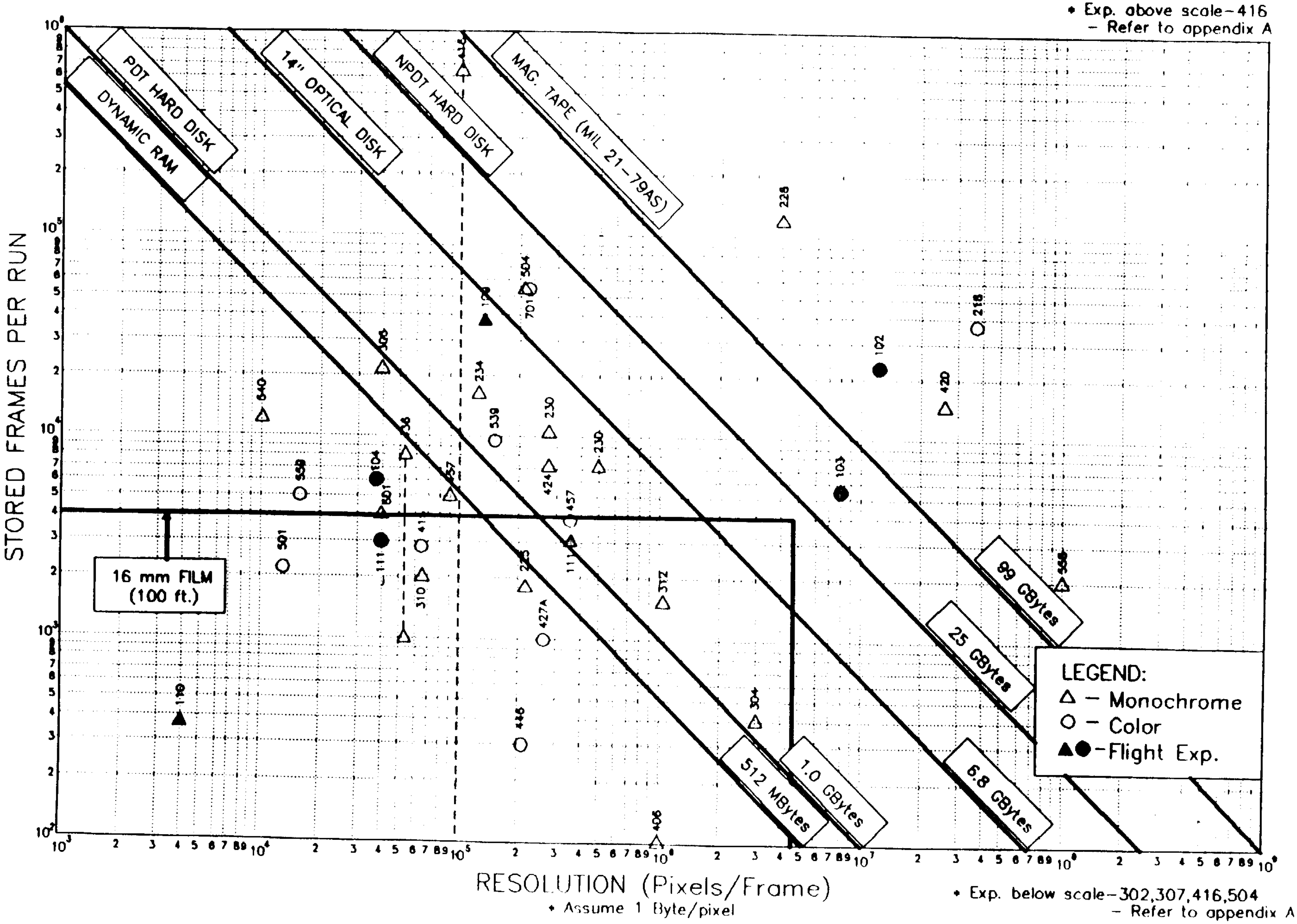

Figure 4

N91-14579

ADVANCED TECHNOLOGY DEVELOPMENT FOR IMAGE GATHERING, CODING, AND PROCESSING

Friedrich O. Huck
NASA Langley Research Center

SUMMARY

Our research activities consist of three overlapping areas. 1) Information theory and optimal filtering are extended rigorously to visual information acquisition and processing. The goal is to provide a comprehensive methodology for quantitatively assessing the end-to-end performance of image gathering, coding, and processing. Information theory allows us to establish upper limits on the visual information that can be acquired within given constraints. Optimal filtering allows us to establish upper limits on the performance that can be attained for specific tasks, even if these tasks require adaptive or interactive processing. 2) Focal-plane processing techniques and technology are developed to combine effectively image gathering with coding. The emphasis is on low-level vision processing akin to the retinal processing in human vision. Our approach includes the familiar lateral inhibition, the new intensity-dependent spatial summation, and parallel sensing/processing networks. 3) A breadboard adaptive image-coding system is being assembled. This system will be used to develop and evaluate a number of advanced image-coding technologies and techniques as well as to research the concept of adaptive image coding. The idea of adaptive image coding is to use knowledge-based supervision to autonomously select the appropriate data compression scheme based on (a) the properties of the acquired image data (and changes in these properties), (b) the visual information required by the investigator, and (c) the available channel capacity. The system would have continual access to the investigators' knowledge of what is significant. Under the investigators' supervision, it could adaptively select image-coding and feature-classification schemes based on properties of the target such as spatial structure, texture, and spectral reflectance.

1. INFORMATION THEORY AND OPTIMAL FILTERING

The performance of (digital) image-gathering systems is constrained by the spatial-frequency response of optical apertures, the sampling passband of photon-detection mechanisms, and the noise generated by photon detection and analog-to-digital conversion. Biophysical limitations have imposed similar constraints on natural vision. Visual information is inevitably lost in both image gathering and low-level vision by aliasing, blurring, and noise. Therefore, it is no longer permissible to assume sufficient sampling as Shannon and Wiener could do in their classical works, respectively, on communication theory and optimal filtering for time-varying signals. Nevertheless, the digital-processing algorithms (for image restoration, edge enhancement, etc.) found in the currently prevailing literature assume sufficient sampling, whereas image-gathering systems are ordinarily designed to permit considerable insufficient sampling. This fundamental difference between assumption and reality has caused unnecessary limitations in the performance of digital image gathering, coding, and processing. It also has led to unreliable conclusions about the correct design of image-gathering systems for visual information processing (as opposed to image reconstruction without processing, e.g., commercial TV) and about the actual performance of image-coding schemes for tasks which involve digital image processing.

Our analyses so far have shown that the combined process of image gathering and optimal processing (see fig. 1) can be treated as a communication channel if (and only if) the image-gathering degradations are correctly accounted for. Correctly restored images gain significantly in fidelity (similarity to target), resolution (minimum discernible detail), sharpness (contrast between large areas), and clarity (absence of visible artifacts). These improvements in visual quality are obtained solely by the correct end-to-end optimization without increase in either data transmission or processing. These results have encouraged us to extend our analyses to various image coding schemes and the associated image-restoration and feature-extraction algorithms.

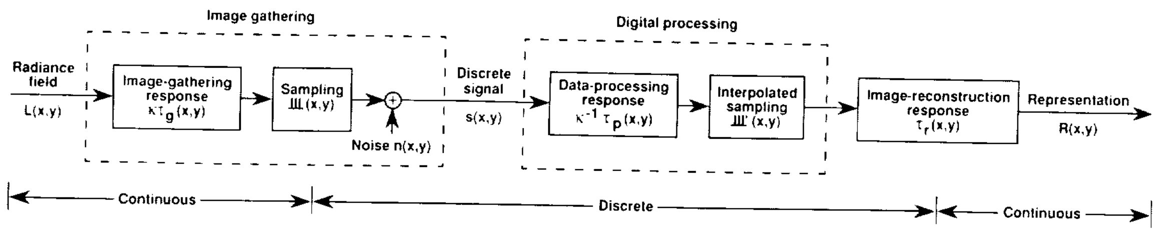

Figure 1. Model of image gathering, digital processing, and image reconstruction.

This work is summarized in references 1 through 6.

1. F. O. Huck, C. L. Fales, D. J. Jobson, S. K. Park, and R. W. Samms, "Image-plane processing of visual information," Applied Optics, Vol. 23, No. 18, pp. 3160–3167, 1984.
2. F. O. Huck, C. L. Fales, N. Halyo, R. W. Samms, and K. Stacy, "Image gathering and processing: Information and fidelity," J. Opt. Soc. Am. A2, 1644–1666 (1985).
3. F. O. Huck, C. L. Fales, J. A. McCormick, and S. K. Park, "Image-gathering system design for information and fidelity," J. Opt. Soc. Am. A5, 285–299 (1988).
4. C. L. Fales, F. O. Huck, J. A. McCormick, and S. K. Park, "Wiener restoration of sampled image data: End-to-end analysis," J. Opt. Soc. Am. A5, 300–314 (1988).
5. J. A. McCormick, R. Alter-Gartenberg, F. O. Huck, "Image gathering and restoration: Information and visual quality," J. Opt. Soc. Am. A6, July (1989).
6. F. O. Huck, S. John, J. A. McCormick, and R. Narayanswamy, "Image gathering, coding, and restoration: Information efficiency and visual quality." Visual Information Processing, Williamsburg, VA, 10–12 May, 1989.

2. FOCAL-PLANE PROCESSING TECHNIQUES AND TECHNOLOGY

Image gathering and coding are commonly treated as tasks separate from each other and from the digital processing used to restore and enhance images or extract features such as primal sketches or contour outlines. However, if we implement the edge enhancement required to draw primal sketches with focal-plane processing by properly combining optical response with lateral inhibition (as depicted by figs. 2 and 3), then a number of advantages can be gained. These advantages include improved resolution by a factor of four, improved robustness to noise, reduced data processing by two orders of magnitude, and reduced data transmission by nearly one order of magnitude. The implementation of a sensor-array focal-plane processor with lateral inhibition is supported by an SBIR contract (NAS1-18287, Phase II). If this approach could be extended to include not only edge enhancement but also edge detection so that only significant primal sketches need to be transmitted, then it would be possible to reduce data transmission by two orders of magnitude without loss of the improved accuracy in edge location.

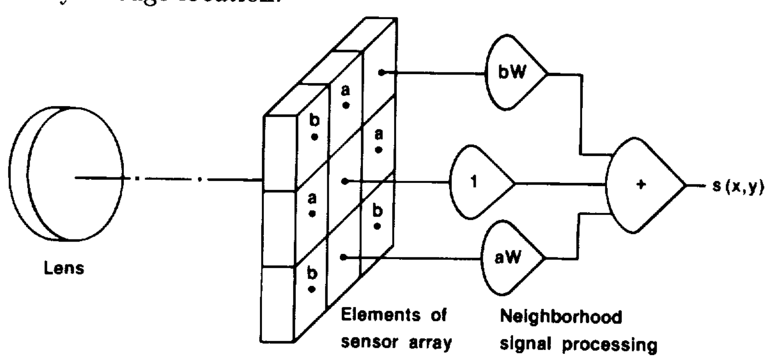

Figure 2. Model of optics and sensor array with focal-plane processing.

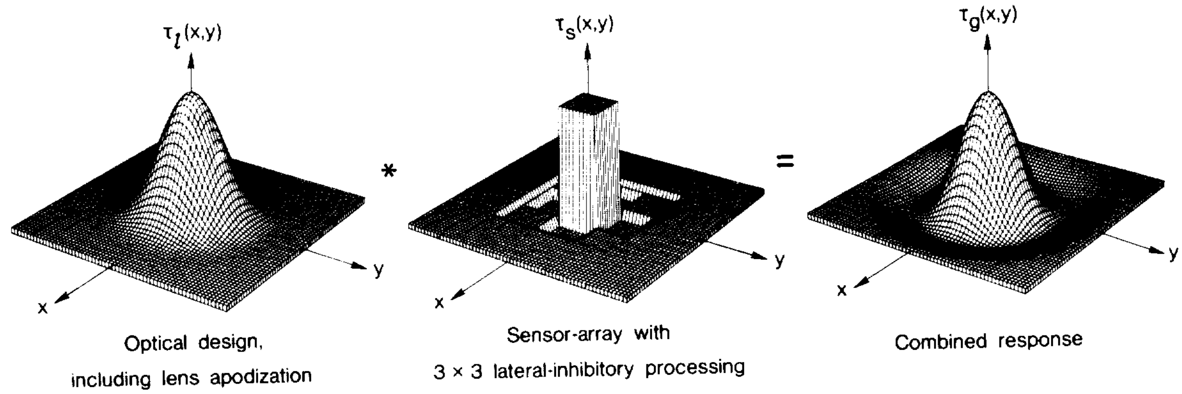

Figure 3. Laplacian-of-Gaussian response created by optical design and lateral-inhibitory processing.

Our major emphasis is on the development of an image-coding method that we refer to as local intensity adaptive image coding. This work is supported by two SBIR contracts (NAS1-18664 and NAS1-18850, both Phase II).

Local intensity adaptive image coding consists of an innovative model of processing in the human retina referred to as Intensity Dependent Spread (IDS) and some additional logic to extract contour outlines and reflectance ratios at the boundary of two surfaces. Figure 4 is a schematic representation of the IDS model. The line of detectors represents a slice through a two-dimensional array of detectors. When an optical image or light distribution falls on the detector array, then each detector sends a signal into a network, where it spreads out. Each channel, in turn, sends out a signal that is the sum of all the signals that arrive in its location in the summation network. The special property of the IDS model has to do with the way the signal from each detector spreads in the summation network. As depicted in the lower half of figure 4, the magnitude of the signal at its center is proportional to the intensity of the light falling on the detector, and the spread of the signal is inversely proportional to this intensity. The total volume under the spread remains constant. That is all there is to the model. It has been demonstrated, in reference 8, that this simple space-variant model of image processing has many of the properties of human visual perception.

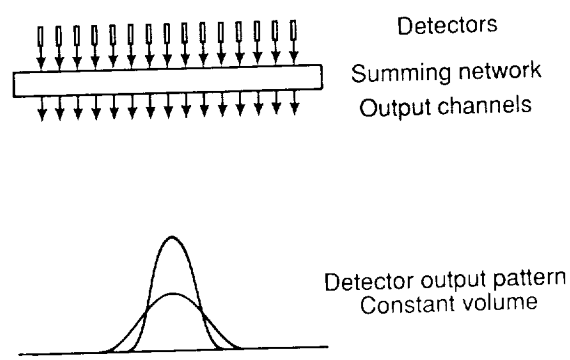

Figure 4. Schematic representation of the IDS model.

Figure 5 shows the response of the IDS processor to a spot, or point source, that is brighter than the background and to a step-type edge. Each detector spreads its signal as governed by the intensity of the light falling on the detector. For example, all of the spreads for the uniform background in figure 5(a) are the same except for the one detector that is more brightly lighted. Its spread is higher and narrower.

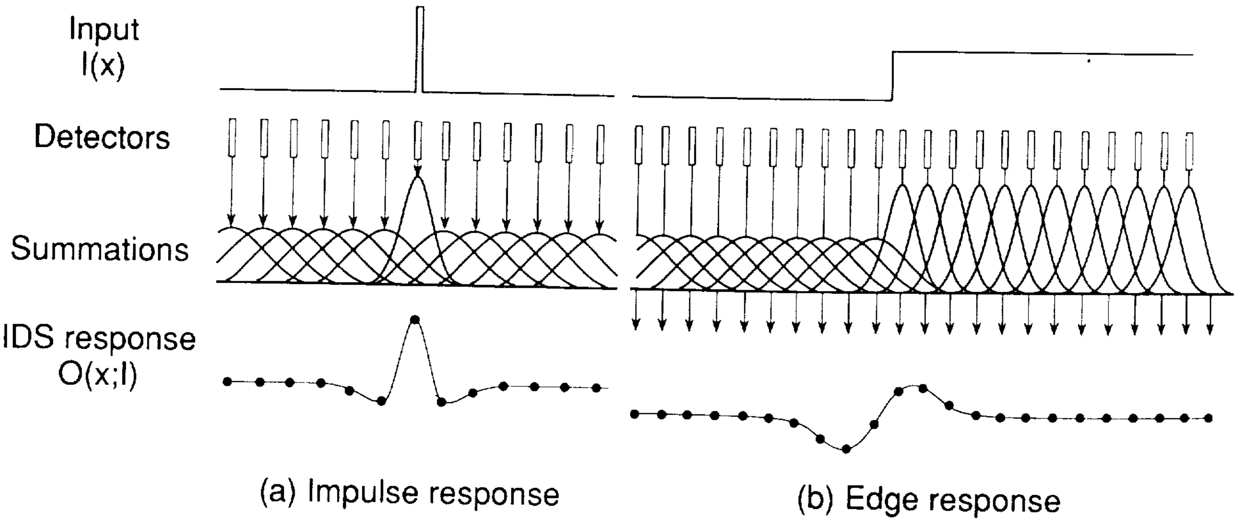

Figure 5. The IDS response to a point source and a step-type edge.

Each output channel just adds up all of the contributions it receives. The result of this processing is shown as the output signal. As can be seen, the IDS response to a point source has a similar shape as the response of Marr and Hildreth's familiar Laplacian of Gaussian ($\nabla^2 G$) operator for enhancing edges (see fig. 2). In fact, the IDS processor exhibits center-surround antagonism and all other manifestations of bandpass filtering that have made the $\nabla^2 G$ operator a favorite algorithm for low-level vision processing. However, the IDS response is nonnegative and spatially variant. As we will show in the next three figures, the IDS processor accounts for several familiar perceptual phenomena of human vision that make it a highly robust low-level vision operator.

First let us compare the IDS operation to conventional imaging. Figure 6 shows intensity profiles taken across conventional and IDS images of a step-type edge input for three illuminations. Conventional image-gathering yields a blurred representation that is visually representative of the target if the signal-to-noise ratio (SNR) is sufficiently high. As the illumination decreases, the representation gets buried in the noise. Image gathering with the IDS processor yields a target representation that consists of pulses. The one-crossing of each pulse locates the position of an edge in the target. The peak and trough values of the pulse are proportional to the ratio of the reflectances at the two sides of the edge, entirely independent of illumination. As the illumination decreases, the width of the pulse becomes broader (thereby trading resolution for sensitivity), but the accuracy of the one-crossing is unimpaired. For machine vision, this property means that edge detection for determining structure is highly robust in widely variant illumination.

Next let us compare the IDS operation to edge detection with the linear $\nabla^2 G$ operator as well as to conventional imaging. Figure 7 shows intensity profiles taken across conventional images and outputs from the $\nabla^2 G$ and IDS operators for two illuminations, high and low. Noise is disregarded for simplicity. The peak and trough values of the $\nabla^2 G$ pulses are proportional to both illumination and reflectance. Therefore, it is not possible to characterize the reflectance properties of the target independent of illumination. However, the peak and trough values of the IDS pulses are proportional only to the reflectance changes. This striking property of the IDS processor mimics human visual perception (Weber's law) and makes it possible to extract the reflectance ratio at the boundary of two areas.

