1 of 1

Initial Laboratory Evaluation of Color Video Cameras (Phase Two)

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Abstract

Sandia National Laboratories has considerable experience with monochrome video cameras used in alarm assessment video systems. Most of these systems, used for perimeter protection, were designed to classify rather than to identify intruders. The monochrome cameras were selected over color cameras because they have greater sensitivity and resolution. There is a growing interest in the identification function of security video systems for both access control and insider protection. Because color camera technology is rapidly changing and because color information is useful for identification purposes, Sandia National Laboratories has established an on-going program to evaluate the newest color solid-state cameras. Phase One of the Sandia program resulted in the SAND91-2579/1 report titled: *Initial Laboratory Evaluation of Color Video Cameras*. The report briefly discusses imager chips, color cameras, and monitors, describes the camera selection, details traditional test parameters and procedures, and gives the results reached by evaluating 12 cameras. Here, in Phase Two of the report, we tested 6 additional cameras using traditional methods. In addition, all 18 cameras were tested by newly developed methods. This Phase 2 report details those newly developed test parameters and procedures, and evaluates the results.

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NOTE:

Additional data on camera laboratory tests referred to in this document (See Section 3.0) can be obtained by calling the author at (505)844-9630 or by writing the author at the address given below:

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CONTENTS

1.0 INTRODUCTION	7
2.0 TEST CAMERAS	7
3.0 AVAILABILITY OF CAMERA LABORATORY TESTS.....	7
4.0 TRADITIONAL CAMERA TEST PARAMETERS	7
4.1 Sensitivity	7
4.2 Resolution	10
4.3 Signal-to-Noise Ratio	10
4.4 Intrascene Dynamic Range	10
5.0 TEST PROCEDURES FOR TRADITIONAL TEST PARAMETERS USING AN OPTOLINER.....	12
5.1 Setup Procedures.....	13
5.2 Sensitivity Verification	13
5.3 Signal-To-Noise Verification	14
5.4 Horizontal Resolution Measurement	14
5.5 Comparative Data at Various Nominal Faceplate Illumination Values	14
6.0 COLOR CAMERA PERFORMANCE FOR TRADITIONAL TEST PARAMETERS USING AN OPTOLINER.....	19
7.0 TRADITIONAL LABORATORY TEST PROCEDURES USING A FRONT LIGHTED EIA CHART	19
7.1 Setup Procedures.....	20
7.2 Intrascene Dynamic Range Test	21
7.3 Horizontal Resolution Measurement	29
7.4 Signal-to-Noise Ratio	29
7.5 Camera Performance at Different Light Levels	29
8.0 NEWLY DEVELOPED TEST PARAMETERS	30
8.1 White Balance.....	30
8.2 Color Rendition Under Commonly Used Light Sources	33
8.2.1 Test Procedures for Color Rendition under Commonly Used Light Sources	33
8.2.2 Results of Test for Color Rendition Under Commonly Used Light Sources	33

8.3 Low Light level Color Rendition	34
8.3.1 Test Setup Procedures	34
8.3.2 Results	34
9.0 SUMMARY	34
REFERENCES	35

Figures

1. Example of Gray Scale	11
2. Theoretical Dynamic Range Response	11
3. Gray Scale Response With Black Level Too High	12
4. Optoliner Setup	12
5. Photo of Front Lighted Chart Setup.....	20

Graphs

1. Initial Inspection Intrascene Dynamic Range Test Results	21
2. Initial Inspection Intrascene Dynamic Range Test Results Continued	22
3. White Balance Test Results (Fourth Vector Magnitude)	32
4. White Balance Test Results Continued (Fourth Vector Magnitude)	32
5. White Balance Test Results Continued (Fourth Vector Magnitude)	32

Tables

1. Test Cameras.....	9
2. Faceplate Illumination Test Data at Forty IRE Units Video Level (Cameras listed By Most Sensitive).....	15
3. Nominal Scene Luminance .422 Footcandles	16
4. Nominal Scene Luminance .125 Footcandles	17
5. Nominal Scene Luminance .044 Footcandles	18
6. Gray Scale Response with Full Lighting	23
7. Horizontal Resolution, and the Signal-to-Noise Ratio Results.....	24
8. Nominal Scene Luminance 25 Foot Lamberts	25
9. Nominal Scene Luminance 5 Foot Lamberts	26
10. Nominal Scene Luminance 2.4 Foot Lamberts	27
11. Nominal Scene Luminance 1.26 Foot Lamberts	28
12. Nominal Scene Luminance .5 Foot Lamberts	29

1.0 Introduction

Because color cameras could enhance the performance of video security systems, Sandia National Laboratories (SNL) has established an on-going program for evaluating color cameras. In the initial phase (*Initial Laboratory Evaluation of Color Video Cameras*) published by Sandia¹ in SAND91-2579/1, 12 color cameras were evaluated. That evaluation concluded that color camera technology was rapidly improving and that further testing of color camera performance was warranted. This report (Phase Two) documents the re-sults of traditionally tested critical parameters for resolution, sensitivity, signal-to-noise (S/N) ratio, and intrascene dynamic range. Included also are newly developed test procedures for auto white balance, color rendi-tion under commonly used light sources, and the results of testing color cameras for low light level color rendition.

The earlier Sandia report¹ briefly discusses imager chips and mono-chrome and color cameras and color monitors. If there are questions concerning the candidate selection process used in this Phase 2 evaluation program, the reader is encouraged to read Reference 1. In Phase 2, we discuss test parameters, procedures, and results.

2.0 Test Cameras

Cameras were selected for evaluation based on their manufacturer-specified performance. Some were chosen because of high resolution and others because of sensitivity. Selections represented different solid-state technologies to determine any distinct characteristics inherent to a particular technology. Cameras were also chosen from different manufacturers to attain a broad representation of camera designs. Table 1 lists the cameras that were selected for this evaluation.

