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FIVE COLOR SEPARATION INVESTIGATION

Final Technical Report No. 6031

November 1967

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
TOPOGRAPHIC SYSTEMS DIVISION
FORT BELVOIR, VIRGINIA 22060

Prepared under Contract No. DAAK02-67-C-0172

THE te COMPANY
SANTA BARBARA, CALIFORNIA

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Task No. 4A623501A85203

Prepared under Contract No. DAAK02-67-C-0172

The Te Company
505 E. Montecito Street
Santa Barbara, California

SUMMARY

The purpose of this program was to determine the feasibility of extracting electronically cartographic type single color imagery from multicolor maps. Unlike conventional three color graphic arts methods of subtractive color extraction, the approach utilized from four to twenty color sample analysis and analog and digital processing of the color data. The object map was line scanned, the resultant optical signal separated into color channels that in turn were converted to electronic signals, and these signals processed to produce a yes-no output recreating the wanted color line scanned on film. Both color matrix optimization and multilevel logic electronic processing functions were evaluated.

The results showed that color matrix optimization was not completely effective. The multilevel logic function, however, produced excellent results for several sample map sections tested. These maps included variations in print color, color overprinting, variations in substrate paper, and a wide variety of print geometries. The overlay of the resultant color extractions produced a faithful rendition of the original map, with the slight exception that fine detail such as halftone printing tended to be enhanced. Setup time to establish the logic extraction parameters for a given map was about 15 minutes for each color.

FOREWORD

This report was prepared by The Te Company, 505 East Montecito Street, Santa Barbara, California, under Contract No. DAAK02-67-C-0172, dated 12 December 1966.

The program, covered by this final report, was monitored by Mr. Henry Wiener, U. S. Army Engineer Topographic Laboratories, Topographic Systems Division, Reproduction Branch, Fort Belvoir, Virginia. The work was conducted at The Te Company under the direction of Dr. R. S. Neiswander. Analytical and computer studies were contributed by Mr. C. W. Harris. Laboratory investigations and operational tests were conducted by C. R. Lierley.

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INVESTIGATION

1.0 INTRODUCTION:

The purpose of this Research and Development Program was to investigate means of automatically making five color separations from multicolor maps. The approach was to scan the object map with a raster scan pattern (similar to facsimile transmission methods) using several color channels, then process the resultant color signals to select the wanted color and reject the remainder, and finally to recreate the portion of the map containing the wanted color. Electronic processing involved real time analog and decision operations, initially based upon a color matrix optimization and later upon a multilevel logic function as discussed below. From the results of this investigation, the optical parameters and requirements for a prototype five color map separation system were defined.

Experimental evaluations of the color extraction functions were performed using the simulator instrument developed and fabricated under ARPA/ONR contracts No. Nonr 4570(00) and No. Nonr 5050(00) and described in References 2 and 3. Experience gained and techniques evaluated under these previous programs proved to be invaluable aids in guiding the effort of the present program.

In the program the procedure was 1) to measure color signals representing a given map sample, 2) select a function and parameters of this function that provided best separation of the colors, 3) perform a static evaluation of the function using the map sample, and 4) if the static evaluation justified it perform an automatic extraction of the map colors. The originally selected matrix optimization function was less effective than anticipated and this was replaced by a multilogic function expanding the initial scope of the contract. In the experimental evaluations, complex factors characteristic of the actual problem were considered. For example, the effects of solid, dotted and halftone geometries upon the extraction, the effects of color overprinting and the variable effects of printing inks and papers were examined. The potential advantages of infrared color analysis of certain inks was explored.

In the following subsections, first the technical program is described and then a brief historical background of related programs at Te is presented.

1.1 PROGRAM TECHNICAL APPROACH:

The work to be accomplished on the program was divided into four phases to meet the following specified basic requirements:

PHASE I - SPECTRAL RESPONSE DATA ACQUISITION

From map samples furnished by the government, individual pure and overprint color combinations shall be isolated on each map and spectral response data measured. Static measurements will be accomplished using the ARPA simulator (explained in detail in Section 2.1.1) and various Wratten and interference type filters covering the 0.4 to 0.9 micron range.

PHASE II - COMPUTER MATRIX OPTIMIZATION AND MULTILOGIC DECISION CIRCUIT OPTIMIZATION

A general computer program to produce an "influence matrix" that will converge on an optimum 20 x 12 matrix shall be provided to evaluate the raw data from Phase I. This computer program will produce various "merit functions" which will be evaluated to determine which are most effective in producing rapid solutions. From these merit functions, raw data from each map sample shall be introduced and optimum filter functions calculated. Additionally, theoretical color extraction effectiveness by multilogic decision techniques will be analyzed and logic functions established. An appraisal of results will be made to determine the most effective color separation approach.

PHASE III - EVALUATION OF RESULTS

For each of the samples, the filter functions shall be appraised from an application point of view. An assessment of the degree of success of the extractions, considering the indeterminances of the map, such as ink application quality, spectral response variations over the map format area for a given color, effects of overprint combinations, measurement precisions, and level of separation achieved, shall be made. The overall results of the program shall establish the effectiveness and capabilities of the selected optimization technique and provide basic data for defining the requirements for a prototype five color opaque copy separator.

PHASE IV - SAMPLE COLOR EXTRACTION

The effectiveness of the selected color separation technique shall be verified operationally on the ARPA optical processing simulator. One color, to be selected by the government, shall be extracted from one of the map samples under evaluation in this program.

1.2 RELATED PROGRAMS TO OPTICAL PROCESSING TECHNIQUES:

The study and investigation into individual map color separation techniques, defined in this program, was an outgrowth of prior work by The Te Company, over the past eight years, in the specific area of optical processing techniques. Specifically, it is an extension of work conducted for the Advanced Research Projects Agency in the study and development of techniques and equipment for target enhancement and extraction by optical processing methods. Three programs in this area were conducted under contract to ARPA/ONR and are listed under References 1, 2 and 3.

During the course of the above contracts, a four channel optical processing machine was designed and built by The Te Company for experimental purposes.

Referred to as the ARPA simulator (see Section 2.1.1), this equipment and its related circuitry were readily adaptable to the requirements of this present program in the areas of data acquisition and opto-mechanical experimental functions. Noninterference use of the ARPA simulator was authorized by the contracting officer at the Office of Naval Research.

Although the primary use of the simulator during the ARPA/ONR contracts, was in target extraction and enhancement of high resolution black and white aerial photography, some experiments were performed on idealized color targets. These preliminary color extraction tests were sufficiently successful to indicate that complete extractions of wanted colors and overprint combinations might be performed.

2.0 INVESTIGATION:

The test and evaluation procedures for the program were performed essentially as follows:

A. Equipment and support material selection, checkout, and calibration.
B. Acquisition and evaluation of IR spectral response data.
C. Study and evaluation of spectral response characteristics to establish spectral intensity and color balance ratio variation parameters.
D. Computer oriented optimization technique analysis.
E. Multilogic decision circuit technique analysis.
F. Theoretical data application to multilogic decision circuit optimization techniques.
G. Operational extraction tests utilizing multilogic decision circuits.
H. Evaluation of operational results versus theoretical predictions and establishment of the basic capabilities and requirements for a prototype 5 color map separation machine.

2.1 TEST EQUIPMENT, MATERIALS, AND PROCEDURES:

2.1.1 ARPA SIMULATOR:

All spectral response test data obtained during this program were measured statically using the ARPA simulator shown in Figures 2-1 and 2-2. Basically, the simulator, used statically, is a top stage illuminated microscope. The object scene element in the field of view is reimaged within the system at a chopper. The modulated signal is then directed through an appropriate filter onto a photomultiplier tube. The amplified signal from the photomultiplier tube is monitored with a digital voltmeter. The optical schematic of the simulator is shown in Figure 2-3. The photomultiplier tubes used in the system were the S-10 spectral sensitive tube, RCA #6217, and the S-1 spectral sensitive tube, RCA #7102. The S-10 photomultiplier is sensitive in the spectral region between 0.30 to 0.75 microns. The S-1 photomultiplier, used in the IR test phase of the investigation, is spectrally sensitive from approximately 0.30 to 1.10 microns. Its very low sensitivity, compared to the S-10 P.M.T., is the reason it was not used for evaluations in the visible spectral region.

DETAILED OPERATIONAL DESCRIPTION

Referring to Figure 2-3, the right hand portion of the drum holds an 8 x 10 inch opaque object scene (usually a photograph) which can be scanned over a 6.5 x 10 inch area. The left hand portion of the drum (of the same diameter) holds the film which is exposed to the object scene at 1:1 size and frame rate. The drum is driven by a synchronous motor which is mounted on the drum carriage, and moves laterally with it. The drum rotating at 20 revolutions per minute generates the pickup and the print-out raster scan lines. (One scan line is generated per drum revolution.) Another synchronous motor drives the drum and carriage assembly linearly on the lathe bed through a