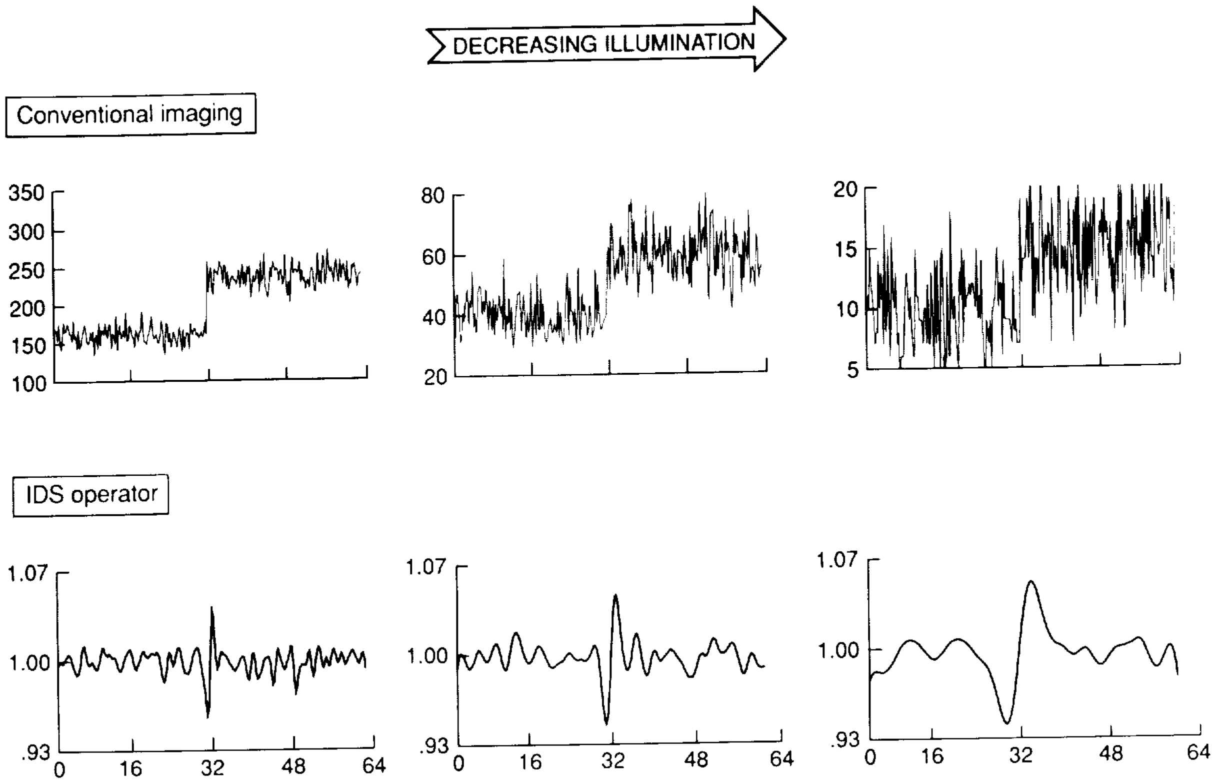

Figure 6. Comparison of IDS operation to conventional imaging.

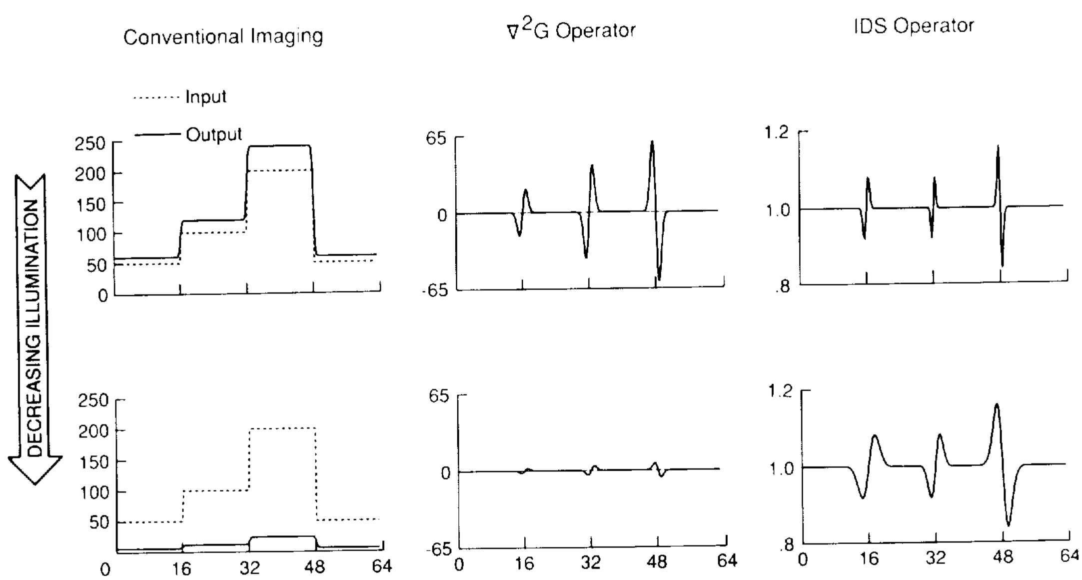

Figure 7. Comparison of IDS operation to conventional imaging and $\nabla^2 G$ operation.

Figure 8 illustrates a particularly important characteristic of the IDS filter, namely, the robustness of its reflectance representation to local variation in illumination (e.g., shadow). The recovered target 8(d) resembles the original one 8(a) and not the shadowy one 8(b), which is the one that was filtered. Traces of the shadow degradation can be seen in the modest loss of accuracy in the actual transition as the illumination decreases. An important extension of IDS processing would be to extract color. Color then could be correctly detected independent of illumination.

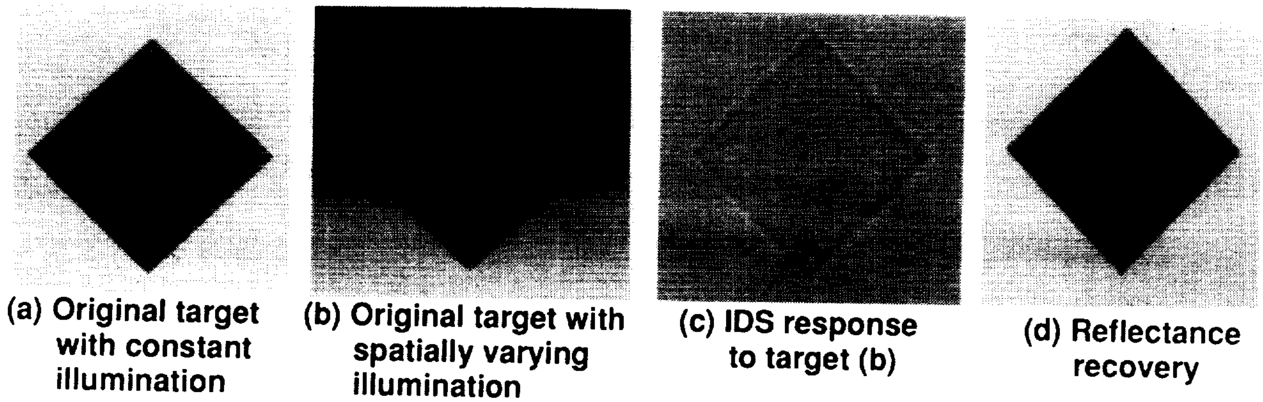

Figure 8. IDS response to target with spatially varying illumination.

Odetics, Inc., is now under contract with LaRC (NAS1-18664, Phase II) to develop a hardware implementation of the IDS processor (see fig. 9). This processor will be capable of handling image data at real-time TV rates (30 frames per second). It will be implemented on several boards for the DATACUBE of Sun image-processing work stations. These boards are expected to become commercially available in Fall 1989.

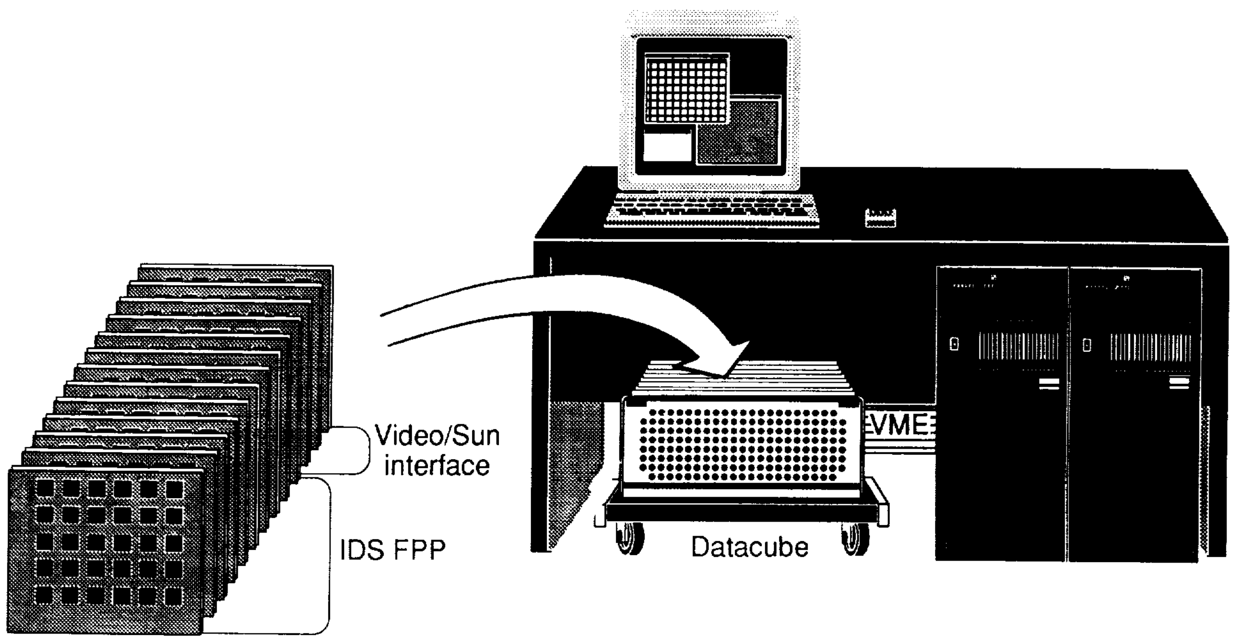

Figure 9. Implementation of IDS for real-time operation in Sun workstation.

The full potential of the IDS processor for data compression as well as image enhancement and feature extraction is realized, of course, only when it is implemented as a focal-plane processor, or "retinal camera," depicted in figure 10. The present design of the IDS processor for Sun workstations could be implemented in one 5" by 5" board with 8 VLSI chips. A more advanced approach is the parallel asynchronous focal-plane image processor depicted in figure 11. This processor, which is being developed under a contract with LaRC (NAS1-18850, Phase II), is representative of a new class of devices that permit full two-dimensional parallel readout and processing perpendicular to the focal plane. Advantages over conventional image-gathering and processing techniques include rapid parallel distributed processing, high dynamic range, and the elimination of conventional charge transfer, multiplexing, and preamplifiers. Vision processing potentially could be performed several orders of magnitude faster than with conventional approaches. Moreover, parallel processing would be ideal for tasks like visual pattern recognition. However, the development of this approach is still in its initial experimental stage.

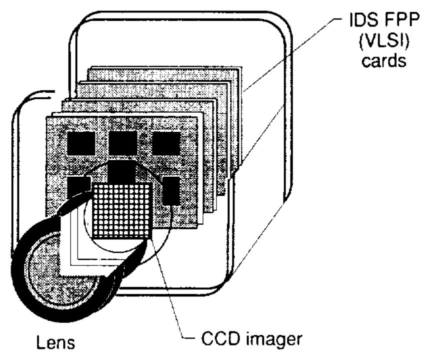

Figure 10. IDS focal-plane processing camera.

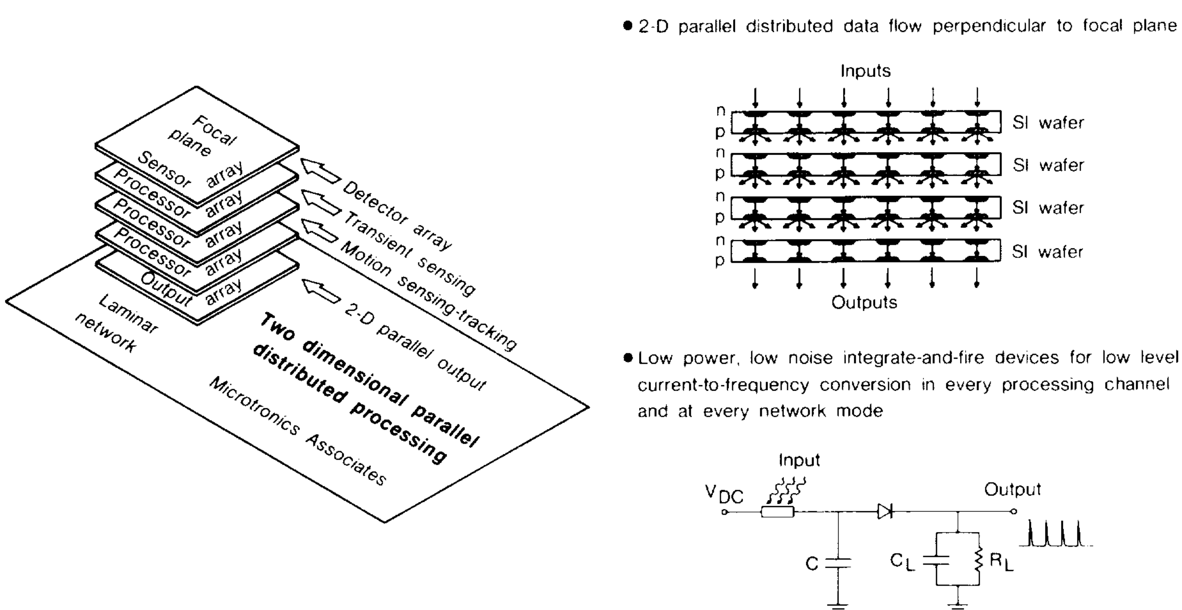

Figure 11. Parallel asynchronous focal-plane image processor.

This work is summarized in references 7 through 12.

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8. T. N. Cornsweet and J. I. Yellott, Jr., "Intensity-dependent spatial summation," J. Opt. Soc. Am. 2, pp. 1769–86 (1985).
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3. ADAPTIVE IMAGE CODING SYSTEM

The problem of image gathering and data compression for the high-resolution, high-frame-rate video system is such that no single data-compression method, or even just a few methods, can satisfy most of the diverse requirements. For some experiments the data-compression requirements even change with time. Consequently, we have started to investigate the concept of adaptive image coding. This investigation is supported by one SBIR contract (Phase I). We are currently seeking additional SBIR contracts under the subtopic 07.01 entitled Focal Plane Image Processing.

Figure 12 presents a block diagram of the basic adaptive image coding system. The idea of this system is to use knowledge-based supervision to autonomously select the appropriate data compression scheme based on (a) the properties of the acquired image data (and changes in these properties), (b) the visual information required by the investigator, and (c) the available channel capacity. The system would have continual access to the investigators' knowledge of what is significant. Under the investigators' supervision, it could adaptively select image-coding and feature-classification schemes based on properties of the scene such as spatial structure, texture, and spectral reflectance.

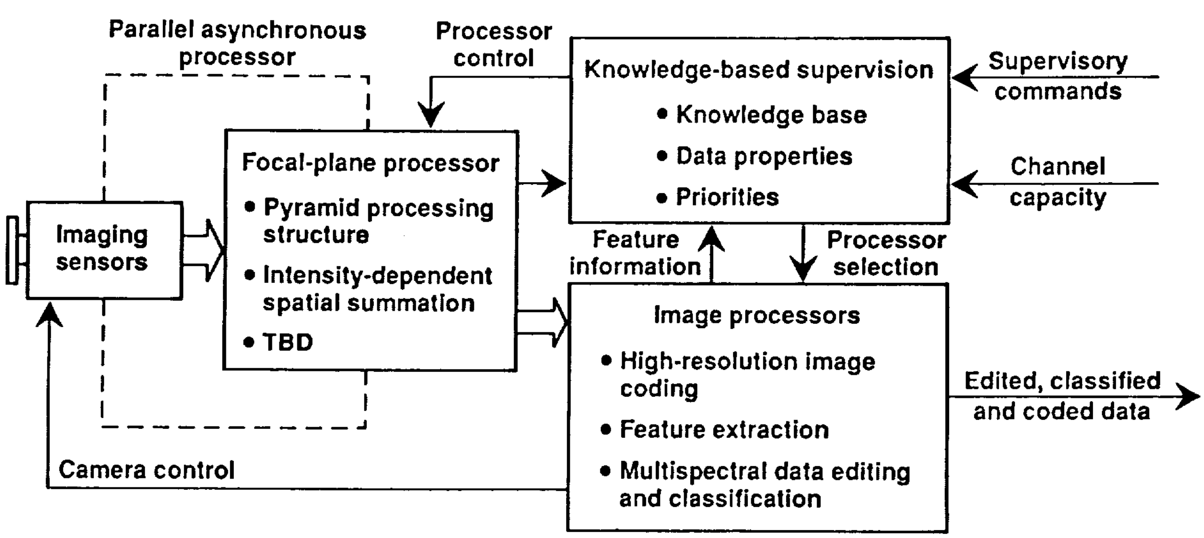

Figure 12. Schematic depiction of adaptive image coding system.

For example, consider figures 13 and 14. In one extreme, if the target of interest is well illuminated, as it is for figure 13, and the goal is to reconstruct an image of this target with pleasing visual quality, then the appropriate data-compression scheme should allow only those degradations to occur that are benign with regard to visual quality. Furthermore, Optivision's OPTIPAC coding system, for which these results are shown, allows the relationship between visual quality and amount of data compression to be continuously adjusted. This adjustment, for example, could be autonomously controlled by the channel capacity that is available for transmitting the desired images.

Figure 13. Data compression for well illuminated target. The compression ratio varies from CR = 22:1 to 92:1 for the original color pictures shown here only in black and white. (Courtesy of Optivision, Inc.)

In the other extreme, consider the scene shown in figure 14. An extreme range of light intensity exists, stretching from deep shadow to highly reflective surfaces in direct sunlight. It is now important to monitor the movements of the astronaut in deep shadow, so an entirely different coding scheme is appropriate. The results shown in figure 14 were obtained with the locally adaptive coding method based on the IDS model of retinal processing described in Section 2 above. Again, it should be possible to transmit only the data required for primal sketches at very high data compressions, or more complete data that permits the recovery of reflectance representations.