3.0 Availability of Camera Laboratory Tests

Section 6.5 in this report makes reference to traditionally tested parameters and states that detailed information on this subject is available from the author. This referenced information is available in the following format:

Section 1 identifies the camera.

Section 2 gives manufacturer specifications and camera cost.

Section 3 provides lens information, and the data that pertains to the cameras performance for traditional test parameters.

Section 4 gives information about the dynamic range test using a front-lighted EIA resolution chart.

Section 5 provides the same information using an optoliner. Test were first conducted with the gain on and then with the gain off. In some cases, the gain control was not selectable.

Section 6 provides the results of the camera's sensitivity test.

Section 7.1 in this report makes reference to white balance and newly developed test parameter procedures. This referenced information is available from the author in table format:

Column 1 indicates the filters used to achieve color temperatures

Column 2 lists the color temperatures

Columns 3,4, and 5 give the vector angles and magnitudes that respectively represent the hue and the amount of chroma of the red, green and blue color bars that were viewed by the camera and displayed on the vector scope.

Column 6 gives the magnitude of the spurious vector that is created when a camera is not perfectly white balanced, and correlates to the camera's white balance performance, the lesser the magnitude the better the white balance.

The data cited in either Section 6.5 or in Section 7.1 is available on request from the author by calling (505) 844-9630. The written address is:

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4.0 Traditional Camera Test Parameters

4.1 Sensitivity

Sensitivity is a primary consideration in camera selection. The more sensitive the camera, the less artificial light is required to produce the desired video signal. An increase in artificial lighting translates into an increase in lighting equipment, and these increases translate into inflated system and operating costs.

Table 1. Test Cameras

<i>MANUFACTURER</i>	<i>MODEL NUMBER</i>	<i>FORMAT IN. MM</i>		<i>IMAGER TYPE*</i>	<i>PIXELS H x V</i>
Burle	TC-252	2 / 3	11	CCD / FT / MFIS	768 X 492
Cohu	6800	1 / 2	8	CCD / FT / SFIS	739 X 484
Cohu	8200	1 / 2	8	CCD / ILT / MFIS	768 X 493
Hitachi	VK-C350	2 / 3	11	MOS / ILT / MFIS	760 X 485
Ikegami	ICD-800	2 / 3	11	CCD / ILT / MFIS	510 X 490
Javelin	JE-3362	2 / 3	11	MOS / ILT / MFIS	576 X 485
Javelin	JE-3462HR	2 / 3	11	MOS / ILT / MFIS	760 X 485
Javelin	JE-3542	1 / 2	8	CCD / ILT / MFIS	510 X 492
JVC	TK-880U(L)	1 / 2	8	CCD / ILT / MFIS	510 X 492
JVC	TK-980U	1 / 2	8	CCD / ILT / MFIS	512 X 492
Panasonic	WV-CL302	1 / 2	8	CCD / ILT / MFIS	512 x 492
Panasonic	WV-CL352	1 / 2	8	CCD / ILT / SFIS	682 X 492
Panasonic	WV-CL702	1 / 2	8	CCD / ILT / MFIS	682 x 492
Pulnix	TMC-574S	2 / 3	11	MOS / PBPT / SFIS	576 X 485
Pulnix	TMC-74	2 / 3	11	CCD / ILT / MFIS	756 X 581
Sanyo	VDC-4124	2 / 3	11	CCD / FT / SFIS	800 X 490
Sony	SSC-S20	1 / 2	8	CCD / ILT / MFIS	768 x 495
Sony	SSC-C350	1 / 2	8	CCD / ILT / MFIS	510 x 492

* *CCD = charge coupled device*

ILT = interline transfer

MFIS = mosaic filter image sensor

FT = frame transfer

MOS = metal-oxide semiconductor

SFIS = striped filter image sensor

PBPT = pixel by pixel transfer

4.2 Resolution

Resolution is another very important consideration in choosing a camera. Larger zones can be viewed by imagers providing greater resolution. This can reduce the number of cameras and associated mounting hardware and cabling required, and thus reduce system cost.

High-resolution-color, solid-state cameras currently designed for security applications exhibit 430 to 460 TV lines of horizontal resolution (compared to 565 to 580 for monochrome cameras).

4.3 Signal-to-Noise (S/N) Ratio

The video S/N ratio directly affects our ability to distinguish detail in an image. Although image quality is often subjectively evaluated, metrics can be useful in evaluating this parameter. Video camera signal quality is a function of the amount of noise present in the video signal. This noise content is commonly expressed as a S/N ratio measured in decibels (dB). Camera manufacturers typically specify the S/N ratio at high brightness levels; they measure the illuminance signal with the color information that has been removed with a filter. The S/N ratio is rarely specified at low light levels or with the color information included because the noise is considerably greater. Some manufacturers will specify a S/N ratio with the automatic gain control (AGC) circuitry switched off and specify the maximum sensitivity with the AGC switched on. Not all manufacturers make note of these subtle, but significant, differences in their specifications.

4.4 Intrascene Dynamic Range

A camera's intrascene dynamic range performance translates into its ability to reproduce different shades of gray. For example, if a camera is viewing an Electronic Industries Association (EIA) resolution chart and its output is connected to the input of a waveform monitor where the line select mode is chosen to display the gray scale (see Figure 1), each gray scale step should produce a unique voltage level and the peak black level should be at 7.5 IRE units (see Figure 2). However, if the gray levels are compressed, different shades of gray may not be discernible (see Figure 3). Therefore, if an intruder is camouflaged and the shade of clothing worn is close to the background of the camera's field-of-view, the intruder may go undetected.

Figure 1. Example of Gray Scale

Figure 2. Theoretical Dynamic Range Response (Not To Scale)

Figure 3. Gray Scale Response With Black Level Too High (Not To Scale)

5.0 Test Procedures for Traditional Test Parameters Using an Optoliner

Manufacturers' specifications for sensitivity use the historical standard; they use an incandescent light source operating at a color temperature of 2854 K as the illuminant. The Optoliner (manufactured by Optical Instruments Corp.) provides this specified source with image format size control, light level control, and internal light measurement capabilities (see Figure 4).