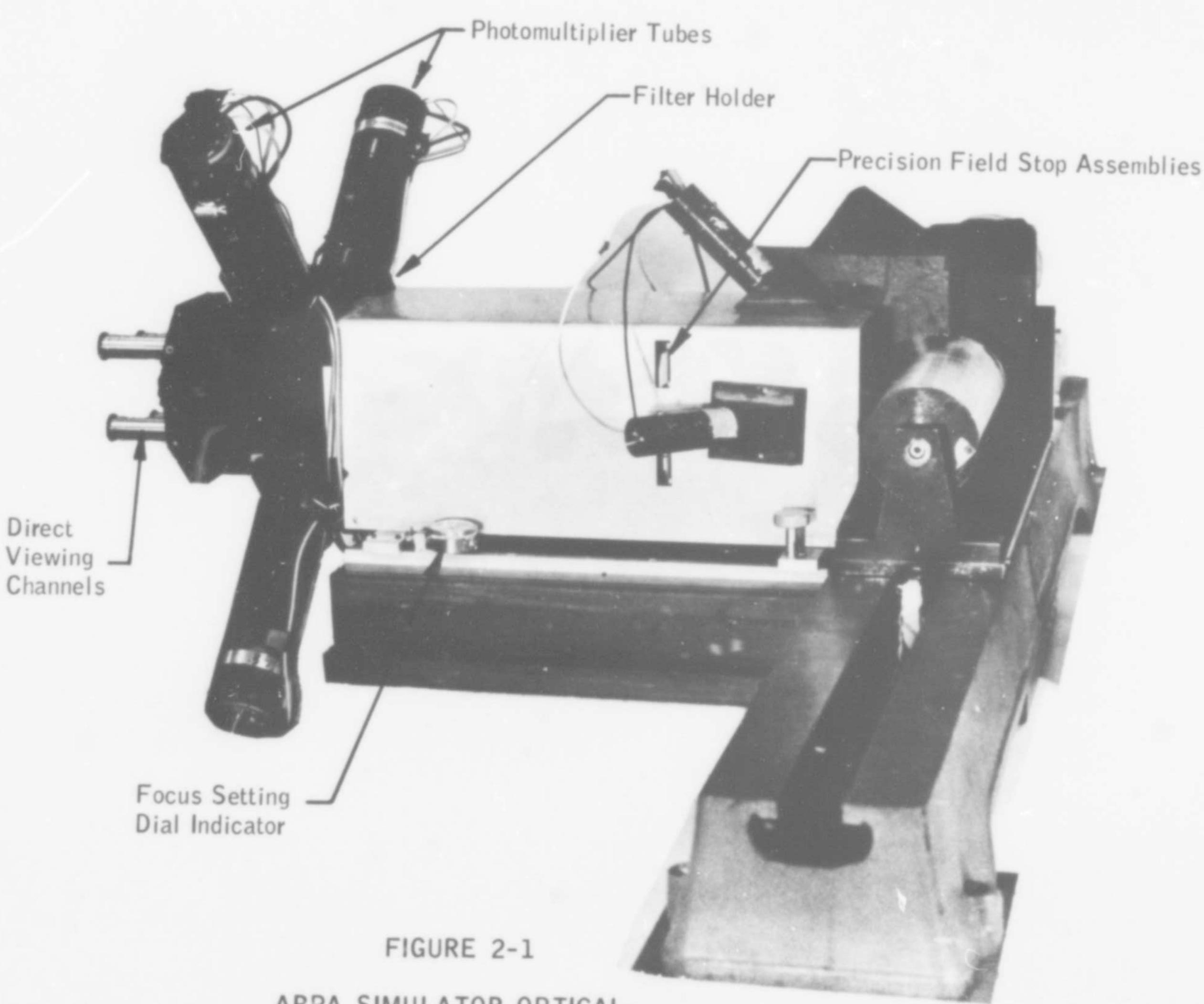


FIGURE 2-1

ARPA SIMULATOR OPTICAL-

ELECTRONIC PROCESSOR (OPTICAL UNIT)

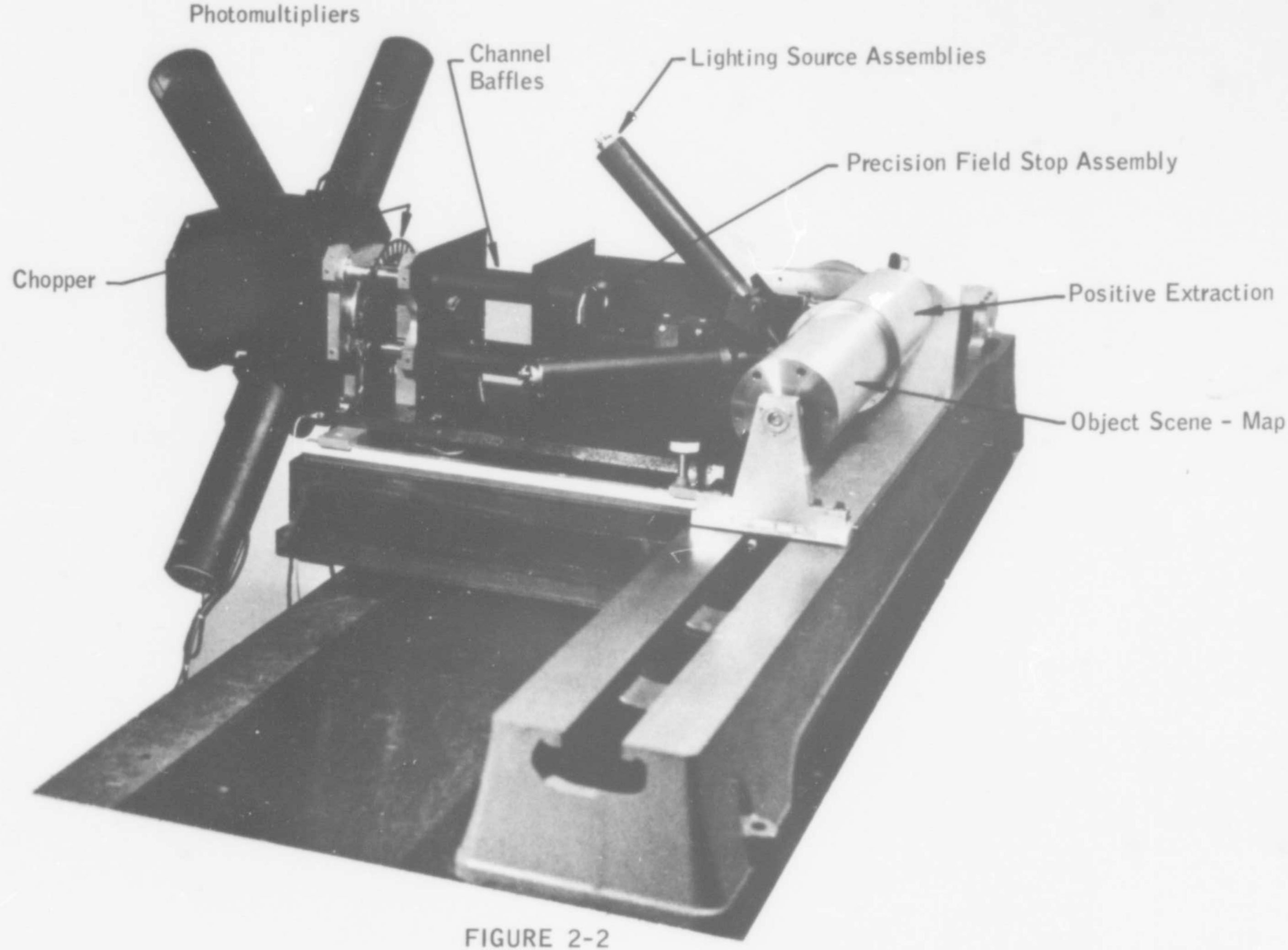


FIGURE 2-2

ARPA SIMULATOR OPTICAL ASSEMBLY

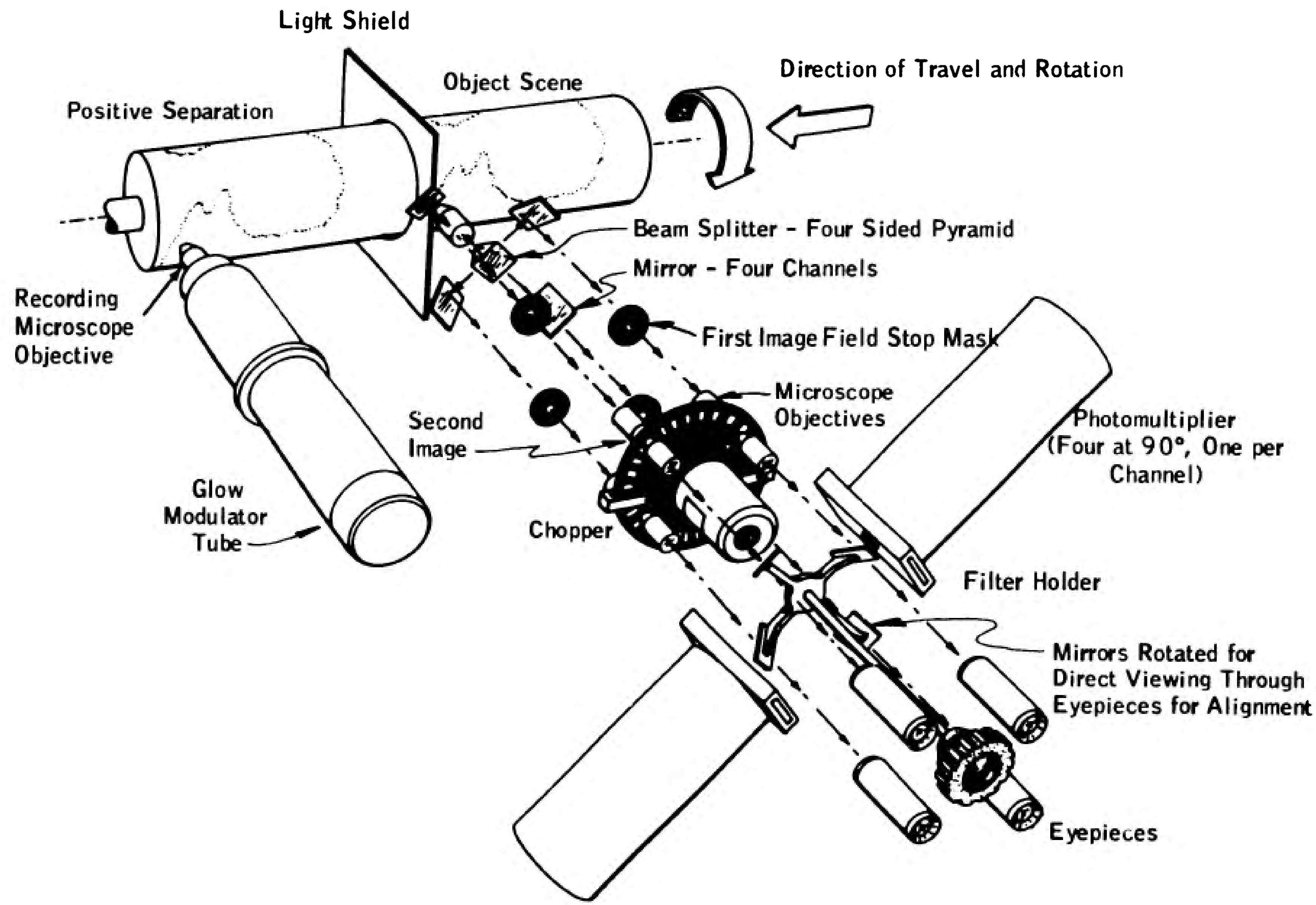


FIGURE 2-3

SCHEMATIC, OPTICAL-ELECTRONIC PROCESSING DEVICE precision lead screw — to generate the 0.004 inch spacings of the raster scan lines. The raster scan frame has 250 lines per inch, with a resolvable scene element diameter of 0.003 inch to 0.004 inch. (Thus, the order of 61000 resolvable scene elements per square inch are available.)

Three illuminating assemblies project the diffuse, defocussed images of "large" coil lamp filaments onto the same object drum area — approximately 0.15 inch diameter. Lighting from the three directions assures that a preferred surface reflection from an imperfect object surface will have a minimal effect on the optical signal output. The lighting is aligned and balanced with the aid of the direct viewing feature of each optical channel.

A single 10 power microscope objective is the "optical pick-up" element for all four optical channels. Immediately behind the microscope objective, a four-side reflecting pyramid splits the beam into equal components that are to become the four optical channels of the processor. At the first image, in each channel, a field stop selects the size and shape of the field observed. The field stops are in precision holders that are interchangeable among all aligned channels. The field stop holders are spring loaded against two reference surfaces.

Beyond the first image, a relay microscope objective, in each channel, produces a second image at the chopping disk. Each optical channel is carefully isolated from the other channels by various baffles - including the tubing shown in Figure 2-2 . The chopped energy in each channel is relayed by a microscope objective and a 90 degree reflection toward the individual photomultiplier tubes. The energy is distributed across the photomultiplier target with a "field" lens. A filter holder is provided in front of each photomultiplier tube - to facilitate the use of neutral density filters, and color filters - in a location which does not effect critical optical alignments or focus.