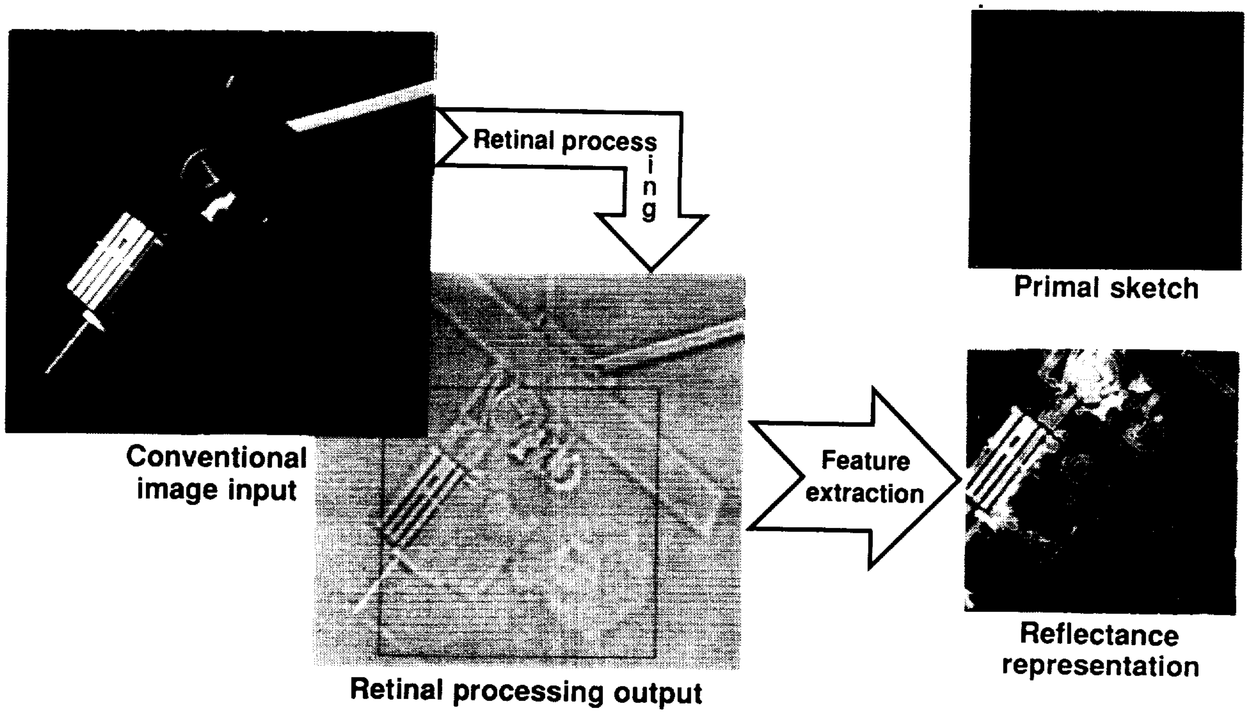

Figure 14. Feature extraction under conditions of extreme variations of light intensity, stretching from deep shadow to highly reflective surfaces in direct sunlight.

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HIGH RESOLUTION, HIGH FRAME RATE VIDEO TECHNOLOGY DEVELOPMENT PLAN AND THE NEAR-TERM SYSTEM CONCEPTUAL DESIGN

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BACKGROUND

The objective of the High Resolution, High Frame Rate Video Technology (HHVT) development effort is to provide technology advancements to remove constraints on the amount of high speed, detailed optical data recorded and transmitted for microgravity science and applications experiments. These advancements will enable the development of video systems capable of high resolution, high frame rate video data recording, processing, and transmission.

The HHVT users' requirements and near-term technology capabilities have been assessed through surveys conducted by NASA Lewis Research Center Space Experiments Division from December 1986 through December 1987. These preliminary surveys were designed to form a database to aid in defining the initial direction of the HHVT development effort. The detailed results of these surveys are presented elsewhere in this conference paper.

In summary, the users' requirements survey showed a very wide range of requirements for resolution, frame rates, and other parameters, many of which are well beyond the capability of today's technology and that of the foreseeable future. The technology survey showed that most of the available image sensors offer maximum pixel scan rates in the range of 5 to 15 Mpixels/sec/channel, while the fastest data storage medium (dynamic RAM) can record at 20 Mbyte/sec/8-bit channel. The largest data storage capacities can be achieved with magnetic tape or optical disk, but at the expense of data transfer rate. The large disparity that exists between the users' requirements and the near-term technology capability makes it obvious that for the foreseeable future, HHVT system performance will be driven by the technology capability rather than by the user's requirements.

Three techniques have been identified which will allow efficient use of the currently available technology

(A) Simultaneous multichannel image scan and parallel channel data transfer
(B) Video parameter tradeoff
(C) Use of dual recording media

(A) Simultaneous Multichannel Image Scan and Parallel Channel Data Transfer

The use of simultaneous multichannel image scan (Fig. 1) and parallel channel data transfer allows potentially very high pixel scan rates to be achieved compared to single channel scan (Fig. 2). This is true since the total pixel scan rate is directly proportional to the number of parallel channels. However, this approach has several disadvantages:

(1) Each channel requires a separate video amplifier and A/D converter

(2) The channels must be closely matched, that is, in sensitivity and gamma, to avoid striped shading in the displayed image

(3) Multiple coaxial cables or fiber optic paths are required to connect the camera to the central processing unit

(4) Circuit complexity is increased in proportion to the number of parallel channels

(5) Data word length is proportional to the number of parallel channels

In view of the advantages and disadvantages cited above, an eight channel parallel configuration appears to be a reasonable compromise between speed and front-end complexity. At 10 Mpixels/sec/channel, the resulting scan rate will be 80 Mpixels/sec.

(B) Video Parameter Tradeoff

More effective use of the 80-Mpixels/sec scan rate can be achieved by trading off video parameters. For example, resolution (pixels/frame) may be traded off to obtain a higher frame rate, as shown below:

$$\frac{80 \text{ Mpixels/sec}}{1024 \times 1024 \text{ pixels/frame}} = 76.29 \text{ frames/sec}$$

$$\frac{80 \text{ Mpixels/sec}}{64 \times 64 \text{ pixels/frame}} = 19\,531 \text{ frames/sec}$$

Similarly, gray scale (bits/pixel) may be traded off to reduce the data storage required per frame, or to increase the frame rate and/or pixels/frame when the system is not sensor pixel rate limited. The use of video parameter tradeoff allows higher resolution or higher frame rate to be achieved, but not both simultaneously.

When trading off resolution (pixels/frame) one of two approaches may be used to reduce the resolution. These are illustrated in Figure 3. The first (A) increases the pixel size, while maintaining a constant scanned area at the sensor target. The second approach (B) maintains constant pixel size, but scans a reduced area or a subframe. Subframing (see Fig. 4) is best implemented in an addressable pixel array and offers the following advantages:

(1) Pixel-per-frame usage is efficient since the size and shape of the subframe may be adjusted to cover only the area(s) of interest within the full image sensor field of view.

(2) In an addressable array, the spatial accuracy of the transmitted image is based on the relatively high full frame resolution of the sensor, not the subframe resolution.

(3) The pixel scan rate (pixels/sec) can be held constant while the system is operating at various subframe sizes and frame rates. This is advantageous for tube-type image pickup devices since the beam scanning

velocity and the resulting device readout sensitivity would be constant. Also, the required beam current would be constant.

(C) Dual Recording Media

The use of dual recording media (i.e., dynamic RAM together with a large capacity magnetic tape recorder) allows the achievement of both high data acquisition rate and large volume data storage. Here, video imagery can be captured in dynamic RAM at a very high rate and then transferred to magnetic tape at a lower rate. The process can be repeated until the mag tape is filled to capacity. The relatively small storage capacity of the dynamic RAM limits the amount of video that can be recorded per run.

TECHNOLOGY DEVELOPMENT PLAN

The approach for accomplishing the objective of the HHVT development effort has two parallel development thrusts consisting of a long range component/system technology development effort and a shorter range development effort focused on delivering a state-of-the-art system capability. The shorter range effort will take advantage of commercially available components/systems and the capabilities of those components/systems expected to emerge from the laboratory over the next few years. The LeRC ATD project schedule covering the HHVT activities through CY 1991 is shown in Figure 5.

(A) Short Range Development Effort

The objective of the HHVT short range development effort is to develop a prototype video system which will take maximum advantage of the limited near-term technology. This will be implemented as an HHVT system designed to enable the tradeoff of video parameters in a single, advanced, flexible, digital video system, so that full advantage can be taken of today's limited pixel scan rates, data transfer rates, and data storage capacity. The short range development effort will be divided into two phases.

For Phase I (based on 1988 technology), a laboratory demonstration breadboard system will be developed which can be upgraded as the technology advances. The breadboard system will be a monochrome, digital video system which will serve as the foundation upon which future HHVT technology can be developed. It will be used as a learning tool and will provide an opportunity to design, develop, and gain experience with the basic techniques and building blocks needed for an advanced HHVT video system.

The following capabilities will be developed and integrated into the breadboard system:

(1) Technology to record and reproduce high resolution, high frame rate video images in dynamic RAM (128 Mbyte) and 1/2-in. rotary head magnetic tape (4-Mbyte/sec, 5.2-Gbyte capacity)

(2) Technology to provide system flexibility (i.e., the ability to trade off frame rate, pixels per frame, and gray scale resolution)

(3) Subframing capability

(4) A high resolution pixel addressable camera. For Phase I, this will be implemented as a modified plumbicon tube camera with 1024 x 1024 pixels, and a 40 Mpixel/sec scan rate

(5) A universal digital video data acquisition, storage, and transmission format

(6) Ancillary experiment data and video system control information recorded with each frame

(7) Remote control of video system via digital commands

(8) Pretrigger on external event

The Phase II effort (based on 1989-1990 technology) will consist of upgrading the Phase I system as follows:

(1) Replacing the Phase I camera with a high resolution (1024 x 1024 pixel), 8 parallel channel, solid state, addressable pixel sensor and camera head

(2) Doubling the pixel scan rate to 80 Mpixels/sec

(3) Quadrupling the dynamic RAM capacity to 512 Mbytes

(4) Adding a magnetic tape recorder/reproducer built to MIL-STD-2179 (30-Mbyte/sec transfer rate, 99-Gbyte capacity)

(B) <u>Long Range Development Effort</u>

The long range development effort will provide the critical components needed to upgrade the near-term systems, and will provide technology advancements needed for future higher performance, advanced video systems. As presently planned, the long range advanced technology development effort will initially address the following:

(1) Design and development of a solid state, addressable pixel sensor and camera head for Phase II of the short range development effort and beyond. (This effort will start as soon as possible after the HHVT Workshop.)

(2) Design of a pixel addressable color (or multichannel spectrally selective) camera using three solid state sensors, each with interchangeable filters

(3) Fiber optics to link the camera head to the central processing unit

(4) Data compression (This effort is already underway.)

(5) Automatic subframe tracking, where the subframe automatically tracks a moving object within the field of view of the sensor.

PROPOSED NEAR-TERM SYSTEM

The hardware built as a result of the short range development effort Phases I and II are called "Phase I Near-Term System" and "Phase II Near-Term System respectively. A basic block diagram of a flight oriented HHVT video system with dual recording media and downlinking capability is shown in Figure 6. This represents the basic configuration of the proposed near-term HHVT systems.

(A) Phase I Near-Term System

Figure 7 shows the Phase I Near-Term System block diagram. This configuration will be implemented initially as the breadboard system. The video signal from the camera head is digitized and demultiplexed into eight digital channels, 8 bits each, with sync and ancillary data interleaved with the video. The composite data is then parallel transferred via the 64-bit high speed video data bus to the 128-Mbyte high speed RAM or the digital magnetic tape. Data transfers between runs are made from RAM to magnetic tape via the high speed data bus and the video data MUX.

The VME bus is used to transmit control commands to the subsystems, to transmit ancillary data to the high speed video interface for insertion into the video data stream, and to transfer low rate video from RAM or mag tape to the communications interface for downlinking. The video system can be remotely controlled via uplink commands or commands from the payload specialist console. The camera control commands are shown in Table 1. The ancillary data to be stored with each frame is shown in Table 2.

Plumbicon Camera

The breadboard system camera head uses a 1.5 in. electrostatic deflection plumbicon tube as the image sensor. The electrostatic plumbicon tube was selected for the breadboard system because it is readily available, has sufficient MTF (60%) at 1024 x 1024 pixels, can scan at 40 Mpixels/sec, and can be operated in a pixel addressable mode. An addressable solid state sensor with sufficient resolution and scanning speed is not presently available and would have to be developed.

The plumbicon camera head will be used as a development tool and is planned to be used only with the breadboard system to permit the development and checkout of the other HHVT system components. A separate solid state sensor/camera development effort will be started early so that a suitable solid state camera will be available for Phase II and ultimately a flight HHVT video system.

The plumbicon is also relatively immune to raster burn. This would normally be a problem with other pickup tubes when returning to full scan after operating in a subframe mode for an extended period of time.

It is proposed that the plumbicon camera optics consist of the following:

(1) Interchangeable Objective Lens (F mount 35-mm camera format)
(2) Removable 40 mm MCP gated intensifier (40 mm image diagonal) with a relay lens (1.43 image reduction ratio)

A digitally controlled pixel addressable electrostatic deflection system is shown in Figure 8. The subframe start and stop coordinates are loaded from the VME bus into the control registers. An external frame start trigger pulse initiates the scanning of each frame.

The horizontal sweep sawtooth waveform is obtained from a D/A converter which is driven by a binary counter. The counter is advanced one count on each pixel clock cycle. Retrace occurs when the count equals the binary number stored in the "horizontal stop address" control register. The horizontal starting position of each line is controlled by the binary number stored in the "horizontal start address" which is used to preset the counter. The vertical scan circuitry operates in a similar manner. The vertical binary counter is advanced one count during each horizontal retrace interval.

Video Image Acquisition Cycle

Figure 9 shows the video image acquisition cycle concept which is a unique design feature of the HHVT near-term system. One frame is scanned per acquisition cycle. Each cycle or frame is initiated by a trigger pulse from the frame rate pulse generator (see Fig. 7).

The frame rate pulse generator is essentially a programmable frequency divider clocked by the crystal controlled pixel clock. The frequency divider ratio, and hence the frame rate, is remotely controlled. The principal advantage of the triggered acquisition cycle approach is that the frame rate can be very precisely set to a wide range of convenient values such as a 100, 200, 500, 1000, 2000, 5000, etc. frames/sec. This is very desirable when the HHVT video system is used for motion analysis.

Pretrigger on External Event

The use of RAM as a video storage medium permits the video system to be operated in a standby recording mode where the "first in" video data stored in RAM is continuously overwritten with current video data. When the external trigger event occurs, the recording process is continued for a predetermined number of frames and then is stopped. Contained in RAM is a continuous sequence of video frames representing time before, during, and after the trigger event.

This mode of operation is useful when attempting to capture image sequences of unpredictable and sporadically occurring experimental phenomena. The images can be recorded without consuming enormous amounts of video data storage while waiting for the event to occur.

(B) Phase II Near-Term System

Figure 10 shows a block diagram of the Phase II near-term system. This is essentially the Phase I system upgraded with a new camera containing an eight channel custom 1024 × 1024 pixel solid state image sensor. The upgrade also includes more dynamic RAM and the MIL-STD-2179 mag tape recorder with its higher data transfer rate and larger storage capacity. The upgraded system has eight parallel video channels from the sensor all the way through to the 64-bit high speed data bus. The Phase II system scan rate will be at least 80 Mpixels/sec.

The proposed Phase II system physically will consist of four packages to house the components shown in Figure 10.

1. Camera head (dimensions to be determined)

2. Chassis (19 in. wide by 14 in. high by 25 in. deep)

3. VME bus chassis (19 in wide by 14 in. high by 25 in. deep) containing the following:

   A. VME BUS backplane
   B. System controller boards (CPU, RAM, ROM)
   C. Mag tape controller board
   D. Data acquisition and ancillary information encoder boards
   E. Communications interface board

4. MIL-STD-2179 mag tape recorder (16 in. wide by 17 in. high by 16 in. deep) with record/reproduce electronics

Figure 11 shows the pixel layout of the solid state image sensor with its eight parallel channels and the 8 × 8 pixel addressable blocks.

Theoretical Performance of the Phase I and II Near-Term Systems

Tables 3 to 6 show the theoretical performance of the Phase I and Phase II systems at various subframe sizes and gray scale levels when recording in dynamic RAM and magnetic tape. The resulting frame rates do not include the effects of the horizontal and vertical retrace blanking intervals. The actual frame rates will be somewhat lower. The increased frame rate and the increased total frame storage capacity which result when pixels per frame are traded off are readily apparent. Trading off gray scale increases the frame storage capacity. However, trading off gray scale will not increase the frame rate once the maximum sensor pixel scan rate is reached.

Figures 12 to 15 show how the Phase I and Phase II system performance compares to the users' requirements on a data acquisition rate basis and on a data storage capacity basis. The performance of each system (i.e., data acquisition rate in Mbyte/sec or data storage capacity in Mbytes or Gbytes) is represented by a diagonal line superimposed on the users' requirements. In general, the users' requirements represented by points below and to the left of the diagonal line can be met by that system. One byte/pixel is assumed for these comparisons.

Sync and Ancillary Data

When scanning and digitizing an image to generate video data, sync information must be periodically inserted in the data stream so that the image can be later reconstructed. For scientific video imagery it is also desirable to periodically insert other ancillary data. See Table 2.

The designer has the choice of inserting the sync and ancillary (S&A) data between each full video frame or placing the S&A data within the video frame where some of the pixel space is occupied by S&A data. There are two advantages to placing the S&A data within the frame.

1. Each frame together with its S&A data always occupies memory in blocks where the number of bits per block is an integral power of two. Such data blocks stack up neatly in disk and tape data storage. For example, a 256 × 256 pixel frame at 4 bits/pixel with S&A data within the video frame occupies 32 768 bytes or exactly 64 disk sectors at 512 bytes/sector. If the 512 S&A data bits are inserted between frames, each frame with S&A data occupies a total of 32 832 bytes or 64.125 disk sectors.

2. With S&A data within the frame, the sync data can be further divided into frame sync and line sync. The use of line sync results in faster initial synchronization and faster resynchronization in the event of momentary transmission loss or sync data errors.

It is recommended that the near-term HHVT systems be designed to place the S&A data within each frame as shown in Figure 16. Each frame starts with a 16 bit frame sync word, followed by a 16 bit line sync word occurring at the beginning of each group of eight lines. The ancillary data (384 bits total) consists of eight groups of 48 bits interleaved among the first eight sync words (one frame sync plus seven line sync words). The frame sync word is shown shaded.

The picture information lost due to the S&A data contained within a 64 × 64 × 1 frame (64 × 64 pixels, 1 bit/pixel) is illustrated in Figure 16. In this frame the S&A data occupies 512 bits. Figure 17 shows the lost picture information in a 128 × 128 × 1 frame. Note that when the pixels per frame is quadrupled the lost picture area is effectively cut in half. As the bits/pixel is increased, the number of lost pixels will proportionately decrease. The vertical column at the left containing the S&A data is blanked off on the displayed image. For the 128 × 128 × 1 frame the actual displayed picture area is 120 × 128 pixels.