Figure 4. Optoliner Setup

Neutral density glass slides are used for major light level control. Fine adjustments can be made with the lamp intensity voltage control. The light level is read out on a digital panel meter located in the lamp power supply module.

5.1 Setup Procedures

The maximum light level generated by the Optoliner is about 4.5 footcandles (fc), more than enough to saturate standard imagers. A glass slide with the EIA TV resolution chart is inserted between the light source and the camera. The camera is attached directly to the Optoliner, without lens, and the image of the test pattern is projected directly onto the imager. The test pattern slide is available for different format size imagers. The light sensor is located between the neutral density filter slide position and the test pattern slide. The transmissivity of the slide must be measured and recorded because each light measurement is adjusted by this factor to determine the light level at the imager.

Measurements made without the lens provide sensitivity curves of the camera imager and electronics without the effects of the auto-iris lens. The effects of the AGC circuits, if designed into the camera, can be noted.

Manufacturers usually publish a camera's sensitivity by stating that at a specified minimum light level a minimum usable video signal should be obtained. Normally, however, they do not define the term "minimum usable video signal." For this evaluation, that minimum signal is the minimum amount of signal needed to produce 40 IRE units of video, peak black to peak white. This criteria was the reference point used to verify the manufacturers' specifications for sensitivity.

5.2 Sensitivity Verification

In order to verify the sensitivity specifications, sufficient illumination was provided to the camera's faceplate so that the camera produced precisely the minimum usable video signal (40 IRE). This was achieved by setting the Optoliner color temperature to 2854 K and using neutral density filters. Any adjustments to the Optoliner illumination control simultaneously affects the amount of illumination that is emitted and the color temperature. At the desired color temperature of 2854 K, the Optoliner emits more than a sufficient amount of illumination to produce the required video signal. Therefore, the neutral density filters were used to restrict the amount of illumination that reached the camera's faceplate to the point that the camera yielded a video signal amplitude slightly greater than the specified amplitude. To set the exact light level, it was necessary to reduce the intensity of the Optoliner light output by adjusting the illumination control. This also resulted in a slight change in the color temperature. The illumination level and color temperature were tabulated along with the measured peak white and peak black level. (See Table 2, Columns 2 and 7.)

5.3 Signal-to-Noise Verification

Verifying the camera manufacturer's specification for the S/N ratio was achieved by providing enough light so the cameras produced the minimum usable video signal. The noise meter inserted in the circuitry between the cameras' video output and the monitor's video input were used to evaluate the signal. The S/N measurements were taken of the video signal; chrominance information was not included in these measurements. (See Table 2, Column 4.)

5.4 Horizontal Resolution Measurement

In order to evaluate the resolution of the cameras, other components in the system had to provide greater resolution. This test setup included the resolution chart, video transmission cable, noise meter, and monitor (see Figure 4).

As mentioned previously, the camera was attached to the optoliner, without lens, and viewed a resolution chart that had been inserted inside the Optoliner (see Figure 4). The horizontal resolution measurement was achieved by viewing the resolution chart projected on the monitor. The point where the lines of the vertical wedges are no longer discernible is the limit of the camera's resolution. The results are tabulated in Table 2, Column 3.

5.5 Comparative Data at Various Nominal Faceplate Illumination Values

We wanted to evaluate the cameras' performance at various illumination intervals. Tables 3 to 5 show comparative data at various nominal face-plate illumination values of the cameras' performance for dynamic range, horizontal resolution, and S/N ratio. The cameras are listed in alphabetical order. Tables 3 to 5 also use the following abbreviations:

P-P: The difference between peak white and black level. Represents the maximum intrascene dynamic range, measured in IRE units.

RES. HORIZ TVL: The limiting horizontal resolution, measured in TV lines per picture height.

L: Measurement of luminance S/N ratio measured in decibels. (The chrominance filter was used to extract chroma.)

L&C: Measurement of the S/N ratio measured in decibels. (The ratio consisted of luminance plus chrominance.)

**Table 2 Faceplate Illumination Test Data at Forty IRE Units Video Level
(Cameras Listed by Most Sensitive)**

<i>Camera Model</i>	<i>Faceplate Illumination (Footcandles)</i>	<i>Resolution Horizontal TV Lines</i>	<i>S/N Ratio</i>	<i>AGC</i>	<i>Neutral Density Filter</i>	<i>Color Temperature (KELVIN)</i>	<i>Comments</i>
JVC TK-980U	.012	300	38	ON	2.6	2950K	VERY NOISY
PANASONIC WV-CL352	.022	430	39	ON	2.3	3030K	ONLY 7 GRAY SCALE STEPS
JAVELIN JE 3542	.026	320	40	ON	2.0	2790K	ONLY 8 GRAY SCALE STEPS
SONY SSC-C350	.026	320	37	ON	2.0	2710K	NOISY
COHU 8210	.028	470	40	ON	2.6	2740K	MODERATE NOISE
KEGAMI ICD-800	.041	310	32	*N.S.	2.6	2860K	VERY NOISY
SANYO VCD-4124	.046	310	32	ON	2.0	2910K	NOISY
BURLE TC-252	.046	300	38	ON	2.0	2900K	VERY NOISY
PANASONIC WV-CL702	.061	410	37	ON	2.0	2990K	MODERATE NOISE
SONY SSC-S20	.061	470	41	ON	2.6	2670K	MODERATE NOISE
PULNIX TMC-74	.064	340	40	ON	1.6	2680K	SLIGHT NOISE
COHU 6815	.066	330	35	ON	1.6	2690K	VERY NOISY
PANASONIC WVCL-302	.091	330	39	ON	1.6	2770K	MODERATE NOISE
JAVELIN JE-3362	.120	330	37	*N.S.	1.6	2860K	VERY NOISY
JVC TK-880U(L)	.194	330	40	ON	1.3	2810K	SLIGHT NOISE
JAVELIN JE3462-HR	.491	470	43	ON	1.0	2840K	MODERATE NOISE
HITACHI VK-C350	.562	470	43	ON	1.0	2880K	CLEAN
PULNIX TMC-574S	.600	360	44	ON	1.0	2850K	CLEAN

* N. S. = Not Selectable

Table 3. Nominal Scene Luminance .422 Footcandles.
AGC is on when selectable.