The four mirror assembly is rotated out of the optical paths of the four channels (with the large knob near the eyepieces) for direct viewing of each optical channel through the microscope eyepieces. The image viewed is the field stop with the object scene picked up by the front microscope objective. The field of view of the visual sighting feature is sufficiently large to cover the entire field of illumination on the object drum. Crosshairs are provided in the eyepieces to assist in verifying channel alignment for each new insertion of a field stop.

The entire pick-up optical system assembly is focussed by moving the entire unit, rather than by adjusting each of the four optical channels. (Figure 2-1 shows the dial indicator which can be used to reset focus, and to monitor focus distance settings.) Each new object scene is tightly mounted around the object drum, and checked for focus in the system. The direct viewing channels are used to visually evaluate the focus setting. Focus is critical; even differences of a few thousandths of an inch in the thickness of photographic prints effect the alignment of the four channels.

The signals from each of the four photomultiplier tubes are fed to individual amplifiers, (see amplifier and glo-modulator drive chassis, Figure 2-4). Fine balance and/or gain setting for each channel is accomplished by adjustment of the individual ten turn "pots" provided. The amplifier and glo-modulator drive chassis provides monitoring jacks for the output signal of each channel to which the digital voltmeter is attached for static measurements. Operationally the signals from the four channels are fed into some type of signal processing device. The processed signal is then fed to the glow modulator tube drive. (The glow modulator tube has a nearly linear light output response to the input current.) The Sylvania, R-1169, source (an illuminated crater of about .025 inch diameter) is projected onto the recording side of the drum with a ten power microscope objective. The focussed spot size is

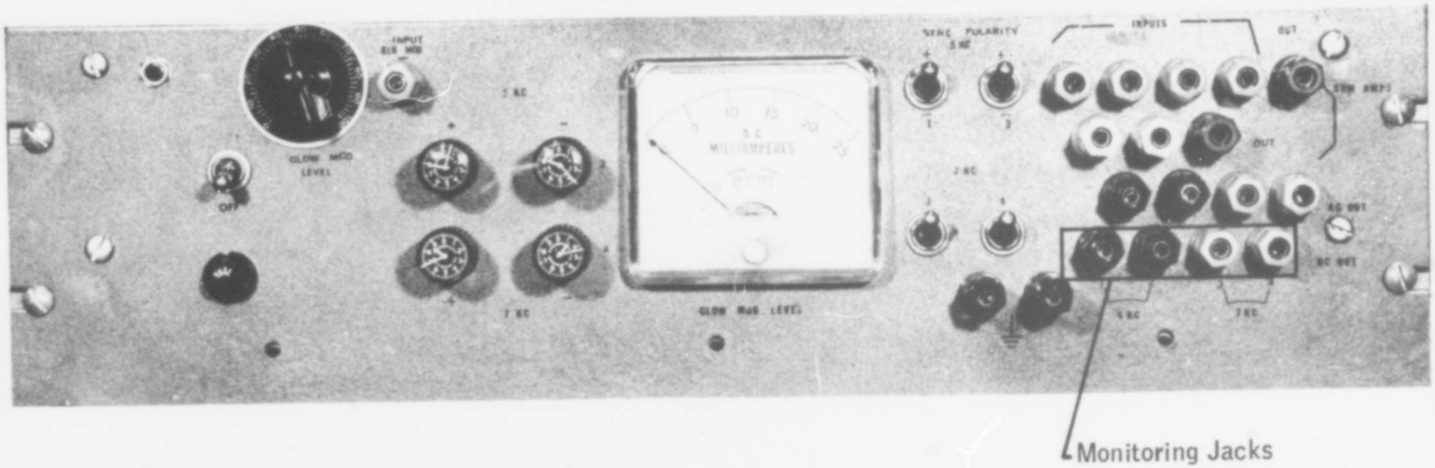


FIGURE 2-4

AMPLIFIER AND GLO-MODULATOR DRIVE CHASSIS nominally .003 inch in diameter. With variable gain and control of the tube quiescent level (zero signal level), exposure and exposure range best matched to the recording film can be preset.

A block diagram of the electronic signal processing function of the ARPA simulator, as it was originally intended for use, is shown in Figure 2-5.

Figure 2-6 shows a graph of the relative system sensitivity versus wavelength using the S-10 sensitive photomultiplier and tungsten illumination.

2.1.2 SPECTRAL RESPONSE DATA ACQUISITION PROCEDURES:

All spectral response data obtained for this program was measured statically on the ARPA simulator using tungsten illumination at rated maximum voltage. The field stop mask (see Figure 2-3) size used was .060 inch, which relates to a resolution element of .006 inch at the object plane. Wanted areas on the sample maps are visually located in the field of view using the reflex capability of the simulator by simply rotating the folding mirror knob next to the eyepiece assembly. After the selection of the wanted scene element, the folding mirrors are rotated back to their normal operational position. The desired filter is then placed in the filter holder and the amplified output signal monitored with a Digitec, Model #201, calibrated digital voltmeter and manually recorded.

2.1.3 MAP SAMPLES:

The map samples used in this program were selected and supplied by the U.S. Army Engineering Topographic Laboratories, Topographic Systems Division Reproduction Branch of Fort Belvoir, Virginia. The eight map samples supplied were chosen to present the wide range of printing techniques, ink color