In playing back a sequence of frames, it is envisioned that once the composite video data is received and stored on disk or magnetic tape, the display processing software will look for three or more consecutive line sync words by means of a repetitive sync window. The line sync words are interleaved with the video data at a known spacing or repetitive pattern where the spacing depends on the specific pixels/frame and bits/pixel. Once the software locks onto the line sync repetition pattern, it will step through the line sync words and eventually find the next frame sync word. In essence, the line sync leads the system to find the frame sync. Once the frame sync word is found, synchronization has been achieved.

It is necessary that the system look for a repetitive sync pattern before attempting to synchronize, since the sync words are not unique from the video data. It is possible from time to time to have consecutive pixels form the same 16 bit word as the line or frame sync word. Looking through a sync window for a repetitive sync pattern and locking onto the pattern makes the system immune to these spurious sync words.

Video Data Format

Figure 18 is a graphic representation of the high speed video RAM. Shown on the left are the 64 parallel data bits from the high speed video data bus.

These are divided into eight video channels at eight bits per channel. The data is sequentially clocked into RAM in 64 bit parallel words starting at address 0000000.

Figure 19 shows how the video, sync, and ancillary data will appear in RAM for the Phase II system. With the data organized in this way, the S&A data will occupy the left edge of the video frame as shown in Figures 16 and 17. In Figure 19, the first 64-bit word (address 0000000) contains the frame sync (16 bits) and 48 bits of ancillary data. The next seven 64-bit words contain the first eight lines of video data. Next is the first line sync (16 bits) and 48 more bits of ancillary data, followed by seven 64-bit words of video for lines 9 through 16, and so on.

This is a flexible format that can accommodate various pixels/frame (needed for subframing) and various gray scale resolutions (bits/pixel). Increasing either simply increases the amount of video data placed between the 64-bit S&A words. In Figure 19 the spacing between the S&A words will increase, as will the total number of 64-bit video data words required per frame.

The memory allocation for each of the eight parallel channels as a function of bits/pixel is shown graphically at the bottom of Figure 19. Each of the four blocks represents the first line (64 pixels) of the raster shown in Figure 16. The first eight bits (shown shaded) of each block are part of the 16-bit frame sync word. Note that the pixels are numbered in Figures 16 and 19.

Figure 20 shows graphically the data organization in RAM for the Phase I system. This organization is different from the Phase II system data organization since the plumbicon is a single channel device. This organization is required so that the S&A data will occupy the left edge of the video frame as shown in Figures 15 and 16.

The plumbicon's single video output, unlike the eight channel solid state sensor, is demultiplexed sequentially to the eight digital channels. The result is that each scan line is distributed among the eight channels. The S&A data is now all contained in channel 1.

The memory allocation as a function of bits/pixel is shown to the right of Figure 20. Again, each of the four blocks represents the first line (64 pixels) of the raster shown in Figure 16.

SUMMARY

The objective of the High Resolution, High Frame Rate Video Technology (HHVT) development effort is to provide technology advancements to remove constraints on the amount of high speed, detailed optical data recorded and transmitted for microgravity science and applications experiments. These advancements will enable the development of video systems capable of high resolution, high frame rate video data recording, processing, and transmission.

The results of the initial surveys show a large disparity between the microgravity science and applications video users' requirements and the near-term technology capability. The initial objective of the HHVT development effort is to develop techniques to allow the most efficient use of the limited capability of the current and near-term technology so that we may begin to close the gap between the users' requirements and the technology capability. Techniques such as multichannel image scan, video parameter tradeoff, and the use of dual recording media have been identified as methods of making the most efficient use of the near-term technology.

A technology development plan has been formulated which has two parallel development thrusts consisting of a long range component/system technology development effort and a shorter range effort that will take advantage of commercially available components expected to be available in the near future. The short range effort will focus on developing the techniques mentioned above to make the most efficient use of the near-term technology. Emphasis will be on system flexibility, that is, the ability to trade off resolution, frame rate, and gray scale in one system so that today's limited pixel scan rates and data transfer rates can be used to full advantage. A video data format designed to accommodate the system flexibility is discussed.

The short range effort will be divided into two phases. Phase I will be the development of a laboratory demonstration breadboard system which can be upgraded as the technology advances and will serve as the foundation upon which future HHVT technology can be developed. As currently planned, the Phase I system will incorporate a pixel addressable plumbicon tube camera.

Phase II will consist of upgrading the Phase I system with a custom pixel addressable multichannel parallel scan solid state camera and other improvements.

The long range effort will provide the critical components needed to upgrade the near-term systems and will provide the technology advancements needed for future higher performance, advanced video systems.

Table 1

CAMERA CONTROL COMMANDS

COMMAND		BITS REQUIRED
SCAN START ADDRESS:	(X)	7
	(Y)	7
SCAN STOP ADDRESS:	(X)	7
	(Y)	7
PEDESTAL LEVEL:		8
VIDEO GAIN:		8
INTENSIFIER GATE TIME:		12
SENSOR INTEGRATION TIME:		12
IRIS OPEN (RATE 1,2,3):		2
IRIS CLOSE (RATE 1,2,3):		2
FOCUS IN (RATE 1,2,3):		2
FOCUS OUT (RATE 1,2,3):		2
ZOOM IN (RATE 1,2,3):		2
ZOOM OUT (RATE 1,2,3):		2
	TOTAL BITS REQUIRED:	80
	TOTAL BITS PLANNED:	128 (16 BYTES)

Table 2

ANCILLARY INFORMATION STORED WITH EACH FRAME

PARAMETER			BITS REQUIRED
CAMERA NO:	(1 THROUGH 8)		3 (BINARY)
FRAME NO:	(0 TO 1,048,576)		20 (BINARY)
TIME:	DAY	XXX	9 (BCD)
	HR.	XX	7 (BCD)
	MIN	XX	7 (BCD)
	SEC	XX.XXXX	27 (BCD)
FRAME RATE:		X.XXEXX	35 (ASCII)
SUBFRAME ORIGIN:	(X)		7 (BINARY)
	(Y)		7 (BINARY)
SUBFRAME DIMENSIONS:	(X)		7 (BINARY)
	(Y)		7 (BINARY)
GRAY SCALE RESOLUTION (BITS/PIXEL):			3 (BINARY)
16 EVENT MARKERS:			16
EXPERIMENT DATA (BCD, BINARY, OR ASCII):			64
		TOTAL BITS REQUIRED:	219
		TOTAL BITS AVAILABLE:	384 (48 BYTES)

Table 3

Theoretical Performance
Phase I Near-Term HHVT Video System
Mode: Burst Record (RAM)

Image Sensor: 1.75 in. Plumbicon Tube
Sensor Pixel Rate: 40 Mpixel/sec
Storage Medium: Dynamic RAM
Max Data Transfer Rate: 40 Mbyte/sec
Storage Capacity: 128 Mbyte
Total Recording Time: 3.2 sec
Reference Note: 100 ft 16 mm Film contains 4000 frames

Subframe Pixels		Gray Scale Levels 256	16	4	2
1024 X 1024	**	38.1	38.1	38.1	38.1
	*	(1.22E2)	(2.44E2)	(4.88E2)	(9.77E2)
512 X 512		152.6	152.6	152.6	152.6
		(4.88E2)	(9.77E2)	(1.95E3)	(3.91E3))
256 x 256		610.3	610.3	610.3	610.3
		(1.95E3)	(3.91E3)	(7.81E3)	(1.56E4)
128 X 128		2441.4	2441.4	2441.4	2441.4
		(7.81E3)	(1.56E4)	(3.12E4)	(6.25E4)
64 X 64		9765.6	9765.6	9765.6	9765.6
		(3.12E4)	(6.25E4)	(1.25E5)	(2.50E5)

** Frames/sec
* Total Stored Frames

Table 4

Theoretical Performance
Phase I Near-Term HHVT Video System
Mode: Continuous Tape Record

Image Sensor: 1.75 in. Plumbicon Tube
Sensor Pixel Rate: 40 Mpixel/sec
Storage Medium: 1/2 in. Magnetic Tape
Max Data Transfer Rate: 4.0 Mbyte/sec
Storage Capacity: 5.2 Gbyte
Total Recording Time: 21.6 min
Reference Note: 100 ft 16 mm Film contains 4000 frames

Subframe Pixels		Gray Scale Levels 256	16	4	2
1024 X 1024	**	3.8	7.6	15.3	30.5
	*	(4.96E3)	(9.92E3)	(1.98E4)	(3.97E4)
512 X 512		15.3	30.5	61.0	122.1
		(1.98E4)	(3.97E4)	(7.93E4)	(1.59E5)
256 X 256		61.0	122.1	244.1	488.3
		(7.93E4)	(1.59E5)	(3.17E5)	(6.35E5)
128 X 128		244.0	488.3	976.6	1953.1
		(3.17E5)	(6.35E5)	(1.27E6)	(2.54E6)
64 X 64		976.0	1953.1	3906.0	7812.5
		(1.27E6)	(2.54E6)	(5.08E6)	(1.02E7)

** Frames/sec
* Total Stored Frames

Table 5

Theoretical Performance
Phase II Near-Term HHVT Video System
Mode: Burst Record (RAM)

Image Sensor: 1024 × 1024 Pixel Array
Sensor Pixel Rate: 80 Mpixel/sec
Storage Medium: Dynamic RAM
Max Data Transfer Rate: 80 Mbyte/sec
Storage Capacity: 512 Mbyte
Total Recording Time: 6.4 sec
Reference Note: 100 ft 16 mm Film contains 4000 frames

Subframe Pixels		Gray Scale Levels 256	16	4	2
1024 X 1024	**	76	76	76	76
	*	(4.88E2)	(9.76E2)	(1.95E3)	(3.91E3)
512 X 512		305	305	305	305
		(1.95E3)	(3.91E3)	(7.81E3)	(1.56E4)
256 X 256		1220	1220	1220	1220
		(7.81E3)	(1.56E4)	(3.12E4)	(6.25E4)
128 X 128		4882	4882	4882	4882
		(3.12E4)	(6.25E4)	(1.25E5)	(2.50E5)
64 X 64		19531	19531	19531	19531
		(1.25E5)	(2.50E5)	(5.00E5)	(1.00E6)

** Frames/sec
* Total Stored Frames

Table 6

Theoretical Performance
Phase II Near-Term HHVT Video System
Mode: Continuous Tape Record

Image Sensor: 1024 × 1024 Pixel CID Array
Sensor Pixel Rate: 80 Mpixel/sec
Storage Medium: MIL2179AS Magnetic Tape
Max Data Transfer Rate: 30 Mbyte/sec
Storage Capacity: 99 Gbyte
Total Recording Time: 55 min
Reference Note: 100 ft 16 mm Film contains 4000 frames

Subframe Pixels		Gray Scale Levels 256	16	4	2
1024 X 1024	**	28	56	56	56
	*	(9.44E4)	(1.89E5)	(3.78E5)	(7.55E5)
512 X 512		114	228	228	228
		(3.78E5)	(7.55E5)	(1.51E6)	(3.02E6)
256 X 256		457	914	914	914
		(1.51E6)	(3.02E6)	(6.04E6)	(1.21E7)
128 X 128		1831	3662	3662	3662
		(6.04E6)	(1.21E7)	(2.42E7)	(4.83E7)
64 X 64		7324	14648	14648	14648
		(2.42E7)	(4.83E7)	(9.67E7)	(1.93E8)

** Frames/sec
* Total Stored Frames

Figure 1

Multi Channel Parallel Scan
(8 Parallel Channels)

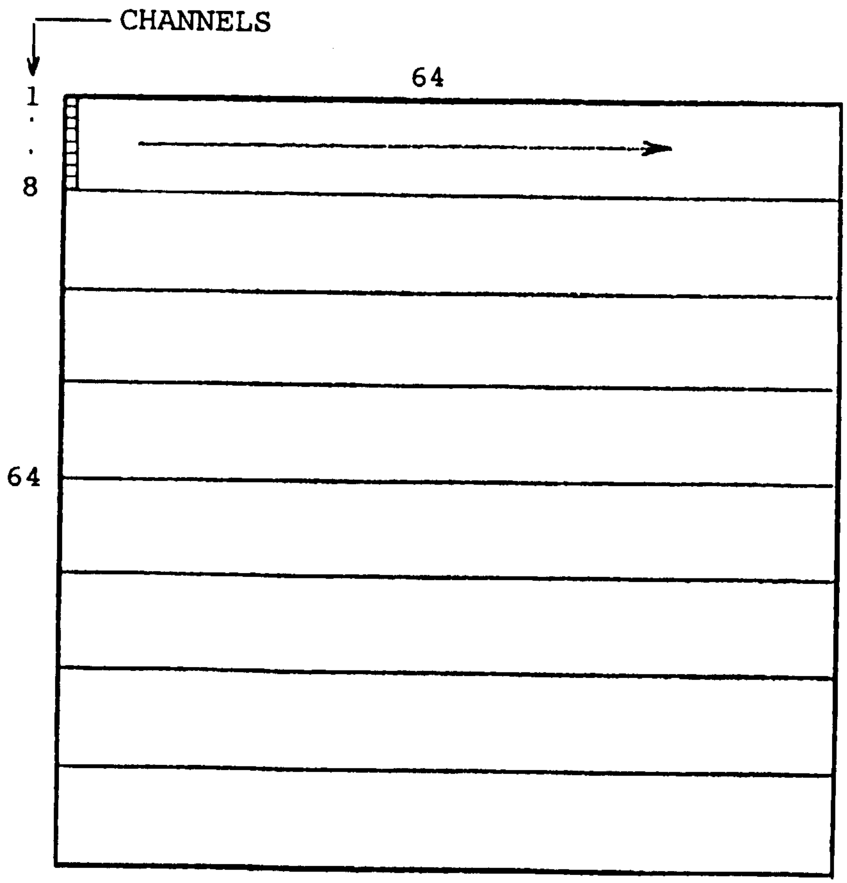


Figure 2

Single Channel Progressive Scan

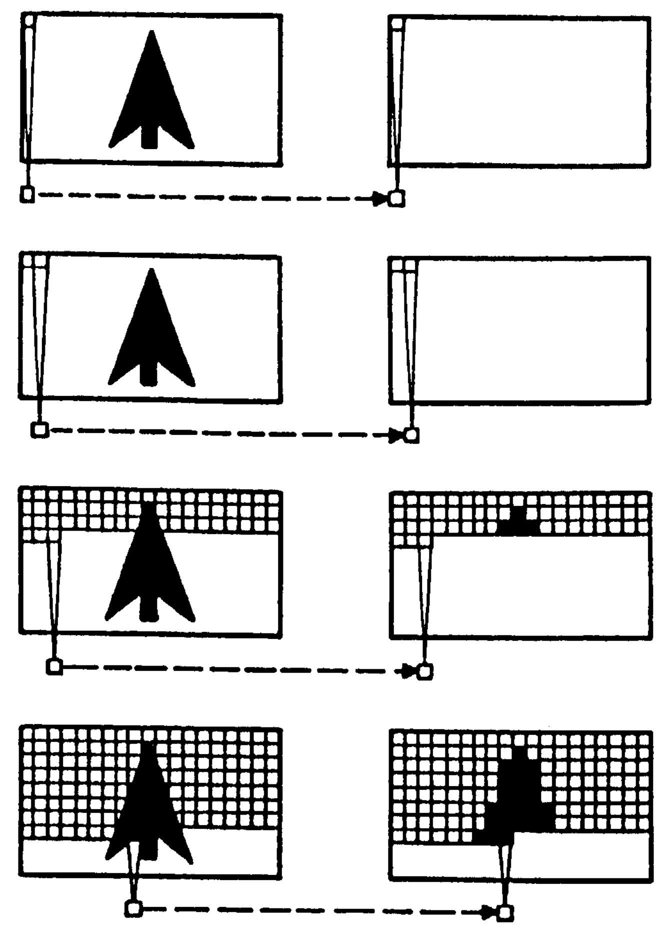


Figure 3

Resolution Reduction Methods

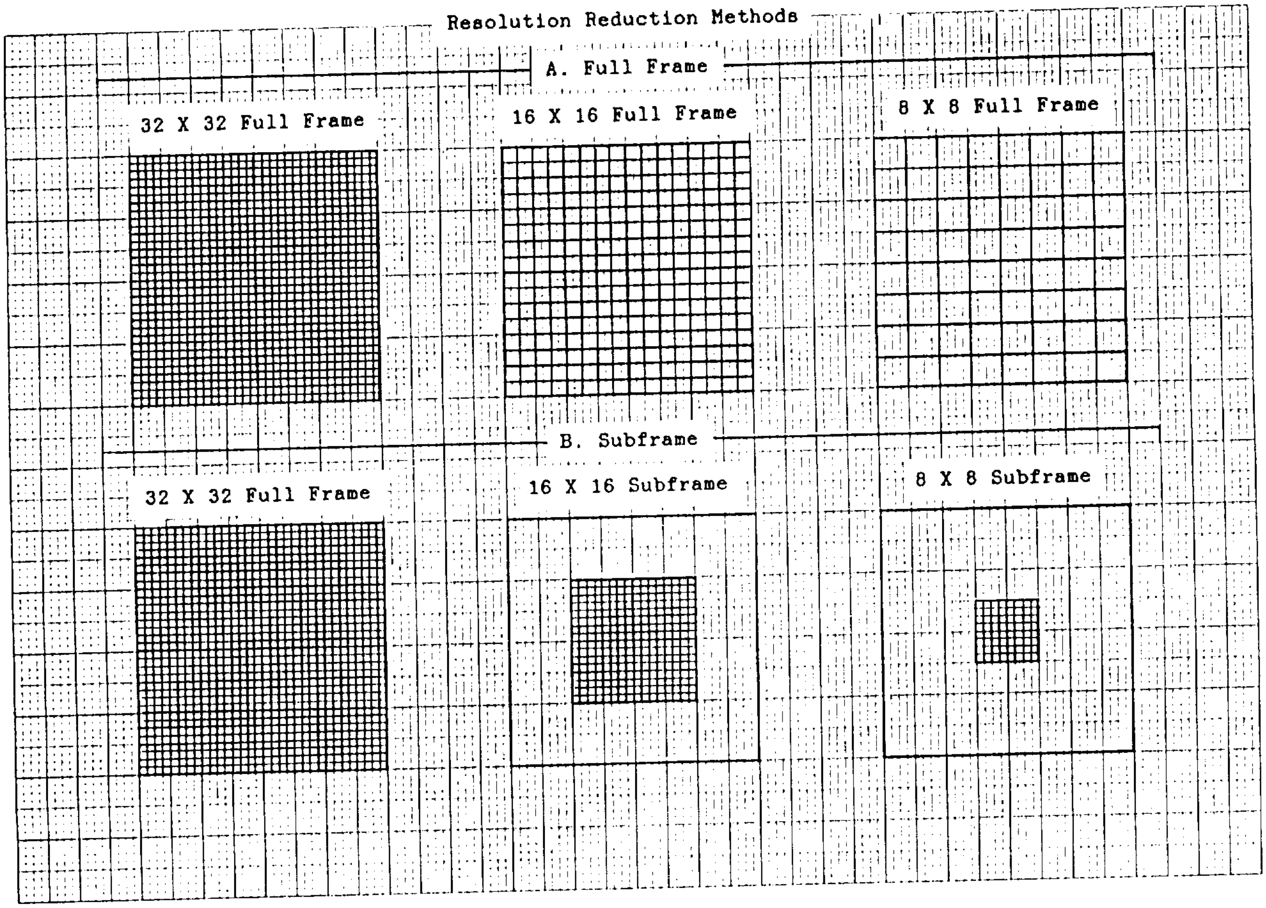
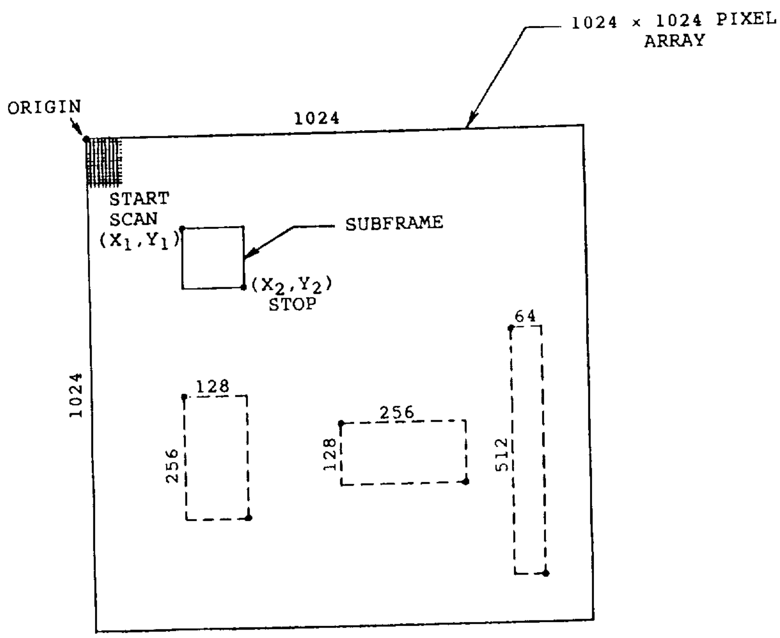


Figure 4

Subframe Examples



NOTE: SUBFRAME COORDINATES ON 128 × 128 GRID.