Camera Model	Faceplate Illumination (Footcandles)	VIDEO LEVEL			RES. HORIZ TVL	SIGNAL TO NOISE RATIO		COMMENTS
		WHITE	BLACK	P-P		L&C	L	
Burle TC-252	.437	70	3	67	300	33	40	
Cohu 6800	.447	80	10	70	305	34	40	
Cohu 8200	.432	80	11	69	470	31	45	
Hitachi VK-C350	.452	47	10	37	460	35	42	Slight Noise
Ikegami ICD-800*	.452	62	3	59	310	32	41	
Javelin JE-3362*	.451	59	6	53	330	28	41	Slight Noise
Javelin JE-3462HR	.451	49	11	38	470	33	43	Slight Noise
Javelin JE-3542	.350	74	8	66	320	38	44	8 gray scale steps
JVC TK-880U(L)	.421	53	11	42	330	30	42	
JVC TK-980U	.351	92	12	80	330	36	44	
Panasonic WV-CL302	.456	60	10	50	330	35	39	
Panasonic WV-CL352	.320	86	10	76	430	35	44	7 gray scale steps
Panasonic WV-CL702	.445	65	10	55	410	34	42	
Pulnix TMC-74	.419	76	7	69	340	25	40	
Pulnix TMC-574S*	.413	42	4	38	360	32	42	
Sanyo VDC-4124	.418	72	7	65	330	29	41	
Sony SSC-S20	.439	64	6	58	470	31	41	
Sony SSC-C350	.439	66	8	58	320	32	42	

*AGC is not selectable.

**Table 4. Nominal Scene Luminance .125 Footcandles.
AGC is on when selectable.**

Camera Model	Faceplate Illumination (Footcandles)	VIDEO LEVEL			RES. HORIZ TVL	SIGNAL TO NOISE RATIO		COMMENTS
		WHITE	BLACK	P-P		L&C	L	
Burle TC-252	.116	64	3	61	300	29	40	Slight Noise
Cohu 6800	.119	67	6	61	305	26	38	Noisy
Cohu 8200	.115	78	11	67	470	30	42	
Hitachi VK-C350	.120	41	10	31	460	27	37	Very Noisy
Ikegami ICD-800*	.119	60	0	60	310	29	37	Slight Noise
Javelin JE-3362*	.120	50	9	41	330	22	37	Very Noisy
Javelin JE-3462HR	.119	40	11	29	470	30	39	Very Noisy
Javelin JE-3542	.173	67	8	59	320	37	44	8 Gray Scale Steps
JVC TK-880U(L)	.112	49	11	38	330	29	37	Very Noisy
JVC TK-980U	.174	90	12	78	330	34	41	8 Gray Scale Steps
Panasonic WV-CL302	.121	55	12	43	330	35	41	Slight Noise
Panasonic WV-CL352	.155	84	12	72	430	33	43	7 Gray Scale Steps
Panasonic WV-CL702	.118	65	10	55	410	26	38	Slight Noise
Pulnix TMC-74	.110	62	7	55	340	27	39	Slight Noise
Pulnix TMC-574S*	.109	40	6	34	300	29	38	Noisy
Sanyo VDC-4124	.110	62	6	56	330	24	36	Slight Noise
Sony SSC-S20	.116	52	6	46	470	29	41	
Sony SSC-C350	.116	60	7	53	320	37	41	

*AGC is not selectable.

**Table 5. Nominal Scene Luminance .044 Footcandles.
AGC is on when selectable.**

Camera Model	Faceplate Illumination (Footcandles)	VIDEO LEVEL			RES. HORIZ TVL	SIGNAL TO NOISE RATIO		COMMENTS
		WHITE	BLACK	P-P		L&C	L	
Burle TC-252	.046	41	2	39	300	30	37	Very Noisy
Cohu 6800	.048	30	6	24	305	27	37	Very Noisy
Cohu 8200	.046	62	8	54	470	28	41	Very Noisy
Ikegami ICD-800*	.048	48	0	48	310	27	34	Severe Noise
Javelin JE-3542	.036	54	7	47	320	34	40	8 Gray Scale Steps, Slightly Noisy
JVC TK-880U(L)	.045	40	10	30	330	26	36	8 Gray Scale Steps, Very Noisy
JVC TK-980U	.037	88	12	76	330	28	37	Noisy
Panasonic WV-CL302	.048	33	10	23	330	35	40	Slight Noise
Panasonic WV-CL352	.037	70	16	54	430	28	38	7 Gray Scale Steps, Noisy
Panasonic WV-CL702	.047	37	7	30	410	26	38	Slight Noise
Pulnix TMC-74	.043	34	6	28	340	29	40	6 Gray Scale Steps, Very Noisy
Sanyo VDC-4124	.043	42	5	37	310	22	33	Very Noisy
Sony SSC-S20	.047	40	4	36	470	30	39	Slight Noise
Sony SSC-C350	.047	54	7	47	320	32	39	Slight Noise

*AGC is not selectable.

6.0 Color Camera Performance for Traditional Test Parameters Using an Optoliner

The results of this color camera evaluation were compared to those of the latest laboratory evaluation of monochrome solid-state video cameras.² The minimum usable video signal for monochrome cameras, 40 IRE units peak white to peak black, was used as a reference to compare the sensitivity of the color versus the monochrome cameras. Although considerable progress has been made toward improving the color cameras' sensitivity, the most sensitive color camera selected for this evaluation is considerably less sensitive than the most sensitive monochrome camera. The color camera produced the minimum usable video signal with 0.012 fc of faceplate illumination, compared to 0.0014 fc for the monochrome camera. There is a factor difference of 9.1. The other color cameras required significantly more illumination to attain the minimum usable video signal. The illumination of these cameras ranged from 0.022 to 0.600 fc.