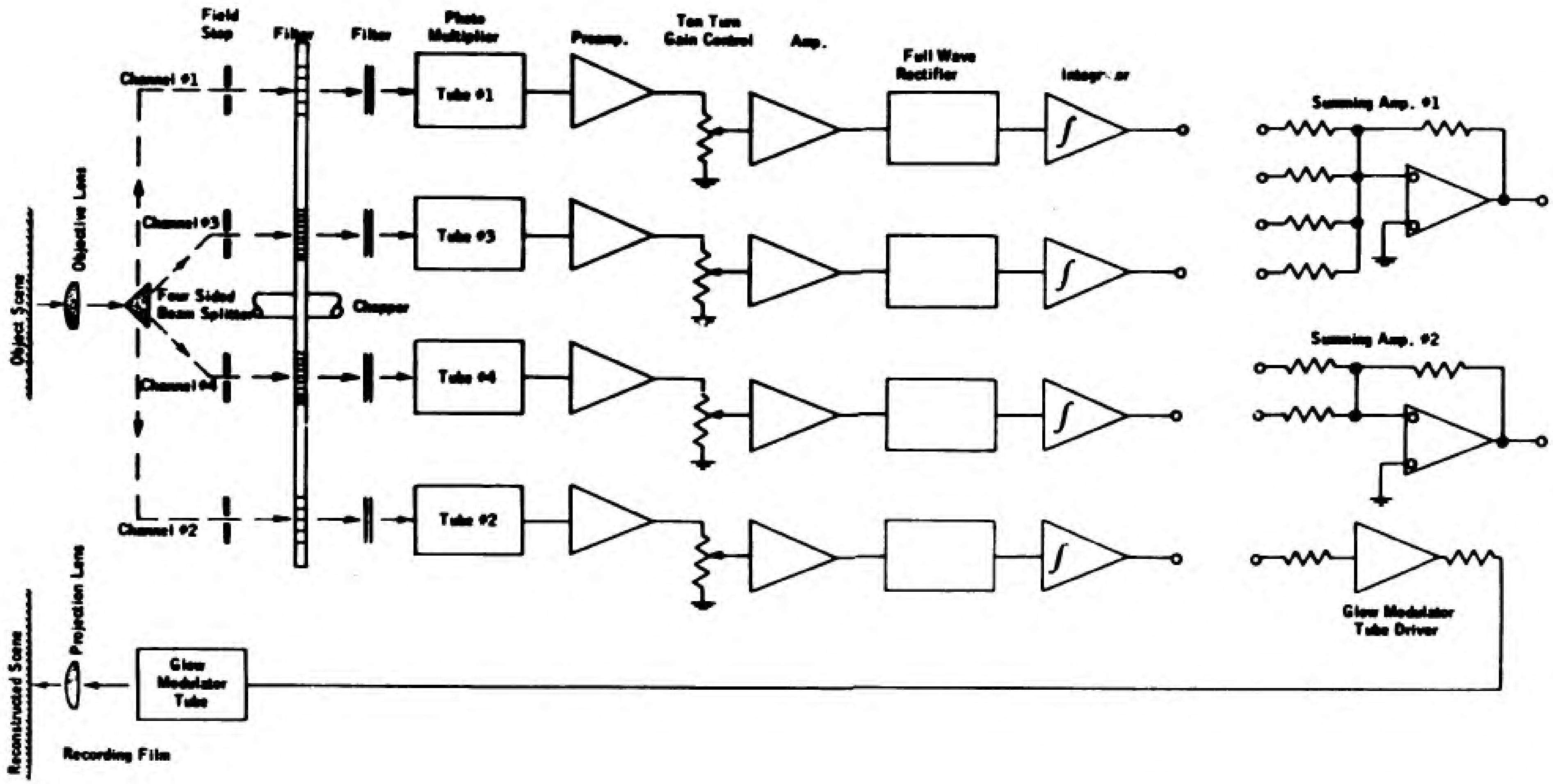


FIGURE 2-5

ARPA SIMULATOR BLOCK DIAGRAM OF SIGNAL PROCESSING FUNCTION

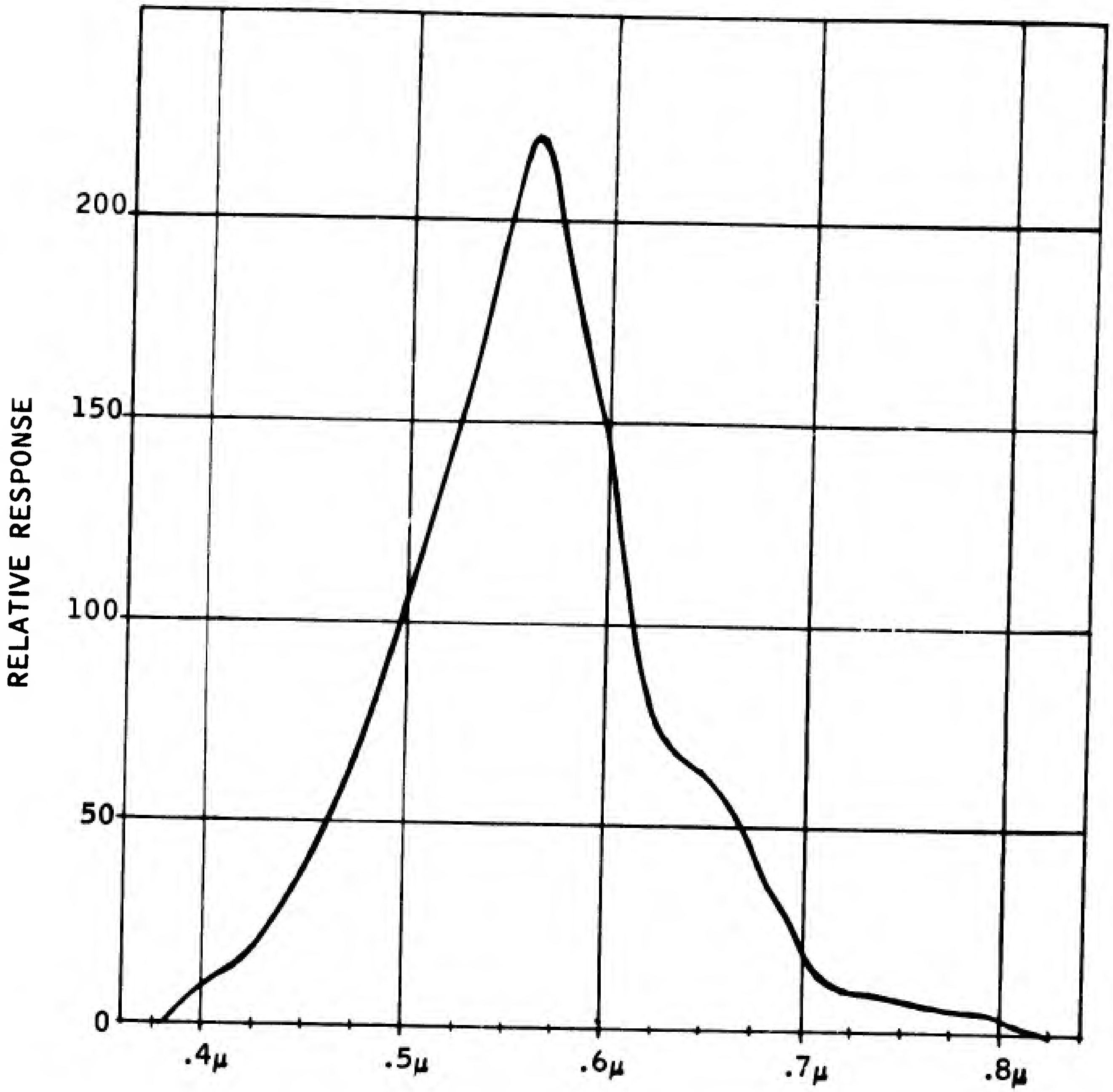


FIGURE 2-6

RELATIVE SYSTEM SENSITIVITY

variation, and map qualities presently being reproduced by various government agencies. All maps evaluated might best be classified as "originals" having a minimum of five distinct colors imprinted. Tints of given colors are accomplished by halftone dot or line patterns on these multicolor printed maps.

VISUAL ANALYSIS AND EVALUATION OF SAMPLE MAPS

At the onset of the program, all eight GFE maps were visually evaluated to determine (1) the ink application quality, (2) number of pure colors and number of overprint color combinations required to be extracted, (3) any special IR characteristics, and (4) resolution requirements. This preliminary evaluation was performed to establish the data acquisition and data processing parameters to be employed in the investigation as well as to uncover unforeseen problem areas. The visual IR analysis was made using a Varo Detectirscope - Model 5500 - C infrared viewer and Wratten IR filters #87, #87-C, and #87-A.

To meet the copy size limitation of the ARPA simulator, representative areas from each map sample (approximately 8 x 10 inches) were selected and removed for the spectral response measurement phase of the program.

RESULTS OF VISUAL MAP EVALUATIONS

GENERAL

The ink application quality is defined, for purposes of this investigation, by the uniformity of the ink's adherence to intended areas and the sharpness of separation at boundaries. Generally, all but one or two of the eight maps could be rated as having good ink application quality. Some individual colors on each given map did exhibit poorer quality than others, however. Overprint combinations varied considerably in application uniformity for particular colors on most map samples.

Six of the eight maps were printed in five colors; one map had six colors; and one map had eight individual colors imprinted. Since the basic concept of the program was to establish the parameters for a five color map separator, the eight color map was eliminated from further test considerations. The six color map was kept in the test program because its basic colors were the same as the five color maps. An evaluation of the overprint color combinations on the remaining seven maps indicated that only six or seven needed to be considered for the analysis phase in order that information and completeness would be maintained.

An IR analysis was included in the program after literature surveys indicated that some printing inks did have special IR characteristics. The visual IR analysis of the maps performed, did in fact, uncover one interesting situation. On three of the maps, blue and blue overprint combinations were highly reflective in the near IR region. Spectral response tests in the IR region were scheduled for the program as a result.

The maximum resolution requirements were found to be approximately .004 inch on most of the map samples. This implies that the smallest point or line width to be extracted was equal to or greater than this dimension.

INDIVIDUAL MAP IDENTIFICATION AND VISUAL APPRAISAL

Results of visual analysis of each map sample and the assigned program identification numbers are as follows:

MAP #1: Indian Head, Maryland and Virginia.
Series #: N-3830 - sheet #: W7700/15

Ink application quality: Red, light blue, green, brown, and overprint combinations of these colors was good. Black and blue inks varied considerably. Overprints of the colors were generally poor.

Number of colors and combinations to be considered: This six color map had five important overprint colors.

IR viewer evaluation: This map had relatively low blue ink reflectance.

Resolution requirements: .004 inch for smallest scene element.

MAP #2: Biên Hòa, Vietnam.
Series #: L-701 - sheet #: 6343-1, Edition #: 2 AMS (FE)

Ink application quality: Ink application was generally even for all colors and overprints. The inks appeared to absorb readily into paper, however, and sharpness was reduced due to diffusion at boundaries.

Number of colors and combinations to be considered: Only five pure colors and two overprints were required for extraction.

IR viewer evaluation: Reflectance of blue ink was low.

Resolution requirements: .004 inch halftone dots are smallest elements.

MAP #3: Port Royal, Virginia.
Series #: V-734 - sheet #: 5560-11, Edition #: 1

Ink application quality: All colors and overprints reasonably good. Black and blue inks have the poorer application quality.

Number of colors and combinations to be considered: Five pure colors and three overprint combinations.

IR viewer evaluation: Blue and blue overprint combinations exhibited high IR reflectivity.

Resolution requirements: Lines as small as .004 inch exist on this map sample.

MAP #4: Meiningen, Germany.
Series #: M-745 - sheet #: L-5528, Edition #: Provisional

Ink application quality: Very poor quality map. An extreme amount of small detailed information is presented on this map. Ink did not adhere well to the paper and colors appear very light. Red appears visually to be very similar to the brown ink.

Numbers of colors and combination to be considered: Five pure and two overprint colors.

IR viewer evaluation: High blue ink reflectance obtained.

Resolution requirements: A great amount of the detail on this map is in the .003 to .004 inch element size.

MAP #5: Mount Vernon, Virginia.
Series #: V-834 - sheet #: 5561 - 11 - NE, Edition #: 4-AMS

Ink application quality: Red, green, and brown ink application is very good. Black ink application varies between poor and good and blue ink application is generally poor.

Number of colors and combinations to be considered: This map has overprints of almost all possible combinations, however, only four are considered for extraction with the five pure colors.

IR viewer evaluation: Blue ink and overprints had low IR reflectance characteristics.

Resolution requirements: Minimum scene element size on this map is .006 to .008 inch.

MAP #6: Alexandria, Virginia.
Series #: V-834 - sheet #: 5561 - 1 - SE, Edition #: AMS

Ink application quality: Generally good quality over the entire format. Red halftone dot areas vary in dot size at different locations on the map giving the visual appearance of a slightly different tint.

Number of colors and combination to be considered: Five pure colors and three overprint combinations require extraction on this map sample.

IR viewer evaluation: High blue ink reflectance.

Resolution requirements: .006 to .008 inch are smallest size scene elements.

MAP #7: Centre Hall, Pennsylvania.
Series #: N-4045 - sheet #: W-7730/15

Ink application quality: General ink application quality is poor on this map although the separation is good giving an appearance to the unaided eye of being very sharp and clear.

Number of colors and combinations to be considered: Five pure colors and six overprint combinations are required for extraction.

IR viewer evaluation: Blue ink exhibits low IR reflectance on this sample.

Resolution requirements: Line widths of approximately .004 inch appear on this map.

2.1.4 FILTERS:

Filters used to obtain spectral response data during the program were of the narrow band interference type and wide band Wratten gelatin type. The narrow band filters, manufactured by Optics Technology Inc., were calibrated prior to the data acquisition phase of the project using a Beckman DK-2A Spectrometer. The Eastman Wratten gelatins were not calibrated.

NARROW BAND FILTERS

The bandwidth of these filters is less than 5% of peak transmission wavelength at a 50% filter transmission level.

Peak Wavelength In Microns	Percent Transmission At Peak Wavelength	Filter Bandwidth In Microns At 50% Peak Transmission
.406μ	24%	.020μ
.427	29	.015
.469	34	.013
.496	37	.014
.537	33	.017
.558	44	.021
.594	43	.019
.626	33	.013
.653	38	.020
.682	35	.018
.705	37	.020
.736	18	.027
.787	39	.027
.817	33	.026
.849	31	.027
.913	20	.024
.946	24	.028
.982	24	.028
.996	31	.025

WIDE BAND FILTERS

Wide band Wratten gelatin filters used for evaluation are listed below with their apparent visual color and approximate transmission bandwidth.

Wratten #	Color	Approximate Transmission Range In Microns
29	Red	.61 to IR
32	Magenta	.32 to .49μ and .64 to IR
34	Magenta-Blue	.32 to .52μ and .60 to IR
47B	Blue	.38 to .49μ
58	Green	.48 to .60μ
65	Orange	.44 to .57μ
87	IR Filter	Cut on at .74μ
87-C	IR Filter	Cut on at .80μ
87-A	IR Filter	Cut on at .88μ

2.1.5 PHOTOGRAPHIC TECHNIQUES:

The extraction tests performed during the program were recorded on Eastman Kodak Kodalith Royal Ortho Estar Base (4 mil) film. Films were processed in D:19 developer at a 1:1 dilution for two minutes at 72°F.

2.2 IR SPECTRAL RESPONSE CHARACTERISTICS:

PURPOSE: An investigation of the spectral response characteristics of the printing inks on all of the map samples was performed in the .8 to 1.0 micron region to verify the visual IR viewer results presented in Section 2.1.3 and to establish any added extraction capability this spectral region might offer.

TEST PROCEDURES: The ARPA simulator electronics was modified to accept the S-1 sensitive photomultiplier tube for the IR spectral response tests. Initially, the tests were scheduled to be performed with the calibrated narrow band interference filters, but due to the very low system signal-to-noise ratio using this photomultiplier, tests had to be run with the higher transmitting wide band Wratten IR filters #87, #87-C, and #87-A. These filters cut-on at .74, .80, and .88 microns respectively. Spectral response data was recorded for each map sample using the above filters and without any filter.

RESULTS: The three maps, (#3, #4, and #7) which showed a high reflectivity of the blue printing inks when observed through the IR viewer exhibited the same results when measured on the ARPA simulator. The intensity measurements were five to eight times higher than the blue inks of the other five map samples. The remaining pure and overprint color combinations were nearly identical on all the maps. The "no filter" spectral response measurements were merely attenuated by the IR Wratten filters. The #87, (cut-on at .74 microns), filter reduced the signal intensity between 70 and 80 percent. The #87-C, (cut-on at .80 microns) reduced the signal intensity between 85 to 95 percent of the "no filter" condition. Signal levels with the #87-A filter (cut-on at .88 microns) were too low to be meaningful.