Figure 5

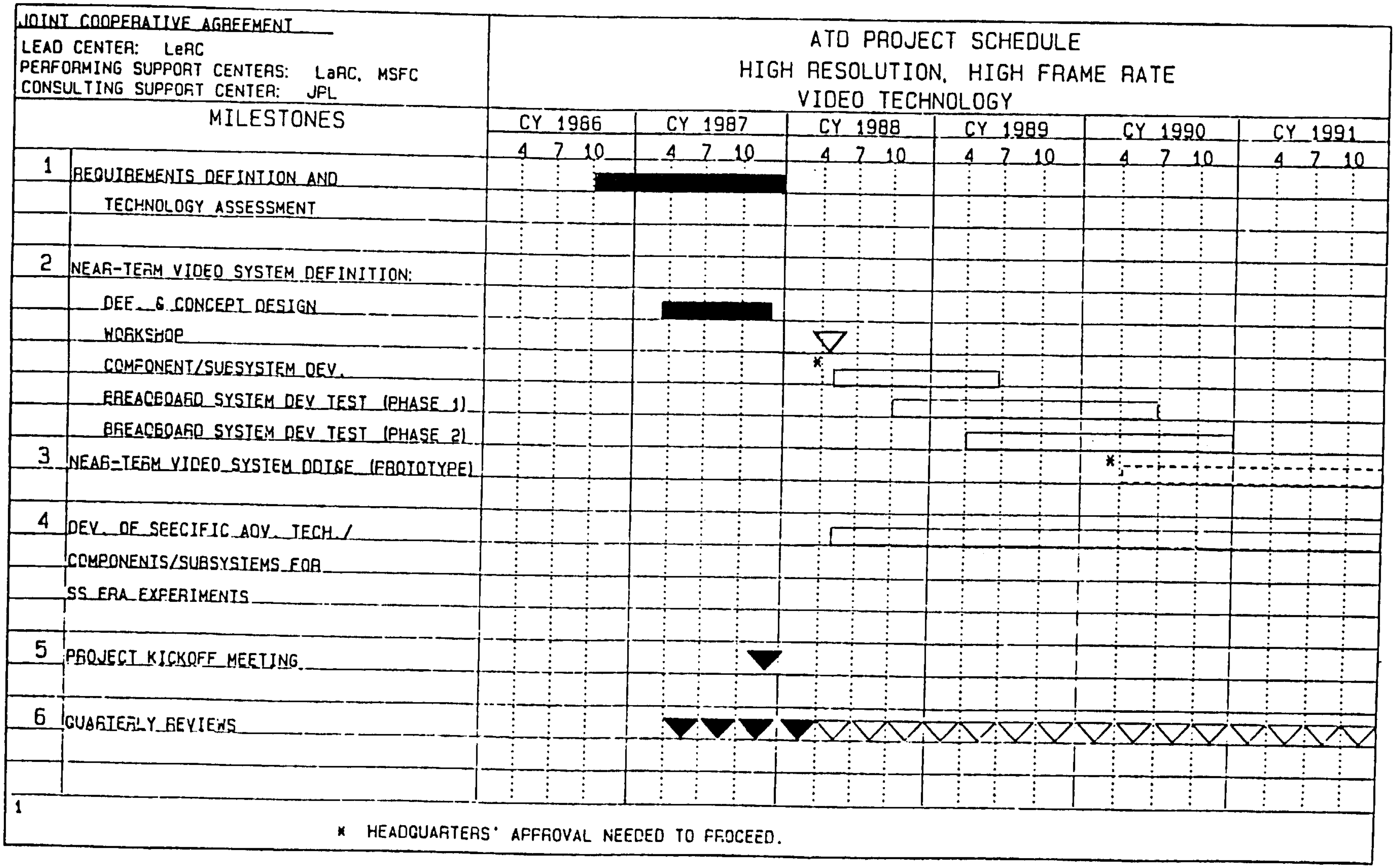

JOINT COOPERATIVE AGREEMENT
LEAD CENTER: LeRC
PERFORMING SUPPORT CENTERS: LaRC, MSFC
CONSULTING SUPPORT CENTER: JPL
ATD PROJECT SCHEDULE
HIGH RESOLUTION, HIGH FRAME RATE
VIDEO TECHNOLOGY
MILESTONES
CY 1986
CY 1987
CY 1988
CY 1989
CY 1990
CY 1991
4 7 10
1 REQUIREMENTS DEFINTION AND
TECHNOLOGY ASSESSMENT
2 NEAR-TERM VIDEO SYSTEM DEFINITION:
DEF. & CONCEPT DESIGN
WORKSHOP
COMPONENT/SUBSYSTEM DEV.
BREADBOARD SYSTEM DEV TEST (PHASE 1)
BREADBOARD SYSTEM DEV TEST (PHASE 2)
3 NEAR-TERM VIDEO SYSTEM DDT&E (PROTOTYPE)
4 DEV. OF SPECIFIC ADV. TECH./
COMPONENTS/SUBSYSTEMS FOR
SS ERA EXPERIMENTS
5 PROJECT KICKOFF MEETING
6 QUARTERLY REVIEWS
1
* HEADQUARTERS' APPROVAL NEEDED TO PROCEED.

Figure 6

HHVT Video System

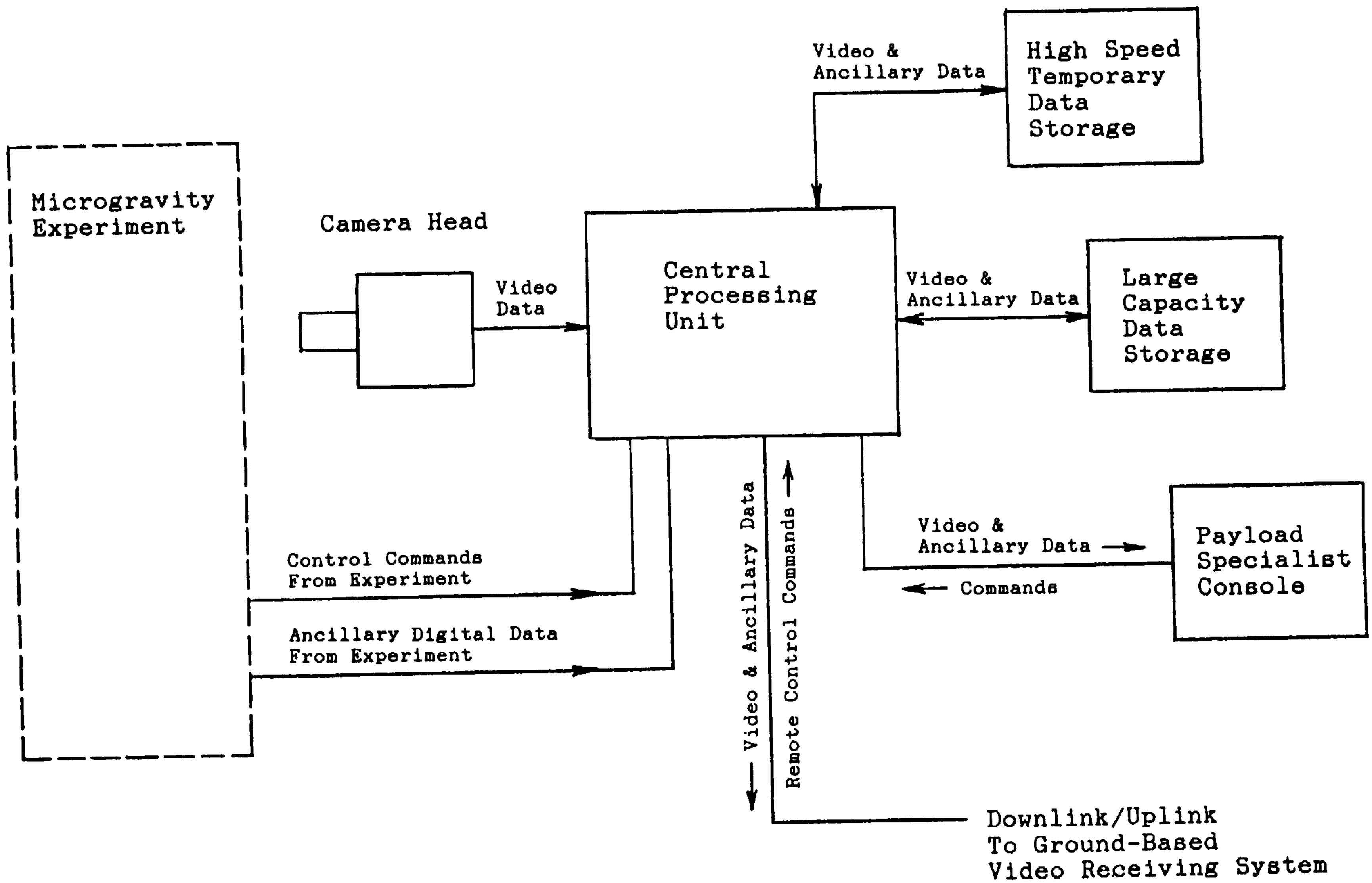
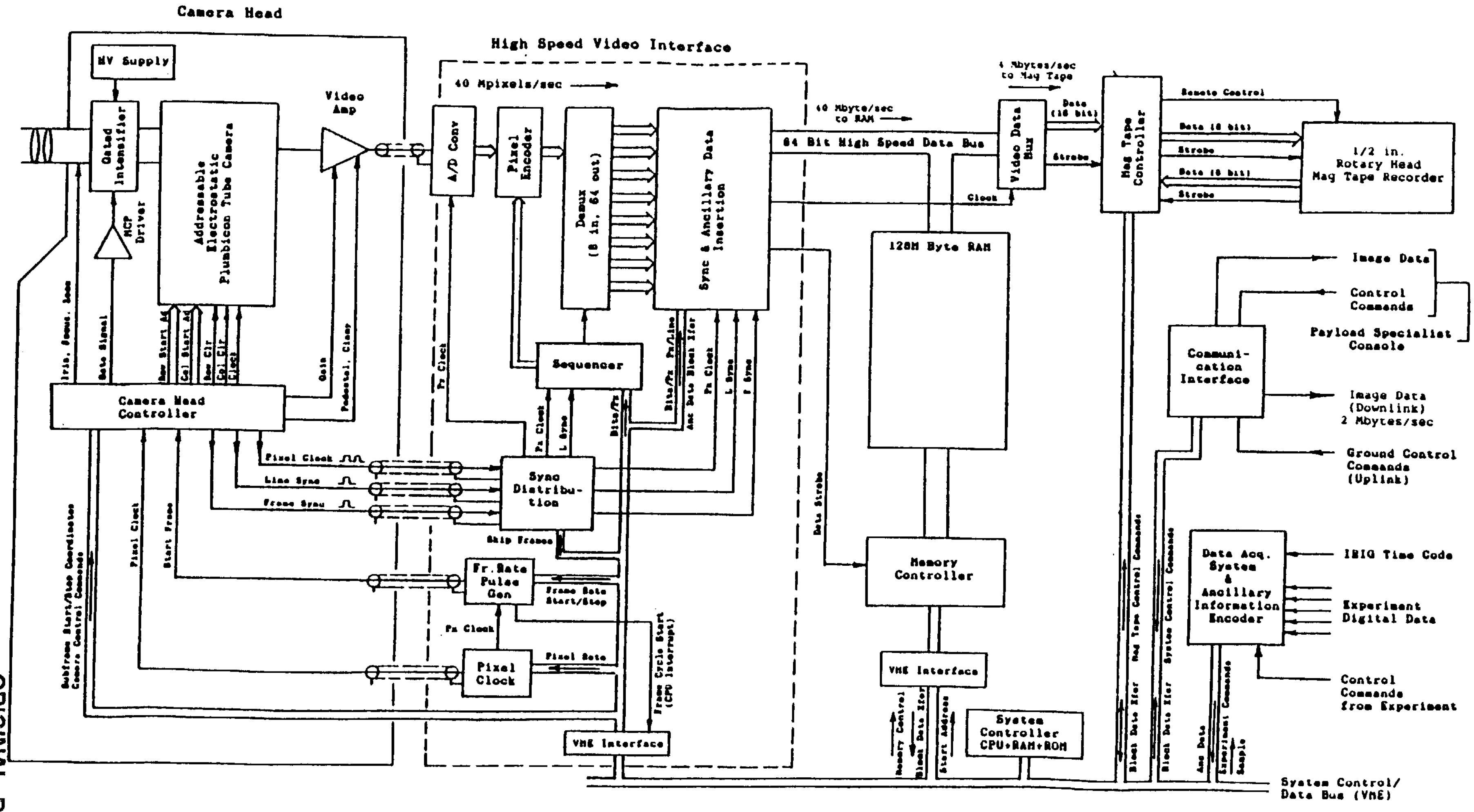


Figure 7

Phase I Near-Term HHVT Video System
(Flight System Block Diagram)

R. Ziemke
6/4/88



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OF POOR QUALITY

Figure 8

Pixel Addressable Deflection Concept for Electrostatic Plumbicon Camera (8 X 8 Pixel Blocks)