Manufacturers specify the S/N ratio of color cameras by measuring the luminance signal only. The color burst that provides color information and unwanted additional noise has been removed. Measuring the luminance signal only (at the illumination needed to produce the minimum video signal), the S/N ratio for both monochrome and color cameras ranges from 35 to 43 dB. At the full illumination levels (92.5 IRE units) obtained from high-faceplate illumination, the S/N ratio for color solid-state cameras (with the color information removed) ranged from 42 to 46 dB; this corresponds to the monochrome camera measurements.

The horizontal resolution of color cameras is less than for monochrome cameras. The higher resolution monochrome cameras provide 550 to 575 horizontal TV lines, compared to 430 to 470 for color cameras. Although the resolution of color cameras does not equal that of monochrome cameras, a great deal of improvement in the resolution of color cameras is evident. Until recently, color cameras produced ~ 330 horizontal TV lines.

7.0 Traditional Laboratory Test Procedures Using a Front-Lighted EIA Chart

The front-lighted EIA chart testing is performed with a lens attached and at different light levels. The first light level produces approximately a full video signal and then decreases in increments down to where the video signal is degraded significantly.

7.1 Setup Procedures

The camera's video output was attached to the video input of a waveform monitor. The video output of the waveform monitor was then attached to the video input of a video monitor. The waveform monitor is used for analyzing the characteristics of the video signal and is indicative of the camera's performance.

An ELA resolution chart was placed at the end of the optical bench (see Figure 5). The chart was front lighted by two incandescent lightbulbs operating at a color temperature of 3200 Kelvin, a standard for testing color camera sensitivity. The lightbulb fixtures were mounted on individual stands and were positioned to a level equal to the midpoint of the chart. The stands were placed in front of the chart, at each side, at approximately three feet away with the lights aimed at 45° angles toward the chart. Dispersion screens were attached to the front of each of the lamp fixtures. The screens help to prevent bright spots.

Figure 5. Photo of Front-Lighted Chart Test Setup

A jack was attached to the top of the optical bench. The cameras were mounted one at a time on the jack and aimed at the chart, making sure the camera was aligned with the center axis of the chart. The camera was then

positioned so that the outer edges of the chart were just inside the camera's field of view. Next the two lamps were turned on, lighting the test chart. With the aide of a photometer, the luminance level was then measured and recorded.

7.2 Intrascene Dynamic Range Test

The LINE SELECT mode on the waveform monitor was chosen to display the gray scale. The peak white and the peak black level and the video level for each of the 10 steps were read and tabled. Figure 6 graphically demonstrates the difference between the peak white and the peak black level. Table 6/Column 5 displays the numerical value.

Graph 1. Initial Inspection Intrascene Dynamic Range Test Results

**Graph 2. Initial Inspection Intrascene Dynamic Range
Test Results Continued**

The last 10 columns of data in Table 6 show the video level at each of the 10 gray scale steps. The video amplitudes of each of the readings has been normalized to 100 IRE units for Step 10 for easier comparison between cameras.

The following abbreviations are used in Tables 6 through 12.

P-P: The difference between peak white and black level. Represents the maximum intrascene dynamic range, measured in IRE units.

RES. HORIZ TVL: The limiting horizontal resolution, measured in TV lines per picture height.

L: Measurement of luminance S/N ratio measured in decibels.
(A chrominance filter was used to extract chroma.)

L&C: Measurement of the S/N ratio measured in decibels.
(The ratio of luminance plus chrominance.)

Table 6. Gray Scale Response with Full Lighting

<i>Manufacturer</i>	<i>Model</i>	<i>Black</i>	<i>White</i>	<i>P-P</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>8</i>	<i>9</i>	<i>10</i>
Burle	TC-252	15	92	77	16	38	50	57	67	75	85	87	96	100
Cohu	6800	30	108	78	23	44	54	61	67	74	81	85	93	100
Cohu	8200	22	96	74	23	42	52	55	71	75	83	85	94	100
Hitachi	VK-C350	39	108	69	36	47	56	63	70	76	83	85	93	100
Ikegami	ICD-800	26	112	86	25	43	52	61	70	73	86	89	95	100
Javelin	JE-3362	31	96	65	31	44	53	63	71	77	83	86	94	100
Javelin	JE-3462HR	34	96	62	35	46	53	61	71	75	84	88	94	100
Javelin	JE-3542	18	104	86	14	31	46	54	63	69	79	83	90	100
JVC	TK-880U(L)	25	103	78	23	39	50	62	72	79	86	89	96	100
JVC	TK-980U	40	104	64	38	50	58	63	69	73	79	81	86	100
Panasonic	WV-L302	21	100	79	21	36	48	52	62	70	80	82	90	100
Panasonic	WV-L352	12	97	85	12	25	35	45	54	63	71	74	82	100
Panasonic	WV-L702	22	108	86	20	39	49	58	68	75	83	86	93	100
Pulnix	TMC-74S	12	90	78	13	36	47	58	67	76	84	87	93	100
Pulnix	TMC-574	12	97	85	12	33	50	60	68	74	85	88	97	100
Sanyo	VDC-4124	19	100	81	19	35	49	59	69	75	83	86	94	100
Sony	SSC-S20	12	88	76	15	34	45	57	67	72	80	82	91	100
Sony	SSC-C350	20	96	76	21	36	47	52	62	70	78	83	92	100