No special IR sensitivity characteristics were found for any of the other inks or the map papers.

2.3 SPECTRAL RESPONSE VARIATIONS:

PURPOSE: Investigation of the spectral response characteristics of the various papers and printing inks was performed to determine the magnitude of intensity range variations and related color balance ratio changes that occur, and must be considered in the data processing and analysis phases of the program.

TEST PROCEDURES: Map #1, (Indian Head, Maryland; Virginia) was selected for the color intensity evaluation. Spectral response measurements of the map paper and ten pure and overprint color combinations were obtained at various locations over the format area. To obtain the largest intensity range possible, the reflex viewing capability of the ARPA simulator was employed to select areas of heavy to poor ink application adherence. Narrow band interference filters, covering the S-10 photomultiplier system sensitivity range, were used for the measurements.

The spectral intensity and response variations of each of the seven map papers under investigation was compared using Wratten wide band filters covering the S-10 PMT spectral range.

RESULTS: Quite large spectral intensity variations were found to exist on the map sample being investigated. The intensity variations of certain colors were also found to be very nonlinear across the spectral range (.4 to .7 microns) considered, resulting in a large color ratio shift for a given measurement location. Figure 2-7 presents a chart of the intensity change factors, computed for minimum and maximum response signals obtained for each color and color combination, at the eleven spectral intervals indicated by the peak filter transmission. As can be seen from the chart, intensity variations up to 4.85 times the minimum response signal were obtained. Referring to the "red on white" color response data, the nonlinearity of the intensity variations, (1.09 to 4.85) indicates the magnitude of color balance ratio changes which can occur.

The results of the spectral sensitivity tests of the seven map papers is shown in the chart presented in Figure 2-8 . These results show that the different map papers have closely identical response characteristics.

Peak Filter Trans. ▶ / Map Color ▼	.406μ	.427μ	.469μ	.496μ	.537μ	.558μ	.594μ	.626μ	.653μ	.682μ	.705μ
White	1.15	1.07	1.05	1.05	1.07	1.06	1.06	1.06	1.04	1.07	1.07
Black on White	*	*	1.60	2.25	2.31	2.20	2.46	1.80	2.00	1.67	*
Dark Blue on White	1.60	1.64	1.44	1.50	1.73	1.78	2.38	2.21	2.30	1.67	*
Light Blue on White	1.15	1.19	1.18	1.18	1.19	1.16	1.20	1.24	1.21	1.27	1.31
Green on White	1.33	1.40	1.64	1.43	1.11	1.14	1.33	1.65	1.64	1.56	1.38
Red on White	*	3.00	4.85	4.60	2.70	2.20	1.40	1.10	1.10	1.09	1.10
Brown on White	*	2.00	2.21	2.20	1.82	1.62	1.44	1.47	1.45	1.46	1.56
Red on Green	*	*	1.70	1.69	1.77	1.70	1.47	1.35	1.33	1.39	1.37
Brown on Green	*	*	1.50	1.64	1.43	1.37	1.40	1.45	1.44	1.40	1.40
Brown on Red	*	*	1.25	1.27	1.29	1.37	1.64	1.80	1.76	1.82	1.86

* = Low S/N Ratio Readings Prevents Evaluation

FIGURE 2-7

SPECTRAL INTENSITY CHANGE FACTOR VARIATION

MAP #1 — Indian Head, Maryland; Virginia

Wratten Filters ▶	None	#29	#32	#34	#47B	#58	#65
Map # ▼							
1	1.98	.36	.80	.21	.12	.52	.90
2	1.95	.28	.66	.16	.10	.43	.72
3	2.03	.34	.78	.19	.13	.49	.86
4	2.00	.34	.77	.20	.12	.49	.86
5	1.97	.31	.71	.18	.12	.47	.79
6	2.00	.35	.81	.20	.12	.50	.89
7	1.99	.35	.79	.20	.12	.51	.90

FIGURE 2-8

RELATIVE SYSTEM SPECTRAL RESPONSE CHARACTERISTICS
OF THE SAMPLE MAP PAPERS

2.4 COMPUTER ORIENTED APPROACHES TO FILTER FUNCTION OPTIMIZATION:

2.4.1 THEORETICAL CONSIDERATIONS:

The goal of the processing is to identify color families; the "red" family, for example, would include red on white, red on green, etc. where these members are significantly different in actual color. This really amounts to identifying the twenty colors and grouping the identifications. The analysis of each of these twenty colors is a spectral density curve whose spectral resolution is adequate to define the color character of the map sample. To fit the capabilities of our computer program, the color spectrum analysis is chosen as 12 intervals between 400 and 1000 millimicrons wavelength (approximately 50 millimicrons bandwidth per color interval).

Thus, for a given object map, the experimental portion of the investigation is to isolate twenty (or less) distinctive colors at the object and measure a spectral distribution function for each of these colors. This raw data, 240 values, fills a matrix as shown in Figure 2-9.

The R (i, j) values are the individual response readings of color i as read through filter j. The computer problem now is to determine a weighting function that optimizes the extraction of the wanted color. This function is, in reality, a set of twelve weighting values, each applied to its assigned spectral interval. Since the signals can be processed electronically, both positive and negative weighting functions are admitted. The overall response of a given set of weighting factors to color "k" is:

SPECTRAL INTERVALS

COLORS

	1	2	3	•	j	•	12
1	R_{1-1}	R_{1-2}	R_{1-3}	•	R_{1-j}	•	R_{1-12}
2	R_{2-1}	R_{2-2}	R_{2-3}	•	R_{2-j}	•	R_{2-12}
3	R_{3-1}	R_{3-2}	R_{3-3}	•	R_{3-j}	•	R_{3-12}
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•
j	R_{i-1}	R_{i-2}	R_{i-3}	•	R_{i-j}	•	R_{i-12}
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•
20	R_{20-1}	R_{20-2}	R_{20-3}	•	R_{20-j}	•	R_{20-12}

FIGURE 2-9

SPECTRAL RESPONSE
COLOR DATA MATRIX

$$C_k = W_1 R_{k1} = W_2 R_{k2} - - - W_{12} R_{k12}$$

$$= \sum_{j=1}^{j=12} W_j R_{kj}$$

What we now want is the best set of W_1 to W_{12} values which clearly separate color k out of the pack. An additional rule is that all of the outputs other than that of color k must be less than, or all must be more than color k output. In other words color k must be uniquely at the high end or the low end of the output values. The reason can be seen by a simple example. Suppose that a weighting function set neatly established the wanted color k as an output value 0, with half the other colors well separated from this at values above +1 and the other half at values well below -1. Anything in the interval -1 to +1 is a wanted color. Although separation here appears to be certain, note the ambiguity when a + - color boundary is crossed. Every boundary between + and - colors results in a zero crossing and a false identification of the wanted color.

If we are attempting to isolate color k, suppose that the response is first normalized, i.e. make

$$C_k = \sum_{i}^{N} R_{kj} \cdot W_j = 1$$

so that

$$W_n = \frac{1 - \sum_{i}^{N-1} R_{kj} W_j}{R_{SN}}$$

and there are now N-1 independent parameters.

What we now need, in addition to the raw data, is a rule by which the computer can determine whether the new solution is better or worse than the previous trial.

Consider the N-1 dimensional vector:

$$F_i = \exp\left[\lambda\ C_i\right] \qquad i \neq k$$

Since C_k (the response to the desired color) has been pegged at one, we would like to prevent any component of this vector from becoming very large. An obvious approach is to minimize the merit function.

$$MF_k = \sum_{\substack{i \neq k \\ i}}^{N} F_i = \sum_{\substack{i \neq k \\ i}}^{N} \exp\left[\lambda\ C_i\right]$$

This function tends to exaggerate the valu of any merit values that are positive, the exaggeration or amplification being set by the factor λ.

With the raw data and the merit function, the optimization of the weighting factors becomes a fully automatic computer process, similar, for example, to that described by Meiron in "Journal of the Optical Society," Vol. 55, p. 1105 (1965). The process entails determining the local derivatives of each matrix element to establish an "influence matrix" and follow these derivatives to minimum values. A damping factor and a metric weighting must be introduced to c 'ch oscillations in the solution.

The result of the computer optimization is, for extracting color k, a set of twelve weighting factors. These, applied to the spectral intervals, form a spectral weighting function. Since this function has, in general, both positive and negative regions, it must be split in the end-result map analyser into two spectral filters, one in a + optical channel and one in a - channel.

2.4.2 "INFLUENCE" MATRIX INVESTIGATION:

The program was given its initial test by making an artifical color data matrix up from the last four digits of 96 telephone numbers taken sequentially from the telephone directory. These represented the hypothetical response of 12 colors measured through 8 filters. Color "7" was arbitrarily chosen to be optimized, and the damping factor λ given the value 0.05.

As an example, the best solution obtained under these conditions was found to be:

j	W_j
1	0.1
2	0.1
3	-0.3
4	0.1
5	0.1
6	0.1
7	0.1
8	-0.73

K	C_k
1	-24.56
2	18.47
3	-26.48
4	-21.71
5	11.40
6	9.33
7	1.00
8	-34.32
9	-28.31
10	-14.95
11	-38.03
12	-28.93

Here $MF_7 = 8.06$. This is not very impressive. "Colors" 2, 5 and 6 are all greater than the desired 7. At this point the effect of changing the parameter λ was investigated, with the results:

λ	MF_7
.001	10.82
.01	9.53
.05	8.06
.10	12.68
.50	10665.0

2.4.3 ITERATIVE VARIATIONAL COMPUTER INVESTIGATION:

The results of the influence matrix investigation suggested defining a rather pragmatic figure of merit:

$$MF_k = \left[C_k - \text{largest remaining } C_i \right]$$

A program was written which employed this definition. It iteratively varied the weighting factors, and did not use the minimizing routine. It was found that color 7 could be moved to one end of the response set, but that success depended very critically on the assumed initial weighting factors. The best procedure seemed to be to find the filter yielding the maximum response to the desired color, set this weighting factor to unity, all others to zero, and then proceed as before.

The processing was quite slow. Of great interest is the fact that ultimately the weighting factors always converged on one or another of the three values:

+1, 0 -1. Small steps always go to the same solution, but large steps (as 1) may end at a slightly different place, not quite the optimum. However the much greater computing speed makes the unit step more appealing.