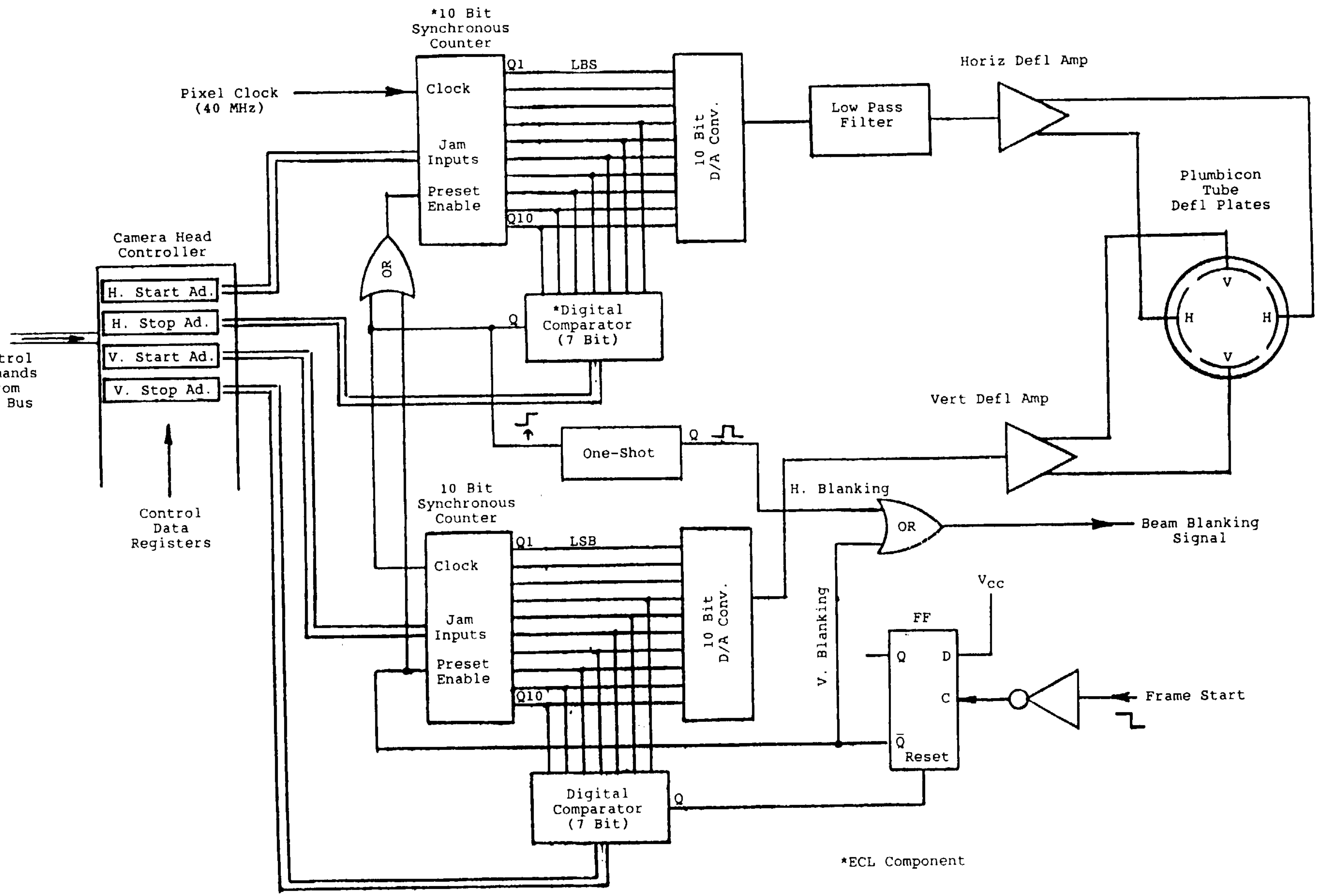

Figure 9

Video Image Acquisition Cycle

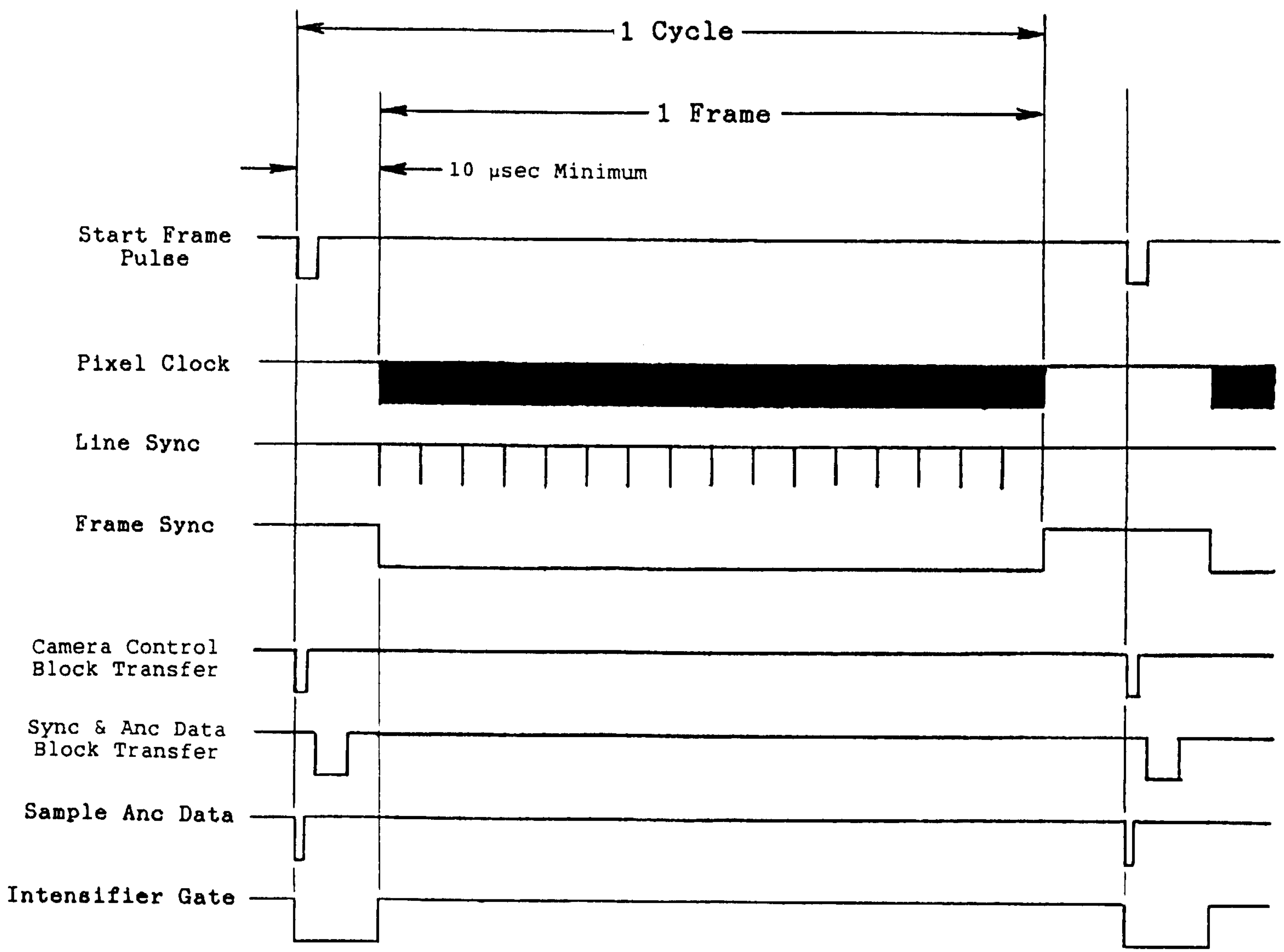

Figure 10

Phase II Near-Term HHVT Video System
(Flight System Block Diagram)

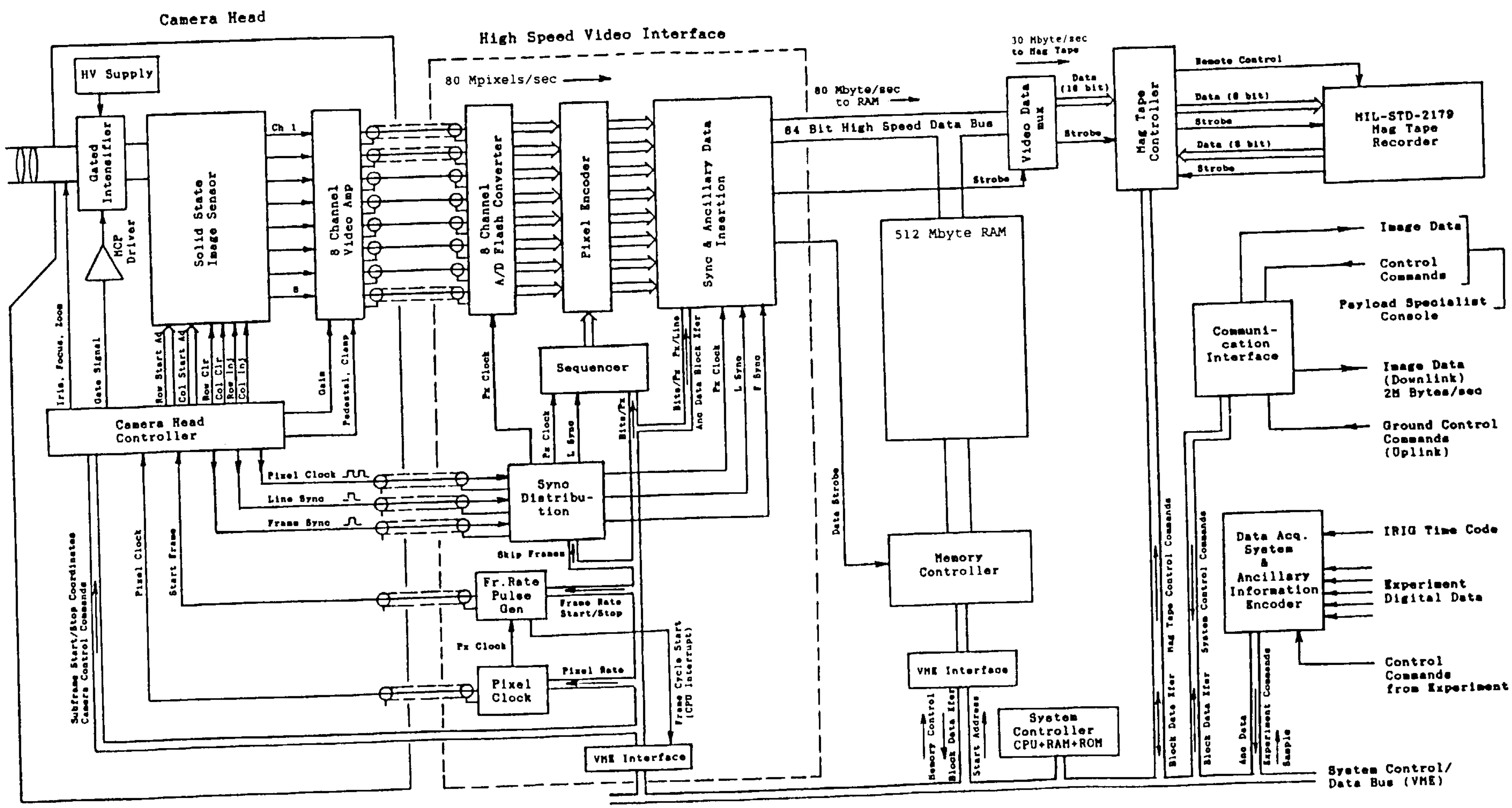

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Figure 11

1024 × 1024 Addressable Solid State Image Sensor
(Phase II Near-Term System)
8 × 8 Pixel Addressable Blocks

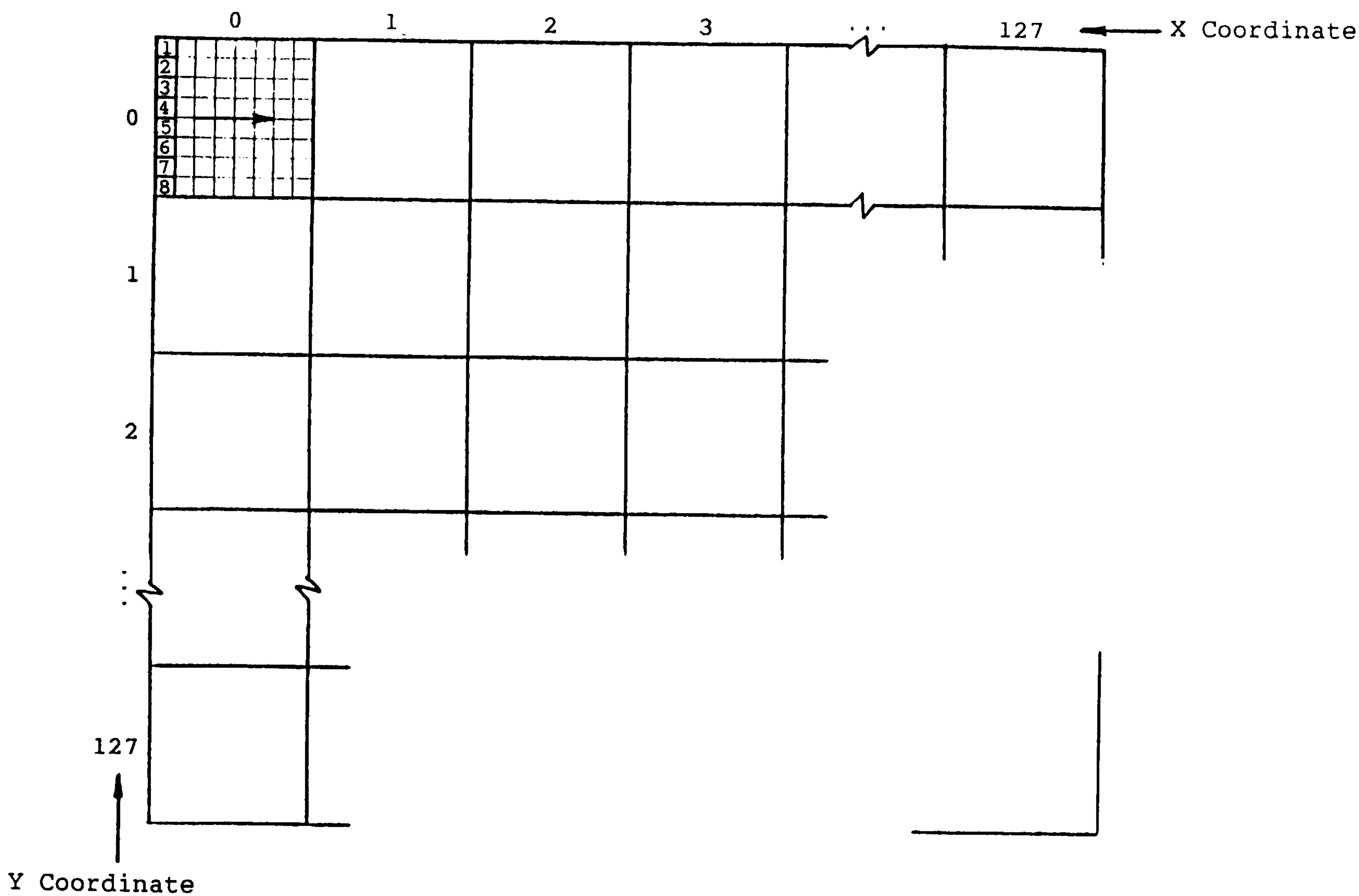
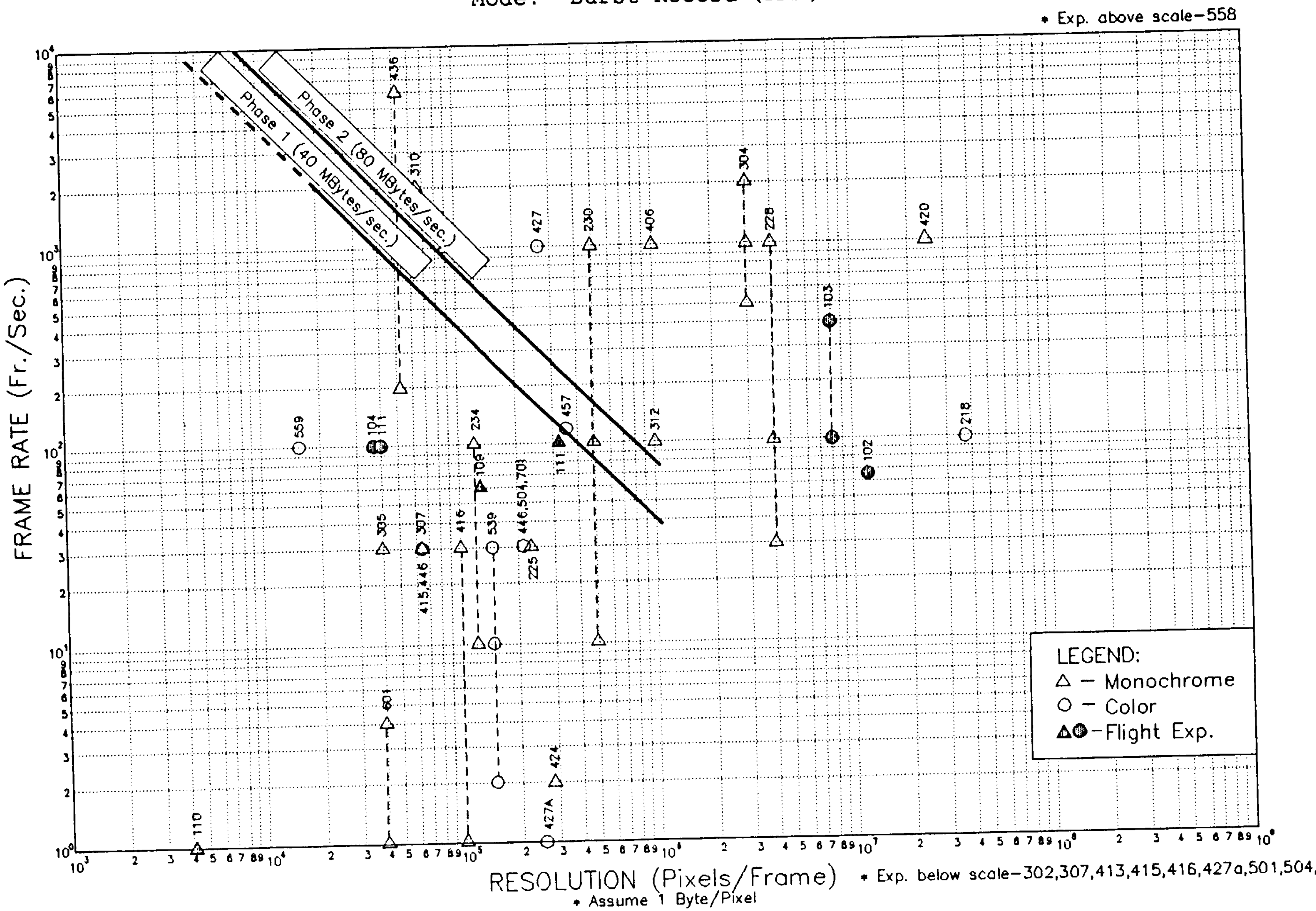


Figure 12

Near-Term System Performance
Data Acquisition Rate vs User Requirements
Mode: Burst Record (RAM)



<u>Figure 13</u>

Near-Term System Performance
Data Acquisition Rate vs User Requirements
Mode: Continuous Tape Record