Table 7. Horizontal Resolution, and the Signal- to-Noise Ratio Results

<i>Manufacturer</i>	<i>Model</i>	<i>Manufacturer Specification</i>	<i>Actual Measurement</i>	<i>Signal-to Noise Ratio</i>	
		Horizontal Resolution	Horizontal Resolution	L&C	L
Burle	TC-252	320	300	30	44
Cohu	6800	300	305	34	45
Cohu	8200	460	470	33	47
Hitachi	VK-C350	430	460	31	48
Ikegami	ICD-800	330	310	36	45
Javelin	JE-3362	340	330	31	46
Javelin	JE-3462HR	> 430	470	32	47
Javelin	JE-3542	320	320	37	46
JVC	TK-880U(L)	330	330	37	49
JVC	TK-980U	330	310	31	44
Panasonic	WV-CL302	330	330	37	46
Panasonic	WV-CL352	430	430	31	44
Panasonic	WV-CL702	430	410	36	45
Pulnix	TMC-74S	330	360	23	45
Pulnix	TMC-574	360	360	25	43
Sanyo	VDC-4124	340	330	33	42
Sony	SSC-S20	470	470	36	45
Sony	SSC-C350	330	320	37	45

Table 8. Nominal Scene Luminance 25 Foot Lamberts.
GC is on when selectable.

Camera Model	SCENE LUMINANCE FOOT LAMBERTS	VIDEO LEVEL			RES. HORIZ TVL	SIGNAL-TO- NOISE RATIO		COMMENTS
		WHITE	BLACK	P-P		L&C	L	
Burle TC-252	23	84	20	64	300	25	44	
Cohu 6800	21.5	84	24	60	305	35	44	
Cohu 8200	25.2	88	28	60	470	32	46	
Hitachi VK-C350	27	100	24	76	460	28	44	
Ikegami ICD-800**	20.4	98	32	66	310	NM*	43	Slight Noise
Javelin JE-3362**	26	96	25	71	330	25	46	
Javelin JE-3462HR	20.6	69	18	51	470	31	44	Slight Noise
Javelin JE-3542	22.2	92	22	70	320	36	42	
JVC TK-880U(L)	27.8	82	28	54	330	33	41	
JVC TK-980U	27.8	82	42	40	310	32	43	
Panasonic WV-CL302	24	60	15	45	330	39	43	
Panasonic WV-CL352	29.7	80	18	62	430	32	43	
Panasonic WV-CL702	24.8	62	16	46	410	36	43	
Pulnix TMC-74	31.1	60	11	49	360	22	44	
Pulnix TMC-574S**	31.5	78	22	56	320	33	43	
Sanyo VDC-4124	23.8	80	20	60	330	31	42	
Sony SSC-S20	22.2	80	17	63	470	27	44	
Sony SSC-C350	21.2	90	24	66	320	38	43	

*Not Measurable, out of noise meters range.

**AGC is not selectable.

Table 9. Nominal Scene Luminance 5 Foot Lamberts.
AGC is on when selectable.

Camera Model	SCENE LUMINANCE FOOT LAMBERTS	VIDEO LEVEL			RES. HORIZ TVI.	SIGNAL-TO- NOISE RATIO		COMMENTS
		WHITE	BLACK	P-P		L&C	L	
Burle TC-252	4.60	62	12	50	300	30	42	<i>Slight Noise</i>
Cohu 6800	4.30	78	40	30	305	32	41	<i>Noisy</i>
Cohu 8200	5.04	69	20	49	450	33	44	
Hitachi VK-C350	5.40	44	12	32	400	32	42	<i>Very Noisy</i>
Ikegami ICD-800**	4.07	60	10	50	300	NM*	41	<i>Very Noisy</i>
Javelin JE-3362**	5.2	61	16	45	330	21	41	<i>Very Noisy</i>
Javelin JE-3542	5.42	63	12	51	320	35	43	
JVC TK-880U(L)	5.56	50	20	30	330	32	41	<i>Slight Noise</i>
JVC TK-980U	5.56	66	24	42	310	34	42	
Panasonic WV-CL302	4.77	60	16	44	300	34	42	
Panasonic WV-CL352	5.94	62	12	50	430	32	43	
Panasonic WV-CL702	4.96	62	14	48	410	32	43	
Pulnix TMC-74	6.22	74	17	57	360	22	42	<i>Slight Noise</i>
Pulnix TMC-574S**	6.30	38	8	30	260	28	42	<i>AGC Not Selectable</i>
Sanyo VDC-4124	4.76	58	12	46	330	27	41	
Sony SSC-S20	4.43	52	9	43	450	24	42	<i>Slight Noise</i>
Sony SSC-C350	4.23	64	15	49	320	36	41	<i>Slight Noise</i>

*Not measurable, out of noise meters range.

**AGC is not selectable.

Table 10. Nominal Scene Luminance 2.4 Foot Lamberts.
AGC is on when selectable

Camera Model	SCENE LUMINANCE FOOT LAMBERTS	VIDEO LEVEL			RES. HORIZ TVL	SIGNAL-TO-NOISE RATIO		COMMENTS
		WHITE	BLACK	P-P		L&C	L	
Burle TC-252	2.3	60	12	48	300	30	41	Slight Noise
Cohu 6800	2.15	67	38	29	305	28	38	Very Noisy
Cohu 8200	2.52	64	20	44	450	31	22	Noisy
Ikegami ICD-800**	2.04	59	8	51	275	NM*	36	Very Noise
Javelin JE-3362**	2.6	44	15	29	330	21	36	Very Noisy
Javelin JE-3542	2.71	58	14	44	320	34	42	
JVC TK-880U(L)	2.78	45	22	23	300	30	38	Noisy
JVC TK-980U	2.78	60	22	38	310	34	40	
Panasonic WV-CL302	2.39	57	18	39	300	35	41	
Panasonic WV-CL352	2.97	62	14	48	430	29	42	Slight Noise
Panasonic WV-CL702	2.48	60	15	45	410	29	41	Slight Noise
Pulnix TMC-74	1.56	28	8	20	360	27	42	Very Noisy
Sanyo VDC-4124	2.38	52	12	40	330	25	38	Slight Noise
Sony SSC-S20	2.22	43	10	33	450	25	42	Slight Noise
Sony SSC-C350	2.12	60	15	45	320	32	41	Slight Noise

*Not measurable, out of noise meters range.