It is interesting to look at an example of this computer program, wherein 11 colors are detected through 10 narrow band color filters. The color filters were:

Identification	Peak Wavelength (μ)	Peak Transmission (%)
I	0.427	29
II	0.469	34
III	0.496	37
IV	0.537	33
V	0.558	44
VI	0.594	43
VII	0.626	33
VIII	0.653	38
IX	0.682	35
X	0.705	37

The map colors measured were:

Identification	Description
A	White
B	Dark Blue
C	Light Blue
D	Green
E	Red
F	Brown
G	Dark Blue on Light Blue
H	Dark Blue on Green
I	Green on Brown
K	Red on Brown

The observed responses, in arbitrary units, were:

	I	II	III	IV	V	VI	VII	VIII	IX	X
A	11	42	83	126	220	150	54	58	26	11
B	5	16	29	27	38	13	3	4	3	2
C	10	41	82	113	175	100	34	40	17	7
D	3	9	32	102	180	76	15	17	9	5
E	2	4	6	11	34	80	48	52	24	10
F	3	5	9	22	55	56	22	25	11	5
G	5	19	32	28	38	13	4	4	3	2
H	3	7	15	25	36	12	4	3	2	2
I	2	3	4	7	16	26	10	12	6	4
J	2	4	8	24	56	43	12	14	7	4
K	2	3	3	5	14	38	24	26	10	5

These values were submitted to the computer, and the following data derived:

	I	II	III	IV	V	VI	VII	VIII	IX	X	MF
A	+	+	+	+	+	+	+	+	+	+	1.62
B	+	0	0	−	+	−	0	−	+	+	0.01
C	−	0	0	−	+	0	0	0	0	−	-0.27
D	−	−	−	0	+	−	+	0	+	0	0.66
E	−	0	−	−	0	+	+	+	+	+	1.02
F	0	0	0	0	0	0	0	0	0	0	0.00
G	0	+	+	−	0	0	+	−	0	+	0.06
H	+	+	−	−	+	−	+	0	−	+	-0.02
I	0	−	−	−	−	+	−	0	+	0	-0.09
J	−	−	−	−	+	0	−	−	0	0	-0.10
K	0	−	−	−	−	+	0	0	−	0	0.02

Here + represents a +1 weighting factor, etc. Three facts are immediately obvious:

(1) White is "pulled" with an all positive weighting, as would be expected.

(2) Brown is totally unrelated to the body of other colors.

(3) The figures of merit show that in 5 of the 11 cases, at least one other color would be accepted with the desired color.

2.5 MULTILOGIC DECISION CIRCUIT APPROACH:

2.5.1 THEORETICAL CONSIDERATIONS:

Preliminary investigations into a more effective method to meet the color extraction objectives of the program, were instigated after the initial results of the computer oriented "matrix optimization" technique proved this approach to be more limited than expected. This was due, in the main part to the wide range of spectral intensity variations and color balance ratio shifts that were found to exist.

After considerable analysis of the overall extraction technique problems, a more effective and basically much simpler approach to the problem was devised. This revised approach shifted the emphasis from "off line" computer oriented preprocessing functions to "on line" machine oriented optimization techniques employing multilogic decision circuits.

The computer "matrix optimization" concept, as initially conceived, might be called a "one dimensional" decision function. It's effectiveness relies on the computer optimization of filter functions obtained from a large number of spectral response samples of the map colors. The effect is to move a wanted color to one end or the other on a spectral number line of one dimension. The multilogic decision circuitry concept introduces a "multidimensional" approach, where more than one condition must be met coincidentally. Theoretically, this approach offered a means to simplify the filter function optimization task by reducing the data acquisition requirements and elimination of computer preprocessing time in favor of optimization of processes at the extraction machine itself. The main advantage offered, however, was the decision making capability functions of the multidimensional approach which appeared to offer the best solution to the wide spectral intensity variations encountered.

Based on the use of readily available electronic components the proposed operational concept of the multilogic decision circuits was as follows:

A. The amplified signals from each of the four spectrally attenuated photomultiplier channels of the ARPA simulator are fed into individual signal comparator circuits. Each channel has two such comparators, whose critical level is controlled by potentiometers. These comparators establish an upper and lower bound to the signal intensity range within the overall system signal intensity range.

B. The output signals from all eight comparators are then fed to two NAND gate circuits. One NAND gate is controlled by the upper bound signal comparators and one by the lower bound comparators. These two NAND gates, in turn, are connected to a third NAND gate. This third NAND gate acts as a switch to control the glo-modulator circuits.

C. For the glo-modulator circuit to be activated, the four input signals to the multilogic unit must fall within the preselected bounds of each channel. A functional schematic diagram of the proposed system is shown in Figure 2-10.

The supposition that only a minimum number of spectral samples would be required was based on the wide latitude afforded by the multidimensional approach theory. As a result of the reduced amount of spectral response

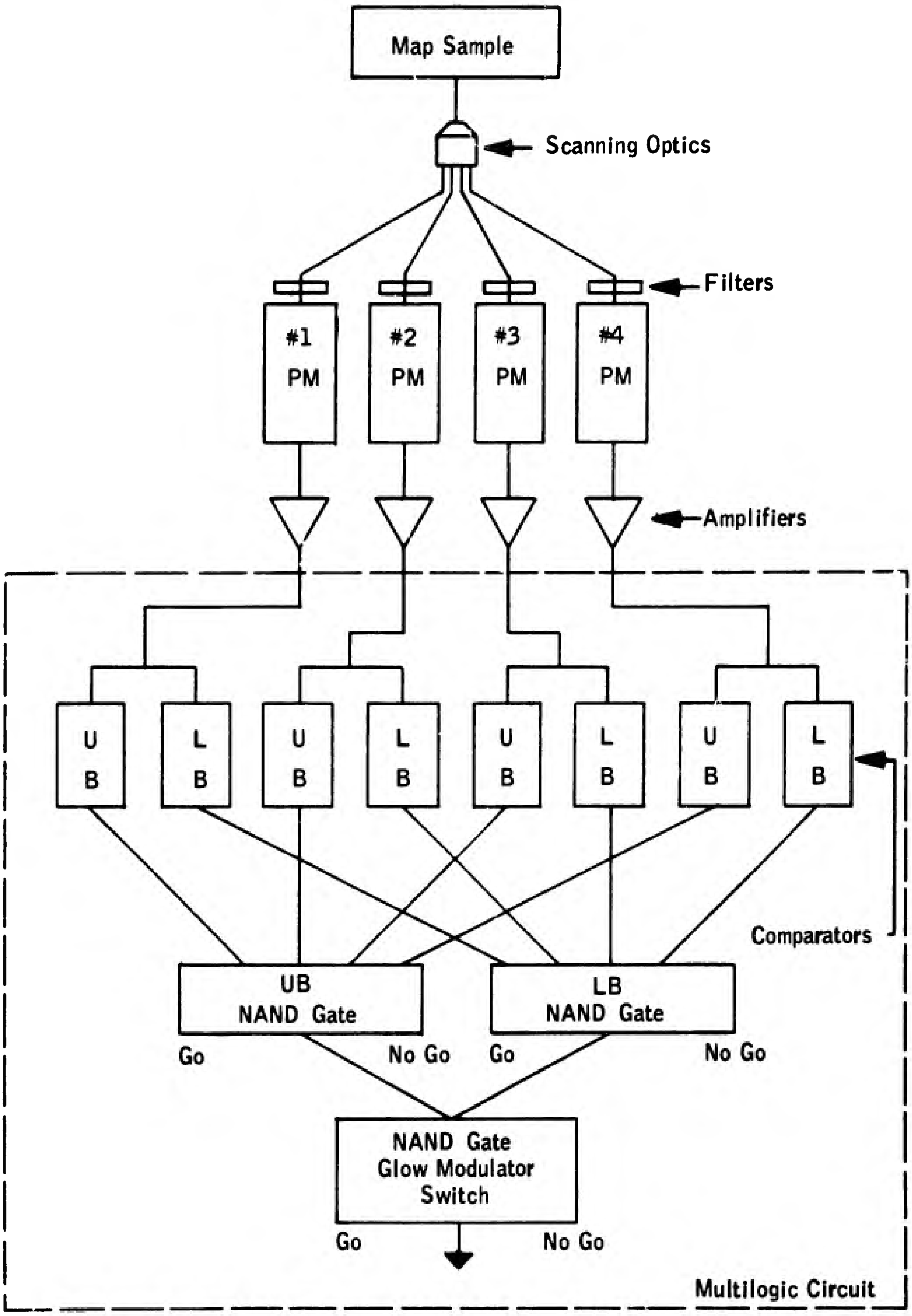


FIGURE 2-10

FUNCTIONAL SCHEMATIC OF MULTILOGIC DECISION CIRCUITS
FOR THE ARPA SIMULATOR

data, optimization of filter functions could be accomplished either manually or with minimum computer requirements. In the final analysis, it is very possible that a unique set of four filters can be found that will be optimum for any five color map separation. Assuming this to be the case, the operational techniques of data acquisition and analysis would be reduced to an "on line" function performed directly ahead of the extraction process.

2.5.2 APPLICATION OF SPECTRAL RESPONSE DATA:

PURPOSE: In order to verify the proposed approach of the preceding section, the wide band Wratten filter spectral response data was analyzed and applied to the theoretical operational parameters established for the multilogic system. The four filters best suited for the extraction technique on all map samples were chosen and an assessment of the degree of extraction success to be expected was made.

TEST PROCEDURES: The spectral response data obtained with the Wratten #29, #32, #34, #47-B, #58, and #65 filters was analyzed for each of the seven map samples. The optimum four filters were selected for each map by a manual evaluation procedure. Application of intensity variation excursions expected were applied to each color sample response. From a comparison of the resulting intensity ranges, as applied to the multilogic circuits, the four filters offering the best possibility of extraction for all maps were selected. Only those colors and combinations required to maintain information and completeness on each map were considered. The minimum number of extraction passes required for each map, to retain all information, was determined by first considering the pure colors, and then grouping associated pure and overprint color combinations together until the best solution was found.

RESULTS: The four filters selected to be used in the theoretical data application tests were the Wratten #29, #32, #58 and #65. The final results of these theoretical evaluations for each map are presented in Appendices #1 through #7. These graphs for each map show the final predicted sensitivity ranges for each filter channel for every color or combination selected for extraction. In interpreting the graphs, if any four filter ranges indicated for one color and/or combination correspond at any point simultaneously with the ranges indicated for another color, the possibility of both colors being extracted exists. As an example, the blue and black ink extraction ranges predicted for map #7, shown in Appendix #7 are very similar. An increase in the predicted ranges would no doubt cause both colors to be extracted at one time.

The predicted number of extraction passes for each map as determined from these tests are as follows:

MAP #	NUMBER OF PURE AND OVERPRINT COLORS	NUMBER OF PASSES FOR COMPLETE FIVE COLOR EXTRACTION
1	6 + 4 - - - 10	6
2	5 + 2 - - - 7	6
3	5 + 3 - - - 8	5
4	5 + 2 - - - 7	5
5	5 + 4 - - - 9	6
6	5 + 3 - - - 8	5
7	5 + 6 - - - 11	5

2.5.3 MULTILOGIC DECISION CIRCUIT DESIGN AND OPERATION:

Based on the high degree of extraction success indicated by the theoretical application of data to the proposed multidimensional technique, design and fabrication of the required multilogic decision circuitry was undertaken to operationally evaluate the concept. The basic design followed the functional schematic presented in Figure 2-10.