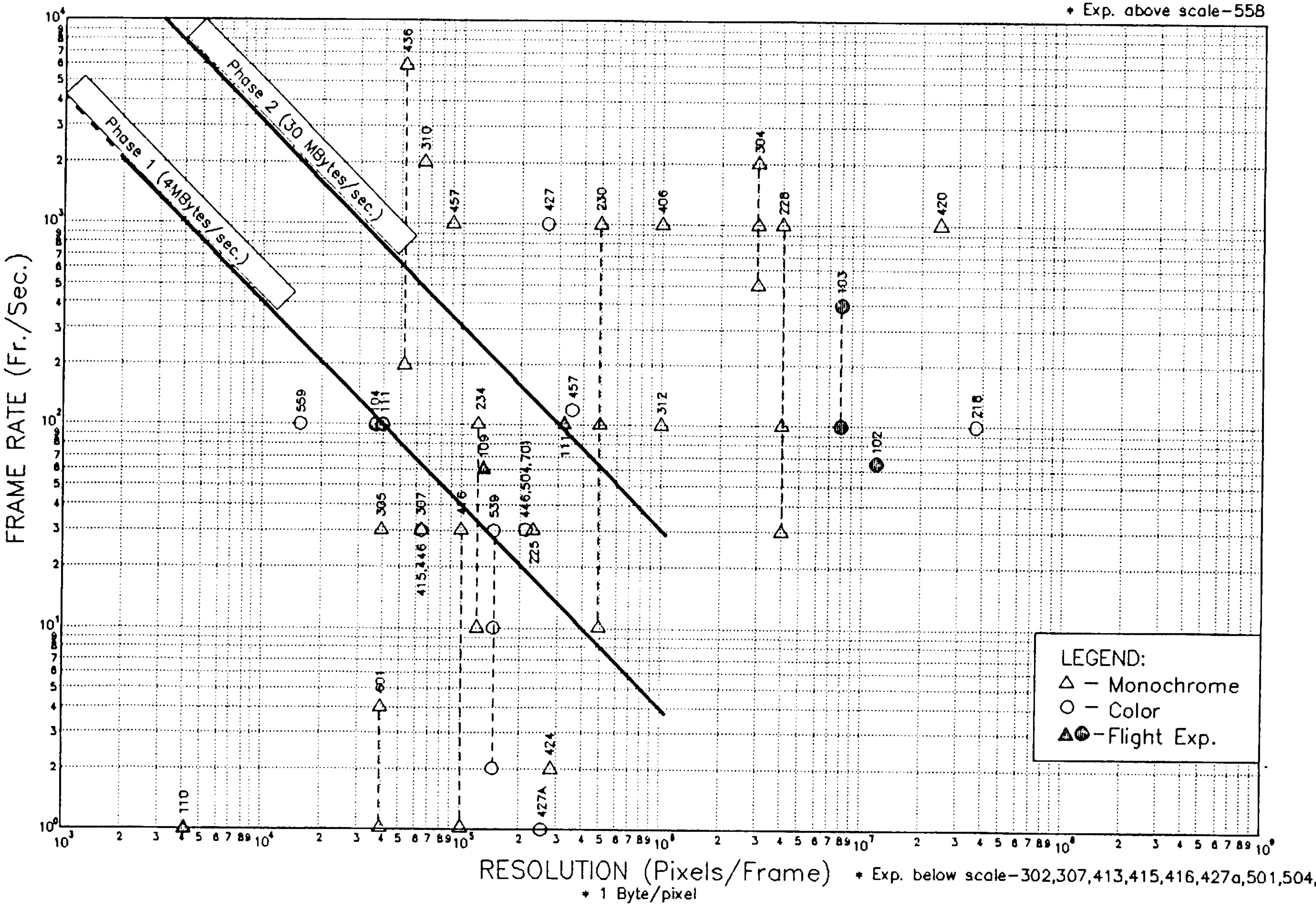


Figure 14

**Near-Term System Performance
Data Storage Capacity vs User Requirements
Mode: Burst Record (RAM)**

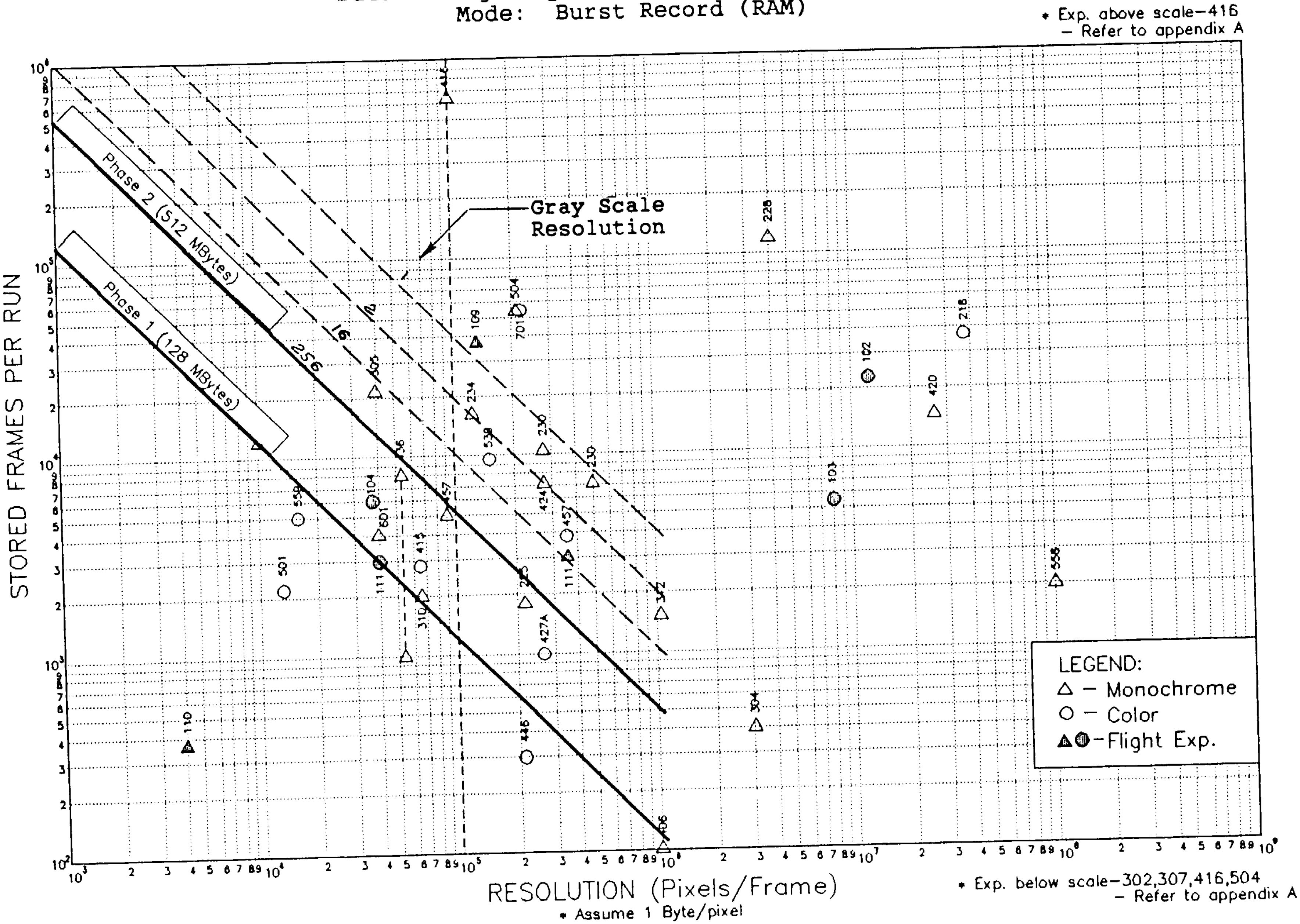


Figure 15

Near-Term System Performance
Data Storage Capacity vs User Requirements
Mode: Continuous Tape Record

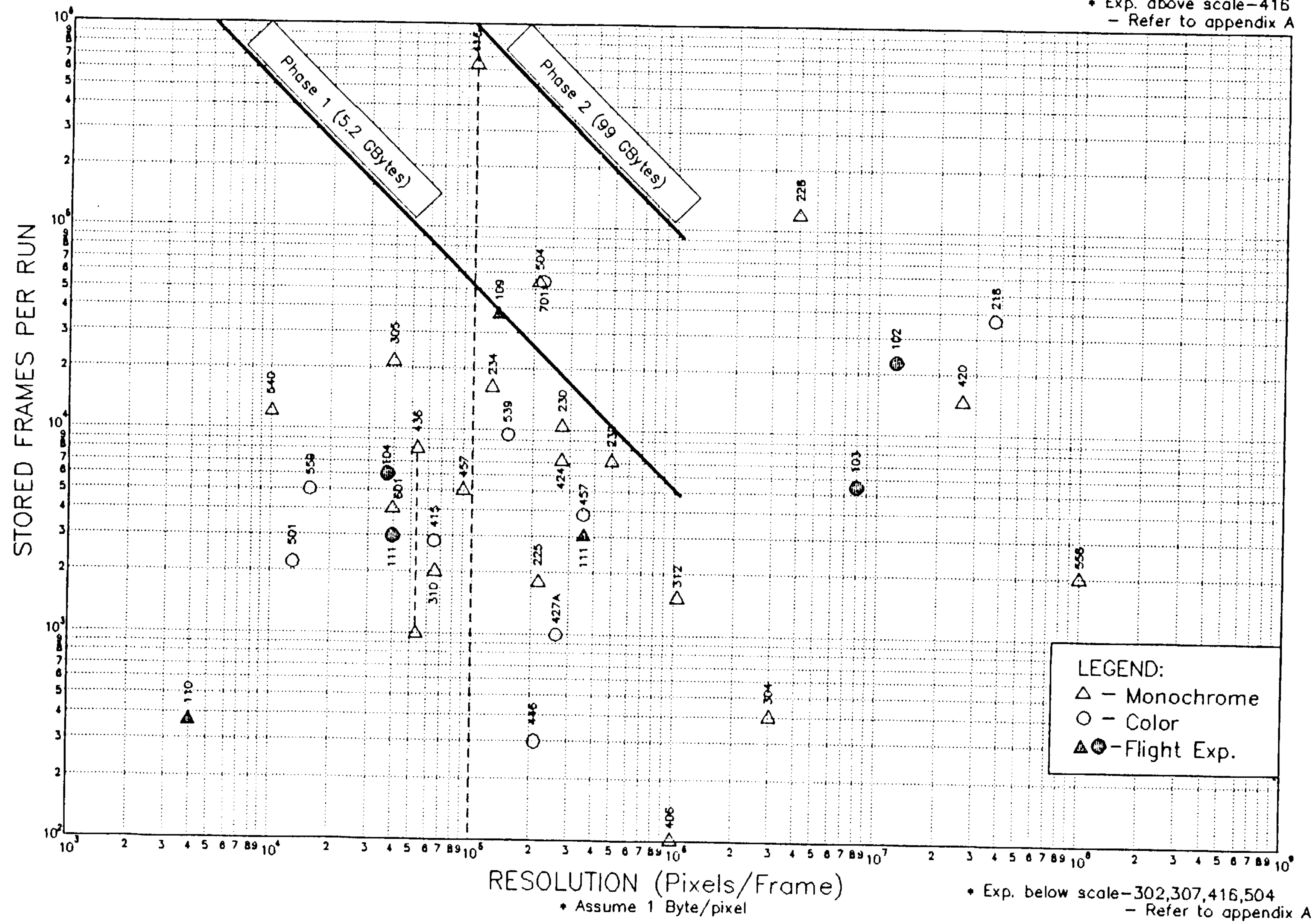


Figure 16

Image Area Occupied by Sync
and Ancillary Data

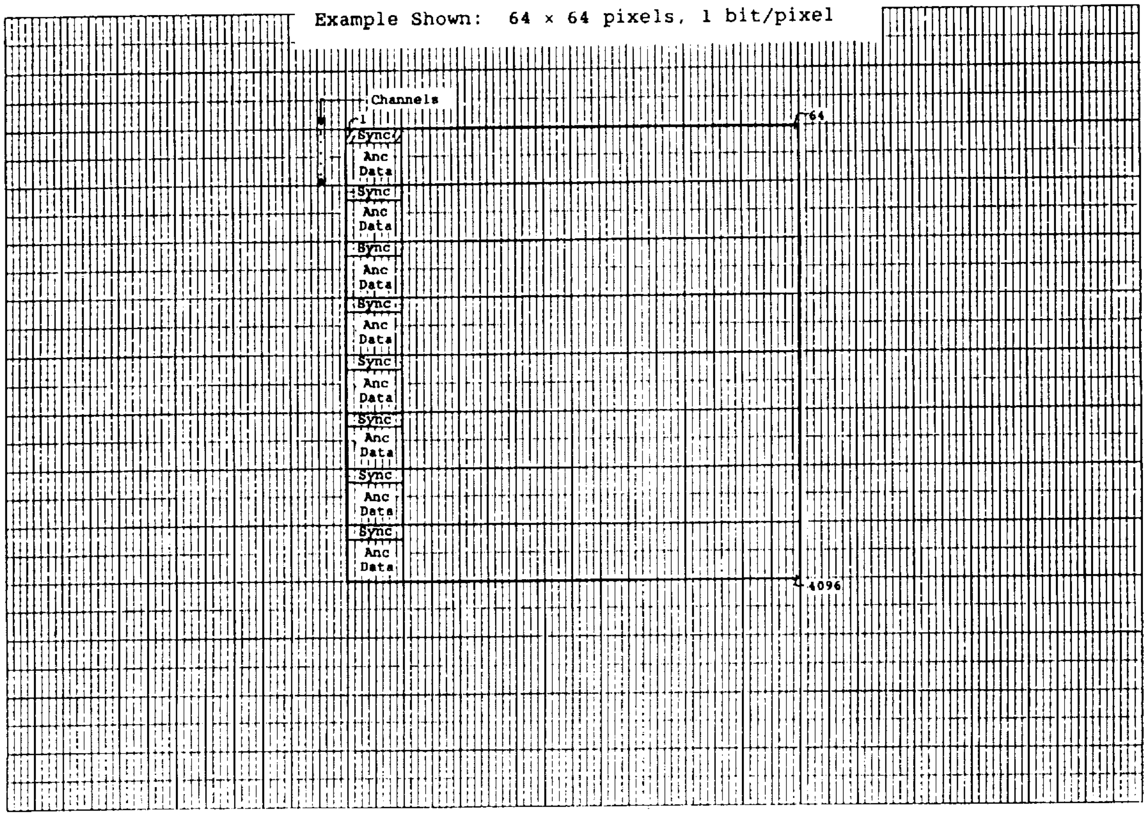


Figure 17

Image Area Occupied by Sync
and Ancillary Data

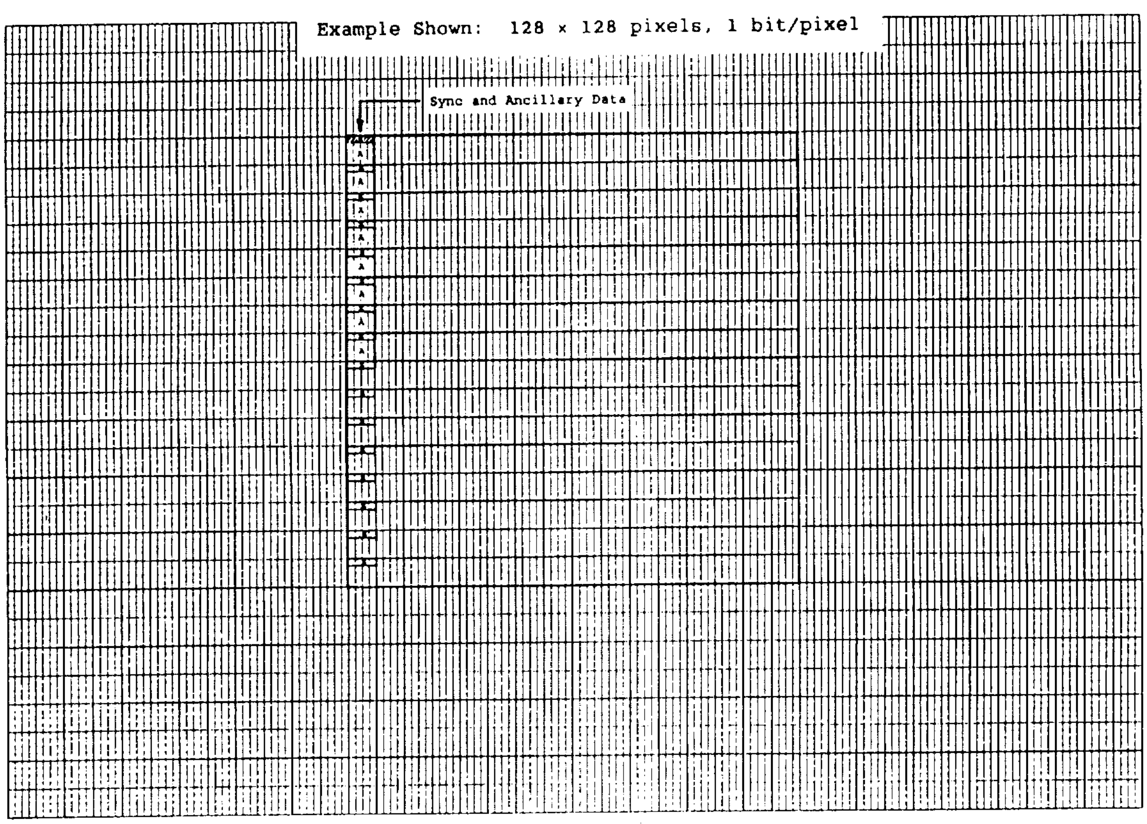


Figure 18

Dynamic RAM Configuration
(Near-Term Phase II)

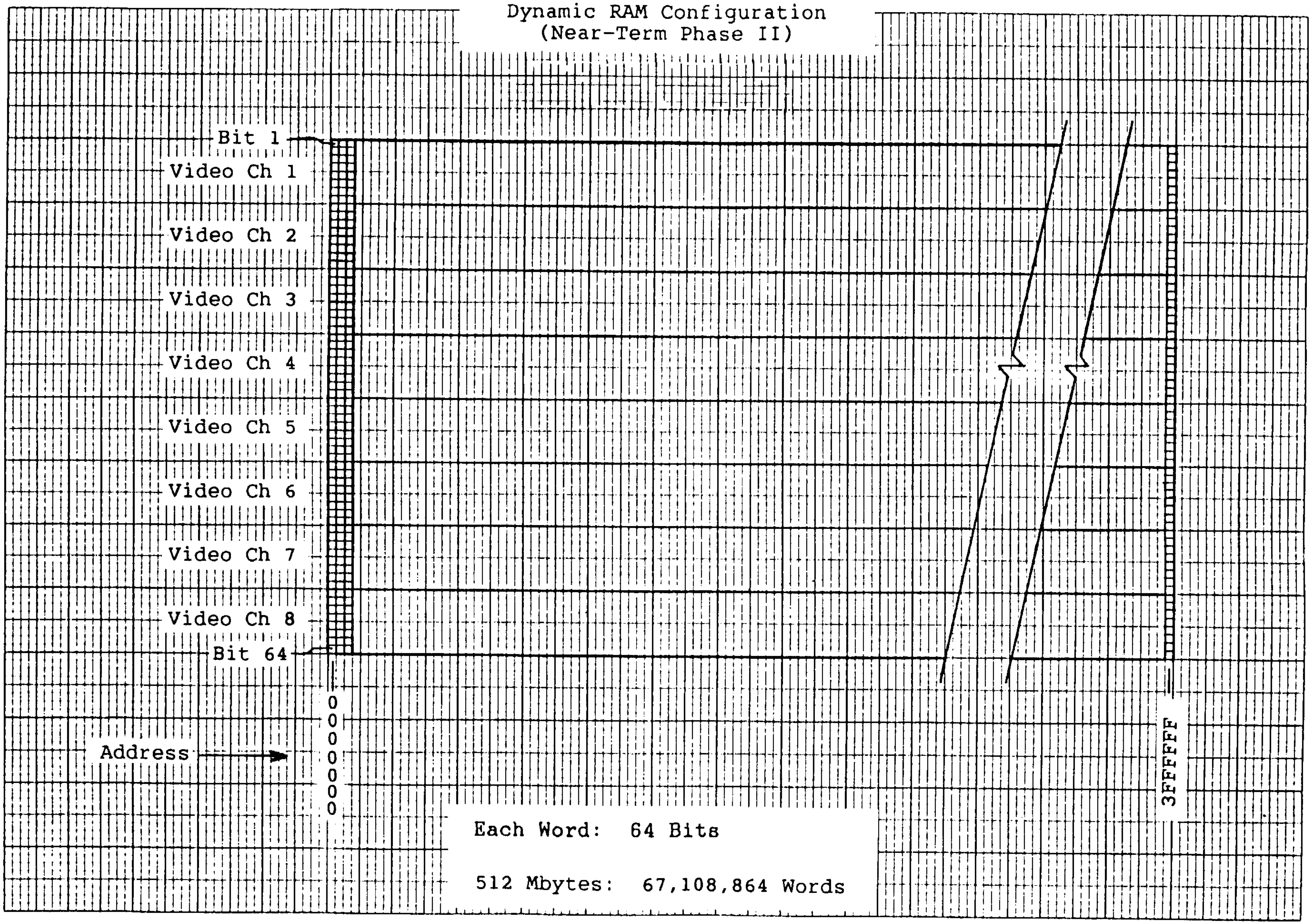


Figure 19

Proposed HHVT Data Format
8 Channel Parallel Scan
(Near-Term Phase II)
Example Shown: 64 × 64 pixels, 1 bit/pixel