**AGC is not selectable.

Table 11. Nominal Scene Luminance 1.26 Foot Lamberts
AGC is on when selectable

Camera Model	SCENE LUMINANCE FOOT LAMBERTS	VIDEO LEVEL			RES. HORIZ TVL	SIGNAL TO NOISE RATIO		COMMENTS
		WHITE	BLACK	P-P		L&C	L	
Burle TC-252	1.15	50	10	40	300	29	38	Noisy
Cohu 8200	1.26	60	20	40	420	29	43	Very Noisy
Ikegami ICD-800**	1.02	42	4	38	275	NM*	31	Very Noisy
Javelin JE-3542	1.36	54	12	42	320	31	42	Slight Noise
JVC TK-880U(L)	1.39	50	22	28	280	26	34	Very Noisy
JVC TK-980U	1.39	62	22	40	310	31	39	Slight Noise
Panasonic WV-CL302	1.19	42	14	28	280	34	40	Noisy
Panasonic WV-CL352	1.48	62	18	44	430	25	37	Noisy
Panasonic WV-CL702	1.24	45	10	35	400	28	38	Noisy
Pulnix TMC-74	1.56	28	8	20	360	27	42	Very Noisy
Sanyo VDC-4124	1.19	48	12	36	330	25	37	Noisy
Sony SSC-S20	1.11	33	6	27	450	NM*	39	Noisy, Picture Still Sharp
Sony SSC-C350	1.06	55	15	40	320	30	40	Severe Noise

*Not measurable, out of noise meters range.

**AGC is not selectable

Table 12 Nominal Scene Luminance .5 Foot Lamberts.
AGC is on when selectable

Camera Model	SCENE LUMINANCE FOOT LAMBERTS	VIDEO LEVEL			RES. HORIZ TVL	SIGNAL TO NOISE RATIO		COMMENTS
		WHITE	BLACK	P-P		L&C	L	
Burle TC-252	.46	28	6	22	270	29	36	Very Noisy
Javelin JE-3542	.54	39	11	28	300	33	42	Noisy
JVC TK-980U	.56	60	22	38	280	25	35	Noisy
Panasonic WV-CL302	.47	22	12	10	280	36	40	Very Noisy
Panasonic WV-CL352	.59	40	10	30	400	25	39	Very Noisy
Panasonic WV-CL702	.49	22	8	14	400	32	40	Noisy
Sanyo VDC-4124	.48	28	22	6	280	23	33	Very Noisy
Sony SSC-C350	.42	42	10	32	300	30	36	Very Noisy

7.3 Horizontal Resolution Measurement

The horizontal resolution measurements were achieved by viewing the resolution chart projected on the monitor. The point where the vertical lines are no longer discernible is the limit of the camera's resolution. Table 7/Column 3 indicates the manufacturers' specification for horizontal resolution of each camera and Column 4 the actual measured value.

7.4 Signal-to-Noise Ratio

To determine the S/N ratio, a noise meter was inserted in the circuitry between the camera's video output and the monitor's video input. The measurements were made with and without the chrominance information. Table 7/Columns 4 and 5 give the results of the measurements.

7.5 Camera Performance at Different Light Levels

Combinations of neutral density filters were placed in front of the cameras' lens to reduce the amount of light that reached the faceplate. Tables 8 through 12

provide comparative data of the cameras' performance for dynamic range, horizontal resolution, and the S/N ratio at various nominal test chart luminance values. The cameras are listed in alphabetical order.

Detailed data of each camera's laboratory tests is available from the author at Sandia National Laboratories, Albuquerque, New Mexico, 87185. The author can be reached at (505) 844-9630.

8.0 Newly Developed Test Parameters

The camera test parameters that were developed and tested are white balance, color rendition under commonly used light sources, and low light level color rendition.

8.1 White Balance

Color temperature of a light source is defined as the absolute temperature of a blackbody radiator having a chromaticity equal to that of a light source. For example, a commonly used, incandescent, house lightbulb has a color temperature of ~ 3200 Kelvin and distributes a reddish light. The color temperature for high pressure sodium is ~ 2100 Kelvin and distributes light that is more saturated by red. On the other hand, fluorescent cool white has a color temperature of 4050 Kelvin and provides close to a preferred white light.

If a color camera used in a closed circuit television system (CCTV) is not white balanced, a scene viewed on a properly adjusted monitor will have an overall tint that appears to be the same color as the illuminating source. The tint can cause object colors to appear different than they will when they are viewed under a white illuminating source. Most color cameras incorporate circuitry that permits them to white balance and most manufacturers refer to these cameras as auto white balancing. This can be quite misleading because in some cameras the process is not completely automatic:

- Some cameras provide a button that has to be pushed to activate the circuitry. Sometimes while performing this procedure, a white object has to be placed in the camera's full field-of-view.
- Other cameras will totally white balance automatically through a broad range of color temperatures.

White Balance Test Procedures

The cameras were tested (see results in Graphs 3 through 5) one at a time using a manual iris lens. This lens was chosen because of the ease of exchanging the same lens amongst various cameras. The cameras' video output was attached to the video input of a vector scope and looped through to a color monitor.

The red, green, and blue color squares on a color chart produced by Macbeth, Inc. were framed in black. Each camera was setup so that the field-of-view framed the squares and a portion of the black, making sure nothing else was in the scene. The three colors (when viewed by a white balanced camera) display three distinct vectors on the vector scope. However, a camera not properly white balanced displays a fourth (spurious) vector and the overall picture tint changes to that of the illuminating source chromaticity. The magnitude of the fourth vector is proportional to the tint.

The framed color squares were first illuminated by two incandescent lamps with a color temperature of ~ 2950 Kelvin and the aperture of the lens was adjusted so that the peak video signal reached 100 IRE units, and the magnitude of the spurious vector, if any, was measured. The magnitude of this vector gives an indication of the overall picture chromaticity and is indicative of the camera's white balance performance.