Figure 2-11 shows the control panel of the multilogic decision chassis. Design considerations were oriented toward the "on line" approach whereby all spectral analysis is performed by the extraction machine operator immediately prior to the actual extraction. (This method assumes the use of four unique filters for all extractions.) Bound level monitoring jacks and indicator lights were provided for each of the eight bound setting potentiometers on the control panel. An electronic schematic of the multilogic circuitry fabricated for this program is shown in Figure 2-12.

OPERATIONAL THEORY: The multilogic circuitry in the ARPA system configuration was designed to be operated basically as follows:

1. The intensity range parameters for the color and/or overprint combination to be extracted is established over the map format area, by the technique described in Section 2.3, for each of the four extraction machine channels.

2. The upper and lower bound potentiometers are then set to include the desired range for each channel. The signal intensity selected is monitored with a voltmeter at the jacks provided by each potentiometer.

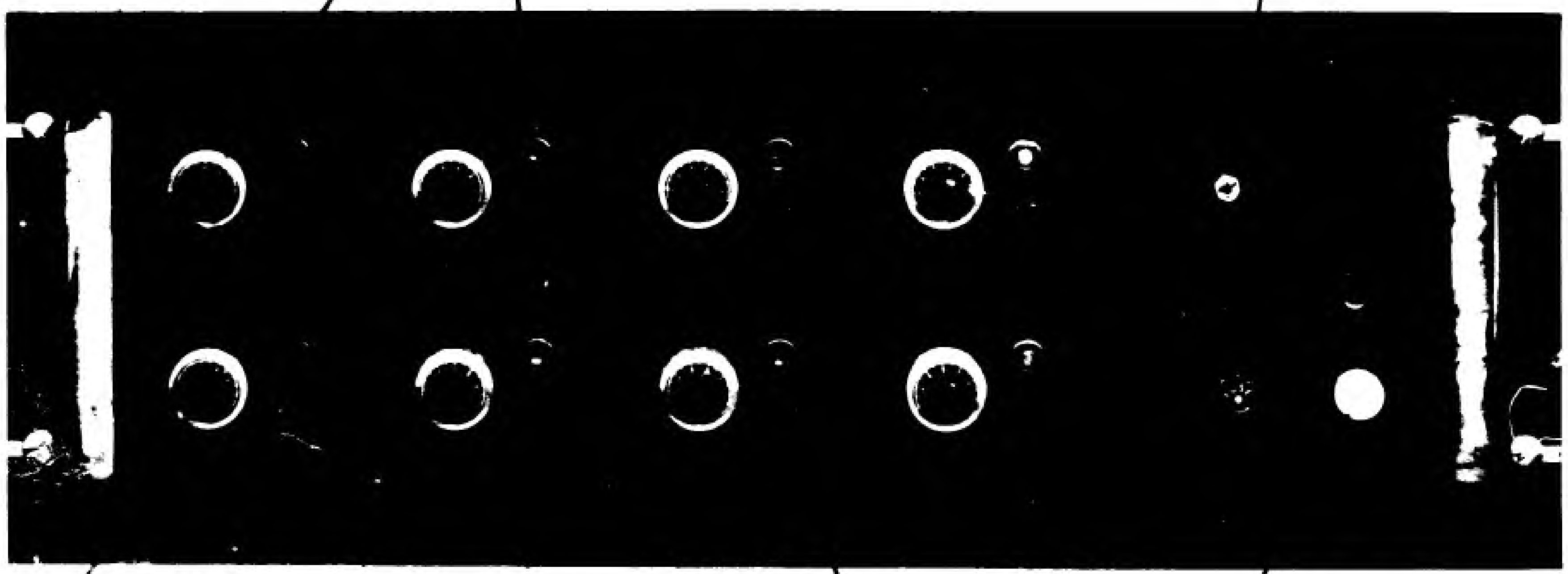
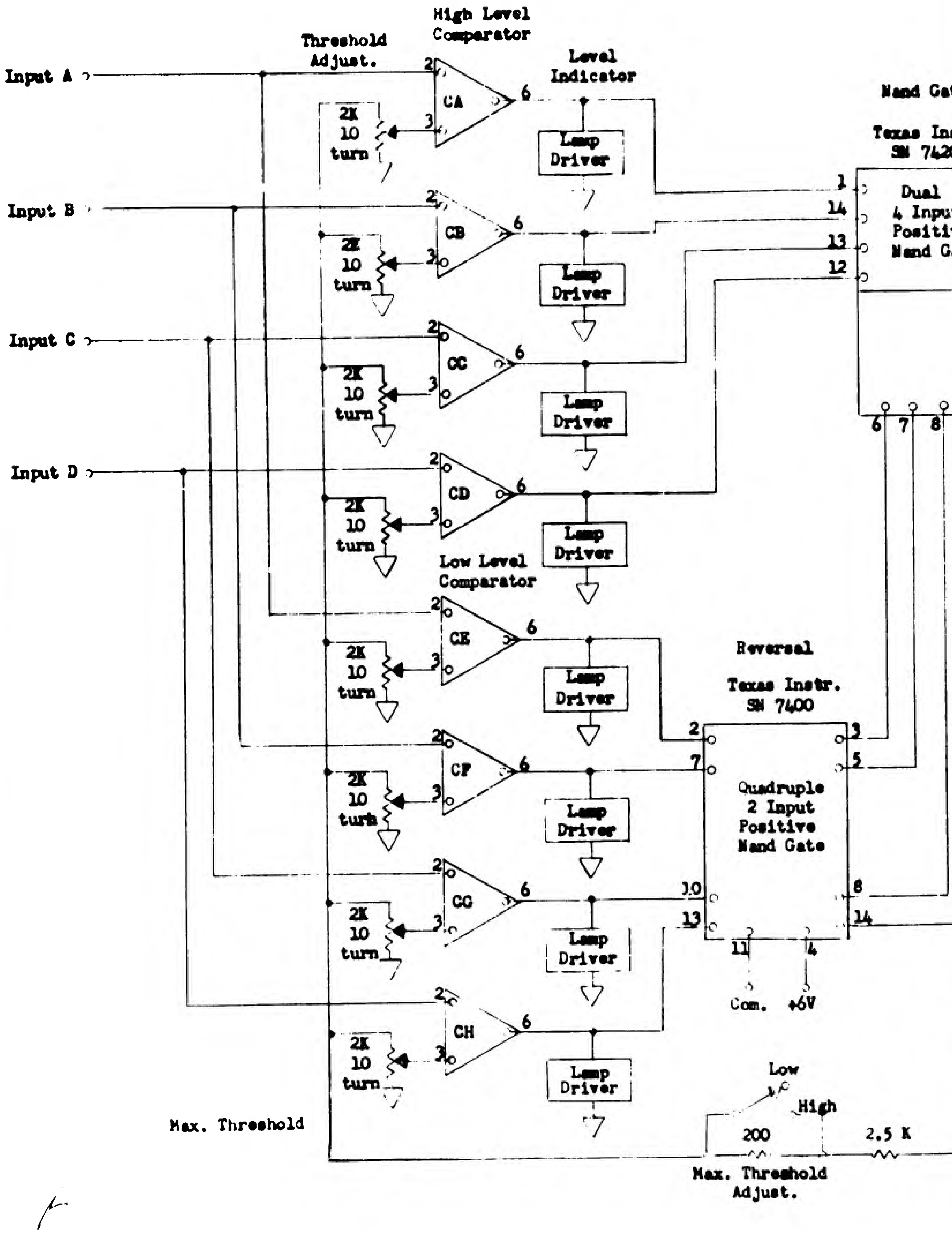


FIGURE 2-11

MULTILOGIC DECISION CIRCUITS CONTROL PANEL


High Level Comparator
Threshold Adjust.
Input A
Input B
Input C
Input D
Level Indicator
Nand Ga
Texas In
SN 742
Dual
4 Inpu
Positi
Nand G
CA
CB
CC
CD
CE
CF
CG
CH
2K
10
turn
Lamp Driver
Low Level Comparator
Reversal
Texas Instr.
SN 7400
Quadruple
2 Input
Positive
Nand Gate
Com.
+6V
Low
High
200
2.5 K
Max. Threshold
Max. Threshold Adjust.

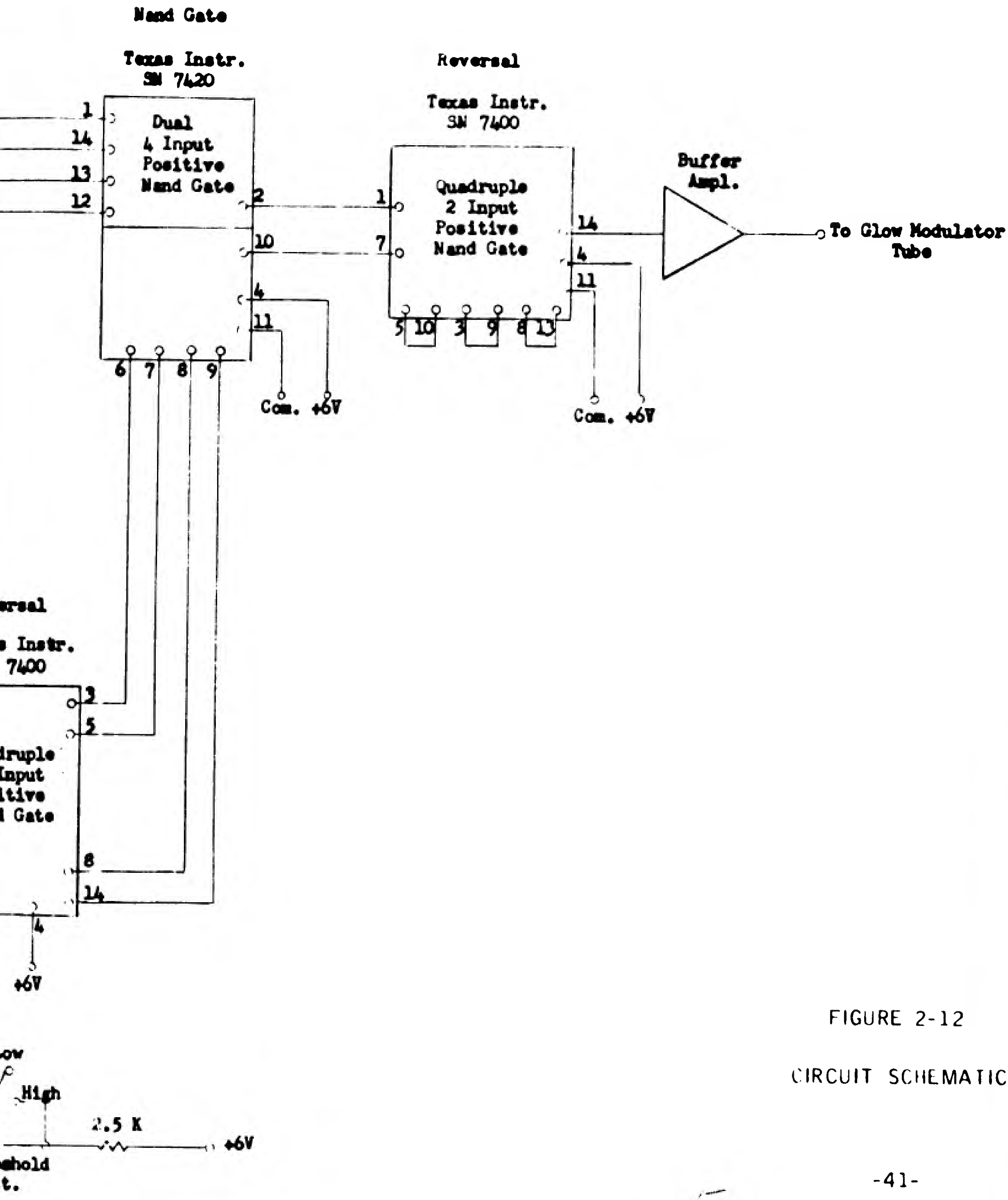


FIGURE 2-12

CIRCUIT SCHEMATIC

3. When an input signal to the multilogic circuits falls below the selected upper bound or above the lower bound on a given channel, an indicator light goes on next to the individual potentiometer controls. All indication lights "on" causes an output signal to be generated to the glo-modulator drive circuit and a print-out on the output film.