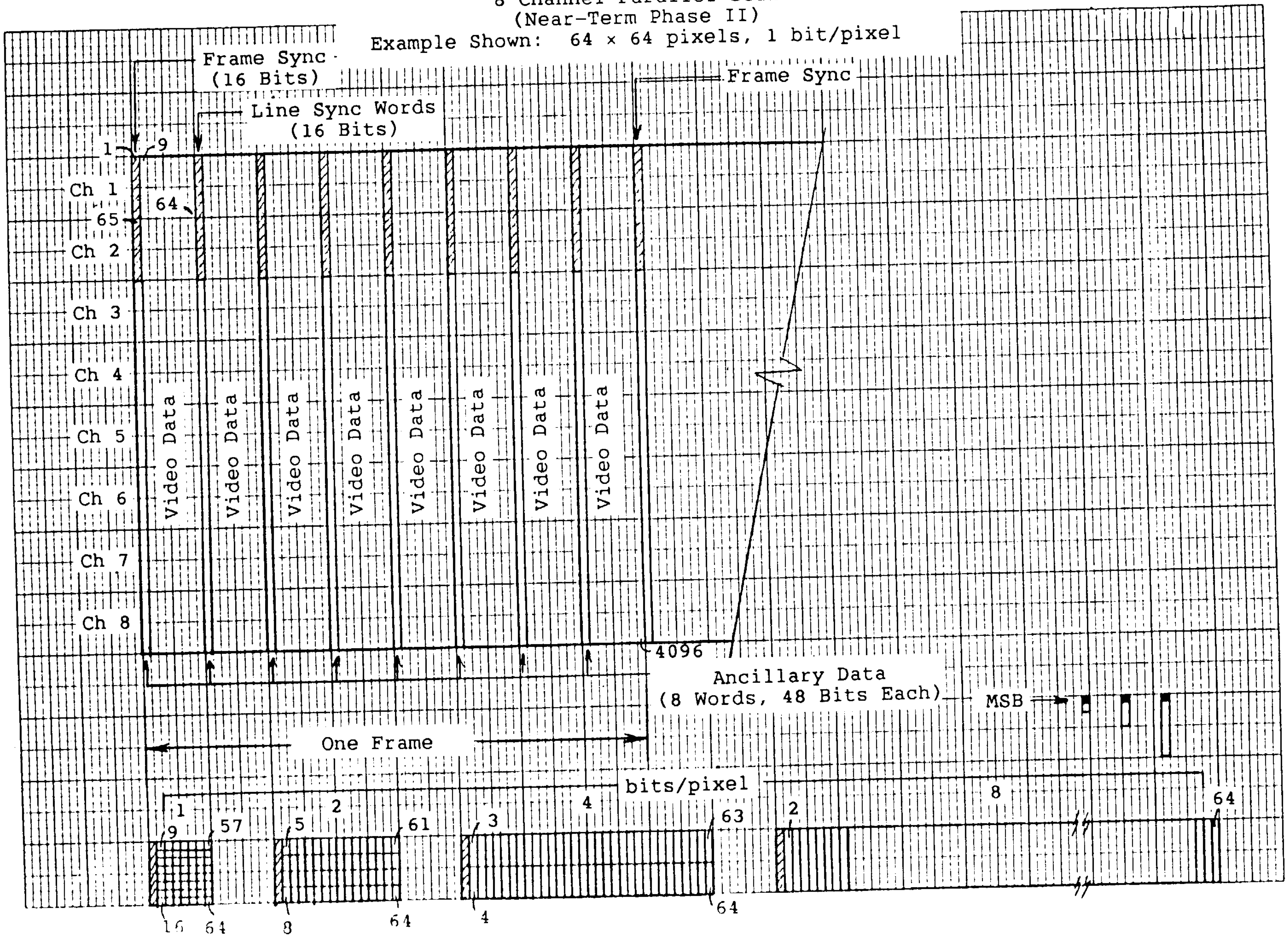
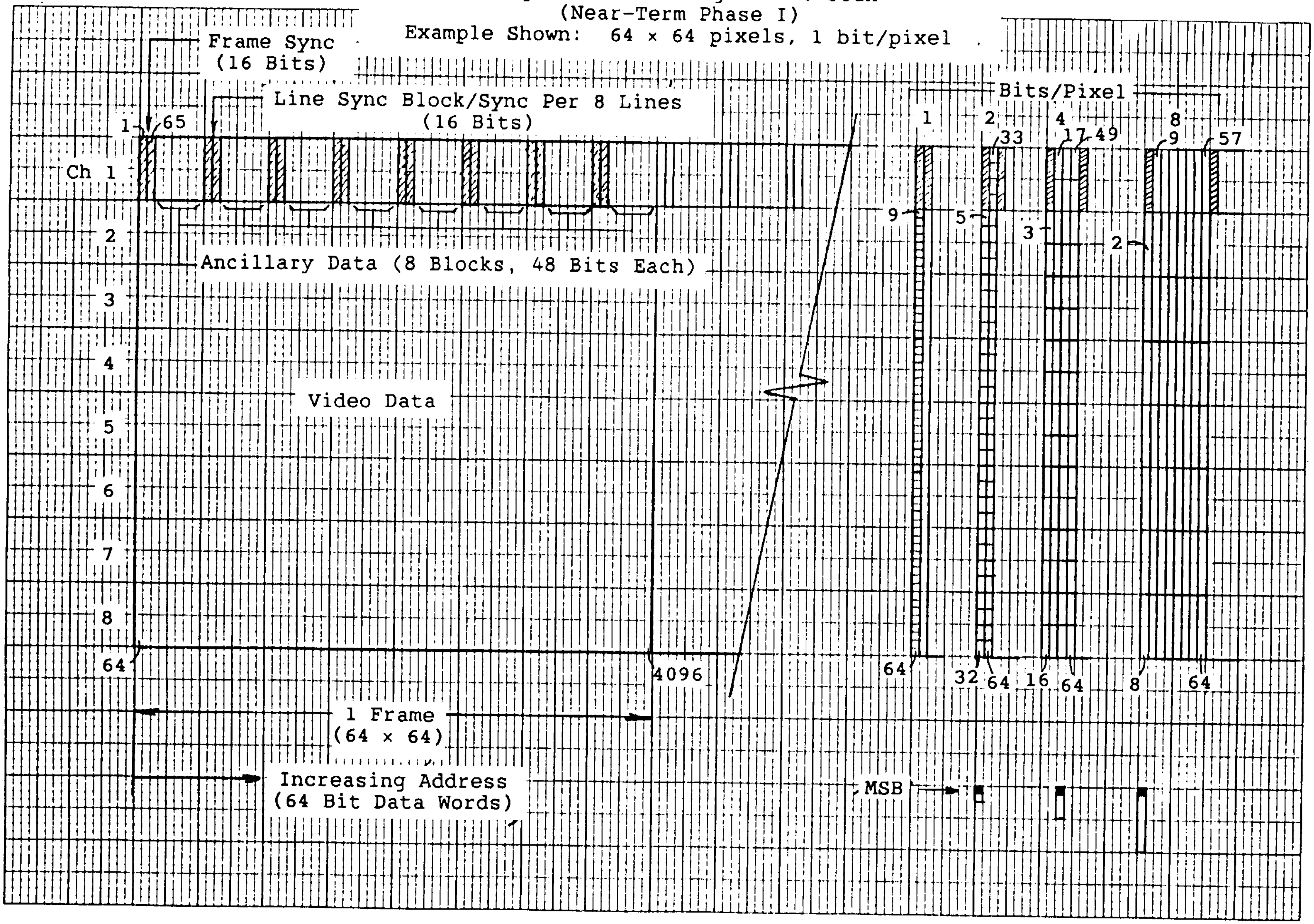


Figure 20

Proposed HHVT Data Format
Single Channel Progressive Scan
(Near-Term Phase I)
Example Shown: 64 × 64 pixels, 1 bit/pixel



COMMENTS FROM THE USERS WORKING GROUP

The following summarizes the comments that were made by the participants in the Users Working Group meeting in response to questions posed by the leader of the discussion, Jack A. Salzman, Chief of NASA Lewis Microgravity Science and Technology Branch.

When asked whether the High Resolution, High Frame Rate Video Technology (HHVT) project appeared to have a realistic assessment of the users' requirements, the concensus of the participants in the Users Working Group was that it did not. The requirements for color imaging and resolution were ill defined. The scientific imaging needs of the experimenters were not requested so much as were the engineering requirements for the proposed HHVT system. Information on the specific part of the spectrum of interest to the user was not requested. The questionnaire should have asked the users whether they needed more than two cameras for their experiments, if they needed magnification of the subject, and the size of the subject. Whoever wrote the questionnaire erroneously assumed that experimenters understand how video technology actually operates. Due to the use of technical terminology, the experimenters could not understand some of the questions on the HHVT users' questionnaire.

In order to complete NASA's survey of users' requirements, the requirements for scientific fields not yet represented in the HHVT users' requirements database should be defined. The majority of the experimenters who responded to the questionnaire have experiments that are in the conceptual design phase already.

One participant recommended that NASA engage a contractor to handle the marketing role of interacting between the users and the design engineers. Several participants commented that the technical experts would leave the HHVT Users Workshop without knowing the real needs of the users. The HHVT project team was advised to go out on a one-to-one basis with the experimenters and solicit information on specific experiments. An effort should be made to identify both the minimum requirements of the users as well as their ultimate requirements for imaging their experiments. This type of one-to-one information exchange would be far more productive than conducting additional surveys. NASA should also establish some forum for acquiring information on users' requirements and then making it accessible to the interested public. NASA should also give high priority to developing video technology to satisfy the requirements of users that cannot be met by existing technology.

When asked whether they thought the correct approach was being applied to address users' needs, the participants answered affirmatively, but they cautioned that the questions in the survey did not fully cover the users' imaging needs. There should be far more communication between the users and the design engineers.

One participant expressed the opinion that it is wasteful for NASA to spend a few million on HHVT development when the video industry is spending far more on research and technology. He thinks NASA could better assist experimenters by developing a system capable of spectral radiance measurements onboard the Space Shuttle. Another participant disagreed and noted that NASA is not constrained by limited bandwidths as is industry. High resolution, high frame rate video technology for space applications is very much needed, and academia and industry expect NASA to be the agency pursuing this area of technology development. It is unlikely that industry would invest in this area of research and development independently. The commercial demand is almost nonexistent. One person asked whether NASA actually intends to fund the development of imaging chips considering the high cost involved.

The purpose of the near-term HHVT system is to function as a breadboard to test the technology. The participants were asked whether they thought developing the breadboard was sensible. One participant commented that the breadboard method is the only logical approach for this type of technology advancement. But he cautioned the HHVT project team not to regard the breadboard as a flight prototype. Another participant observed that no one system could meet all of the users' requirements. A more flexible type of system with interchangeable components will be needed. NASA will have a good system when NASA builds one that satisfies 80 percent of the users' requirements, after those requirements have been better defined.

To some participants the idea of using a plumbicon imager for the Phase I HHVT system seemed inappropriate. They advised against using tube cameras in a flight prototype of the HHVT system. They recommended that more emphasis be placed on the development of a solid state sensor and more thought given to fast CCD readout. The near-term HHVT system should have at least three different types of cameras for ultraviolet, infrared, and visible light imaging. The rest of the system must be designed to accommodate all of these cameras, one at a time. According to the participants, there is no requirement identified for true color. False color imaging, achievable with the use of trim filters, will suffice. But there is a need for the HHVT system to enable spectral radiance measurements.

The participants were asked whether a data compression capability should be an integral part of the HHVT system. For some, data compression will be user and image dependent, and should be implemented by the user as he sees fit. It should not be an integral part of the HHVT system. Other participants disagreed, but they pointed out that users would want to be able to control the application of compression to their image data. One person observed that data compression is a TDRSS-driven problem. Whenever the shortage of downlink channels is alleviated, the need for data compression will dissipate. The HHVT project team was advised to solicit information on the planned in-space operations for each experiment, so as to be able to assess whether real-time downlink for a given experiment is a necessity. The participants thought the cyclic buffering capability of the HHVT system would be useful.

When asked what they thought would happen if the HHVT program were discontinued, the participants expressed the opinion that the users would all build their own video systems tailored to their specific needs. Then someone, somewhere along the way, would come up with the idea of building one system having all the capabilities of the individual video systems. The participants applauded NASA for initiating this High Resolution, High Frame Rate Video Technology development project and encouraged the project team to continue with the development of the near-term HHVT systems as breadboards.

COMMENTS FROM THE TECHNICAL EXPERTS WORKING GROUP

The following summarizes the comments that were made by the participants in the Technical Experts Working Group meeting. James A. Burkhart, Chief of NASA Lewis Instrumentation and Data Systems Branch, led the discussion.

One of the technical experts advised the High Resolution, High Frame Rate Video Technology development project team to consider the signal-to-noise ratio problems associated with the use of image intensifiers. Twenty electrons per pixel exposure is almost worthless for low contrast images. A solid state imager is a better front end than a gated intensifier because it has a higher quantum efficiency, lower noise, exposure gating, better MTF, better response uniformity, no signal lag, and much higher in-scene dynamic range.

Another participant questioned the luminosity of the phenomena being observed in some of the experiments. He wondered whether the users understood the technical meaning of "16 gray levels," because "16 gray levels" implies a very high dynamic range, on the order of 1000 to 1. The human eye can only distinguish 16 gray levels. Often six or seven gray levels is sufficient for an observer to interpret an image, provided the image has high contrast. The HHVT project team was advised to better define requirements given on future user surveys. Probably less than 10 percent of the users who responded to the HHVT users' requirements questionnaire are video equipment experts. Terms such as "lumens" would not be familiar to them. In defining the requirements for resolution, "ISO" is not the correct figure of merit to use. Overall, the HHVT users' survey did not provide enough information for sensor manufacturers to understand the imaging requirements of the experimenters. For each experiment they would need to know the source of light, frame exposure time, frame rate, dynamic range requirement, and spectral distribution. Knowing how an experimenter views his final images, and whether those images are high or low in contrast would also be helpful. The technical experts further advised the HHVT project team to solicit information on the type of optical system and film used by the experimenter in his laboratory. It may be necessary for each user to determine his scientific imaging requirements quantitatively, instead of just qualitatively. It remains NASA's responsibility to translate the scientific requirements presented by the users into engineering requirements for the design of the near-term HHVT system. The experts also recommended that the HHVT project team follow up on the responses they receive from users on future surveys. There should be more interaction between the system developers and the users.

With regard to data compression, the experts advised NASA to address this problem as an end-to-end issue. Also NASA should consider the possibility of compressing data prior to storing it in the high speed memory. There are commercial systems that could be used.

In closing, the observation was made that the microgravity science community has set forth requirements to stimulate video technology development, and these requirements are for a general purpose system. In trying to satisfy all the users, the HHVT project team may not be able to satisfy any of them. The HHVT project team should periodically remind the users that the near-term HHVT system is being designed to satisfy a constrained set of their stated requirements.

FINDINGS AND RECOMMENDATIONS

After the users and the technical experts had separately discussed the results of the HHVT users' requirements survey, the proposed near-term HHVT system, and the future course of the HHVT development project, both groups reconvened to share their findings and recommendations. The following list of findings was mutually agreed upon by the users and the technical experts:

(1) The HHVT project does not have a realistic assessment of users' requirements.

(a) More information is required on each specific experiment.

(b) The requirements should be expressed as scientific requirements rather than as engineering requirements.

(2) The Phase I system should be pursued as a breadboard system, but not as an operational (flight prototype) system.

(3) The Phase I and Phase II HHVT systems should be designed to accept a variety of modular subsystems as the technology advances.

(4) True color is not a requirement, but the ability to make spectral radiance measurements is. This will require a 12 bit system (an 8 bit system is currently planned for both the Phase I and Phase II systems).

(5) The "burst mode" is highly desirable.

(6) Onboard viewing is highly desirable.

(7) It is premature to decide whether subframing is preferable to the use of integrated pixels. Therefore, both methods should be developed.

(8) Edge definition processing should be accorded a high priority.

The following list of recommendations was mutually agreeable to the users and the technical experts:

(1) Each of the investigators should be contacted on an individual basis in order to obtain more detailed information on the scientific imaging requirements.

(2) Once the engineering requirements for the HHVT systems are defined, the HHVT project team should follow up with the investigators to discuss possible tradeoffs.

(3) In proceeding with the Phase I breadboard system, the HHVT project team should make use of their updated survey requirements. Also, they should keep the system flexible and involve the user in system testing and evaluation.

(4) The HHVT project team should concentrate on developing areas of video technology that industry is not developing. One example is flexible ways of compressing data.

ABBREVIATIONS AND ACRONYMS

ATD	advanced technology development
ATDRSS	Advanced Tracking Data Relay Satellite System
BER	bit error rate
bit	binary digit
byte	eight bits
CCD	charge coupled device
CID	charge injection drive
G/T	gain-to-noise temperature ratio
Gbit	Gigabit
GSTDN	Ground Spacecraft Tracking and Data Network
IDS	intensity dependent spread
MCP	multichannel plate
MOS	metal oxide semiconductor
MTF	modulation transfer function
MUX	multiplexer
NPDT	nonparallel (magnetic) disk transfer
PDT	parallel (magnetic) disk transfer
pels	picture elements
pixels	picture elements
RAM	random access memory
RGB	red, green, blue
SBIR	Small Business Innovative Research
SCSI	small computer system interface
SFR	spatial frequency response
TDRSS	Tracking Data Relay Satellite System
VLSI	very large scale integration
YIQ	luminance (Y) and chrominance (I,Q) signals

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15. Supplementary Notes

16. Abstract

This publication is a compilation of papers and working group summaries presented at the High Resolution, High Frame Rate Video Workshop held at NASA Lewis Research Center, Cleveland, Ohio, May 11-12, 1988. Presentations were made by NASA engineers engaged in the development of a high resolution, high frame rate video system intended for future use on the Space Shuttle and Space Station Freedom. The papers covered the following topics:

(1) State of the art in video system performance
(2) Development plan for the high resolution high frame rate video system
(3) Advanced technology development for image gathering, coding and processing
(4) Data compression applied to high resolution, high frame rate video
(5) Data transmission networks
(6) Results of the users' requirements survey conducted by NASA

This workshop was held for the dual purpose of (1) allowing potential scientific users to assess the utility of the proposed system for monitoring microgravity science experiments and (2) letting technical experts from industry recommend improvements to the proposed near-term high resolution, high frame rate video system.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Advanced video technology; High resolution; High frame rate video; State-of-the-art video; Advanced image processing	Unclassified – Unlimited Subject Category 35

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