These procedures were repeated at 1800 and 5000 Kelvin, the approximate color temperatures of low pressure sodium and fluorescent cool white, respectively. Color temperature changing filters were placed in front of the camera lens to achieve these temperatures. The following three graphs show the magnitude of the spurious vector produced at the three selected color temperatures, where 0 IRE units is the optimum level, indicating that a camera is white balancing perfectly.

Detailed data of each of the camera's laboratory tests for white balance is available from the author.

Graph 3. White Balance Test Results
(Fourth Vector Magnitude)

Graph 4. White Balance Test Results Continued
(Fourth Vector Magnitude)

Graph 5. White Balance Test Results Continued
(Fourth Vector Magnitude)

8.2 Color Rendition Under Commonly Used Light Sources

What objects "color" is perceived under different light sources is an area of concern. For instance, will a red object appear red if it is illuminated by low pressure sodium lighting and if the object is viewed through a CCTV system? If so, would that same object appear the same hue of red under fluorescent?

The electromagnetic energy reflected from an object causes its perceived color; all other energy is absorbed or transmitted. The dominant wave-length of the energy determines the hue or color, and the amount of reflected energy determines its brightness.

For instance, if a light source does not emit energy in the wavelength that will be reflected by an illuminated object, that object will appear gray or black. With that being the case, the spectral power distribution characteristics of an illuminating source are critical. The term "spectral power distribution" characterizes a light source's ability to emit electromagnetic energy at different wavelengths. For example, luminaires that exhibit good spectral power distribution emit representative electromagnetic energy evenly throughout the visible spectrum. These luminaires demonstrate good "color rendering" properties.

An incandescent lamp that demonstrates good color rendering properties was used as a reference against which to compare other commonly used light sources. The other light sources chosen for the color rendition evaluation were fluorescent, high pressure sodium, and low pressure sodium.

8.2.1 Test Procedures For Color Rendition Under Commonly Used Light Sources. The same framed red, green, and blue color squares that were used in the white balance test were first illuminated by an incandescent light source and a recording was made. Next, the chart was recorded while being illuminated separately by the other three light sources.

The recordings were then played through the video input of a vector scope and the signals were analyzed. The vector scope displays a discrete vector for each of the three color bars. The hue can be determined from the vector angle. The magnitude represents the amount of color. This procedure provided a means of objectively determining each lamp's color-rendering property. The recordings were also viewed on a monitor and were subjectively analyzed.

8.2.2 Results of Test For Color Rendition Under Commonly Light Sources. By knowing the spectral power distribution of the different lamp sources, the results were as we expected. The fluorescent lamp retains the hue closest to that of the incandescent. Because the high pressure sodium lamp distributes a significant amount of energy in the wavelength of the color bars,

the hues also very closely matched that of the incandescent lamp; however, the amount of color was less. The low pressure sodium caused the wavelengths to appear gray to near black because of the lack of energy emitted in the wavelengths that would be reflected by the color bars,.

8.3 Low Light level Color Rendition

There was a desire to determine at what low light level "colors" would no longer be discernible, so the following test was devised.

8.3.1 Test Setup Procedures. Using the Optoliner, a camera was attached to view a color bar chart. The illuminating source inside the Optoliner was set to a color temperature of 2850 Kelvin. At this temperature, the illumination provided is more than enough for the camera to produce a full video signal (100 IRE units peak to peak). Combinations of neutral density filters were placed between the light source and the camera lens to reduce the amount of light reaching the faceplate of the lens. The intent was to discover at what minimum light level the color bar "color" would no longer be discernible.

8.3.2 Results. The low light level color rendition test showed that the picture degrades to a point where it is no longer usable before the color bar "color" becomes indistinguishable. The picture becomes noisy and this causes resolution loss.

9.0 Summary

The initial laboratory evaluation was conducted on 18 solid-state color video cameras by traditional test methods for sensitivity, resolution, S/N ratio, and intrascene dynamic range. All 18 were tested by newly developed test procedures for white balance, color rendition under commonly used light sources and low light level color rendition. The results of the evaluation for traditionally tested parameters were compared to those of the latest laboratory evaluation of monochrome solid-state video cameras.

For intrascene dynamic range performance, the evaluation demonstrates that no significant differences exist between monochrome versus color cameras. It also shows that the S/N ratios are similar when the chroma information is filtered out from the video signal. (This filtration is an industrial standard procedure.) The evaluation further concludes that monochrome cameras are still more sensitive and provide greater resolution than chromatic cameras. Because their higher performance can reduce system cost, choosing monochrome cameras for perimeter security applications, where the objective is to classify rather than identify an intrusion, would be prudent. The more sensitive the camera, the less light fixtures, light poles, and other related

lighting equipment are necessary. Higher resolution cameras result in longer and larger zones and thus require less cameras, camera towers, and other related video equipment.

Three newly developed test procedures were contrived as a result of the evaluation. These procedures were established specifically for testing color cameras "color" performance. The test were for white balance, color rendition under commonly used light sources and low light level color rendition. The evaluation showed that methods for achieving white balance varied between different camera manufacturers. It also revealed that some of the cameras white balance performance was inconsistent at different color temperatures. Some cameras white balanced perfectly and automatically through a broad range of temperatures. Other cameras white balanced only after performing procedures such as pushing a switch to activate the white balance circuitry, or placing a white object in the full field of view of the camera.

The evaluation also concluded that for cameras to exhibit good color rendition, a light source with good "spectral power distribution" is needed to illuminate the scene. For instance, low pressure sodium that emits strong electromagnetic energy only in the wavelength that displays yellow, when reflected by an illuminated object, is not a good illumination source.

The evaluation furthermore concluded, that for color rendition under low light level, the image quality deteriorates to a point deemed unusable before there is any appreciative color degradation.

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