4. The operator statically checks the correctness of his settings by manually scanning the map sample prior to the actual extraction run.

EQUIPMENT TESTS AND RESULTS: Prior to actual photographic extraction tests, the multilogic circuitry was statically checked out in the ARPA simulator system. The electronic support equipment, including the multilogic circuitry, for the ARPA simulator is shown in Figure 2-13. Only a few minor electronic interface problems occurred during the installation, which were easily solved. The operating range of input signals was found to be limited by the multilogic circuitry to a maximum of two volts.

Several sample maps were evaluated and set up operationally as described above. The manual scanning and monitoring for each given color and/or combination indicated that the intensity ranges predicted from theoretical analysis, generally had to be increased by a slight amount to obtain separation by this manual test mode. No major separation problem was noted during the static tests. The time required to evaluate and establish the operating bounds, was less than 15 minutes, for a given color.

2.5.4 PHOTOGRAPHIC EXTRACTION TESTS:

PURPOSE: Extraction tests were scheduled, using the ARPA simulator, to prove the feasibility of the separation techniques developed theoretically during the course of the program, and to define certain parameters such as,

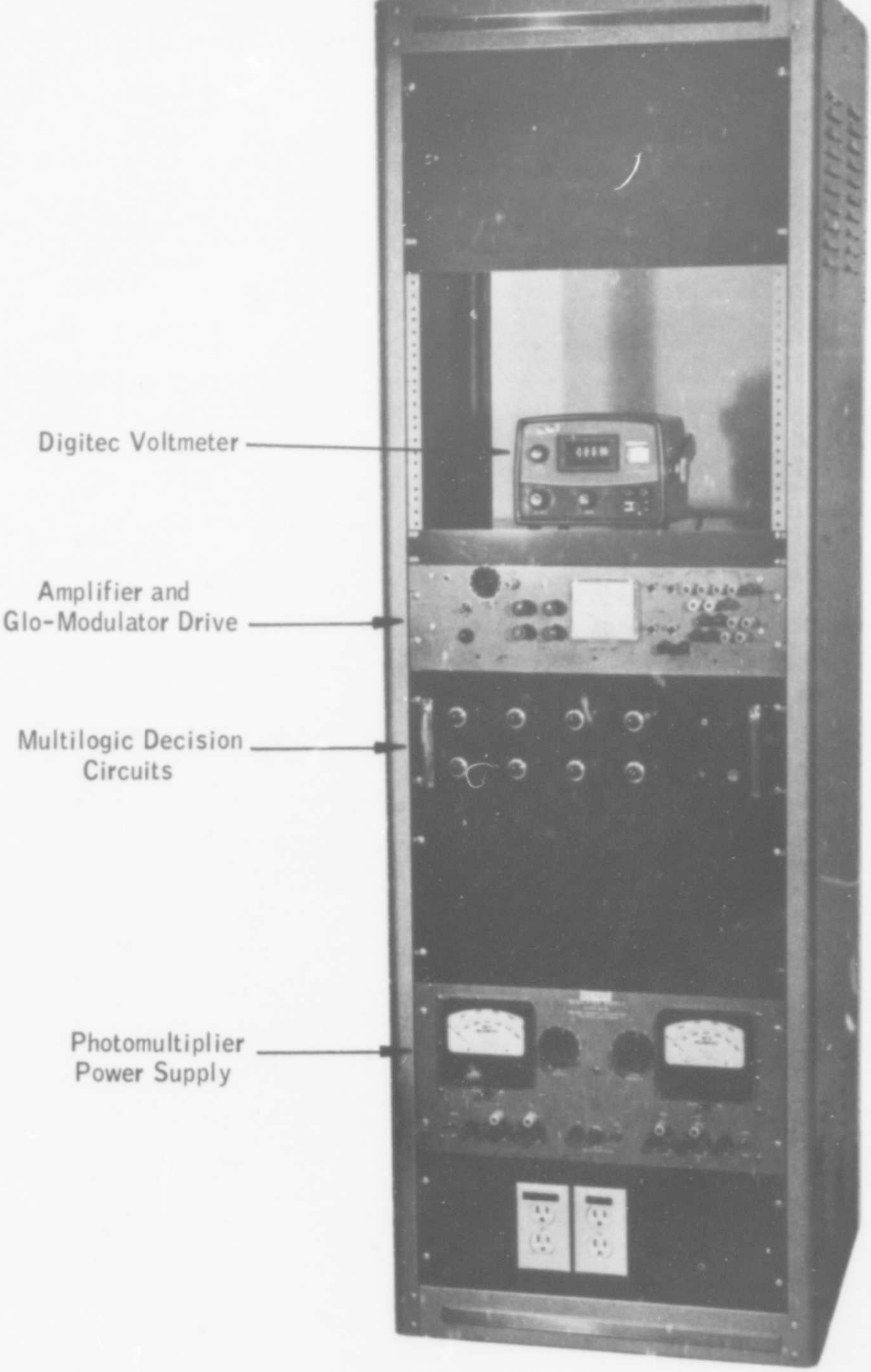


FIGURE 2-13

ARPA SYSTEM, ELECTRONIC SUPPORT EQUIPMENT resolution requirements, effects of halftoned screened areas and problems dealing with overprint combinations and spectral intensity variations. Three maps were selected for full or partial extraction to demonstrate the various parameters.

TEST PROCEDURES: Map #3, a five color map of Port Royal, Virginia, was selected for the initial full 5 color separation test on the basis of printing quality and data analysis indicating that it would have the best chance for extraction success. Each of the 5 colors and their associated overprint combinations were well separated spectrally from each other based on system response data.

Map #7, Centre Hall, Pennsylvania, was chosen for full extraction. This map was selected for its poor ink application quality. As discussed in the visual analysis, the separation or sharpness of the boundaries was very good but the ink adherence in the intended area was very spotty, giving rise to very large intensity variations for given colors. In addition, the great number of fine lines on this map, equal to the maximum system resolution, provided a good subject for the resolution capability evaluation. The black ink record was selected to evaluate the intensity variation aspects. As can be se n the spectral intensity range chart of Appendix #7 for this map, an increase in the black intensity ranges would probably cause the blue ink record to be partially or fully extracted. The brown ink record was selected to evaluate the resolution capability requirements. The smaller contour lines, represented by brown, were all approximately .004 inches wide. The remaining three color extractions provided added comparative data for the "theoretical versus actual" test results.

Map #6, Alexandria, Virginia, was selected to evaluate the effect of halftoned screened areas. The red halftone dots on this map were large enough (.006 to .008 inches) not to be affected by the limiting resolution of the system, which for this test was a .004 inch diameter spot.

The operation procedures for establishing and setting the spectral intensity range bounds were performed in the same manner as described in Section 2.5.3. The tests were performed in the following order:

1. Full five color separation of map #3.
2. Full five color separation of map #7 to evaluate resolution capability and effects of intensity variations.
3. Red separation on map #6 to evaluate effects of halftone screened areas.

Actual intensity range bounds required to produce a good quality separation were compared to the predicted intensity range bounds for each actual separation attempted. Actual bounds are shown on the intensity range graphs of Appendices #3, #6, and #7.

RESULTS

EXTRACTION TEST #1: The full five color extraction tests on map #3 was started with the black ink extraction performed first. The ARPA system resolution capability, for this first extraction attempted, was set for a minimum scene element size of .006 inch. The results of the black ink extraction was good except that lines on the map sample equal to or less than the resolution capability of the equipment were missing either in whole or part, depending upon their orientation to the drum scan direction. Those lines that were close to or perpendicular to the scan direction were not extracted. The system ...olving power was reduced to a .004 inch diameter spot (maximum resolution attainable for present ARPA system) by the use of smaller field stops (.040 inch diameter) in each photomultiplier channel. The test on the black ink extraction was repeated with much improved results resolution wise. Scene elements equal to the resolution capability of the equipment were still only extracted intermittently. However, this map contains very few lines or points of this size.

The brown ink extraction test was run second. An extraction effect, not considered during the theoretical phases of the program, was found to exist when the brown separation was evaluated. All the brown areas separated quite well, but in addition a good portion of the black to white boundaries also tended to be extracted. Investigation of this effect resulted in the discovery that anytime each of the four channels have any part of their intensity ranges in common, this effect will occur. When scanning across a black-white boundary, an effect similar to putting neutral density filters in each optical path occurs, causing an almost linear signal intensity change in all four channels. At some point in the transition, the equal intensities in each channel match the selected ranges that are in common, resulting in a print-out signal to the glo-modulator drive.

The red ink record was extracted next. This record on the map was used to indicate main roads and was bordered in black in most cases. The extraction appeared excellent by itself, but upon overlaying it with the black extraction record, it could be seen that the red line width was narrower than the original and did not fill in the area between the black lines completely. This effect was more noticeable where the lines were oriented perpendicular to the scan direction. This effect is inherent in the equipment and was expected. A second extraction was run where the exposure level of the glo-modulator was increased. The theory being that the overexposure condition would widen the lines on the output film. Results confirmed this technique and a near perfect extraction was obtained.

The green and blue ink records were extracted in one attempt each. No special problems of any type were noted for these extractions.

An overlay diazochrome type replica of this test is shown in Figure 2-14. A copy of the original map is presented in Figure 2-15.

<u>EXTRACTION TEST #2:</u> Map #7 was fully extracted in 5 machine separation passes. The black ink extraction was satisfactory for the black but it also pulled the blue ink record as well. This result was expected in this case, as the predicted intensity ranges had to be greatly increased due to the poor ink adherence. The results are illustrated graphically in Appendix #7.

The brown extraction test was used to evaluate the resolution capability requirements. Results showed that the very fine contour lines, equal to the present system capability, only pulled intermittently. The wider lines were extracted without any problem.

The blue, red, and green records were separated without any noticeable problems.

<u>EXTRACTION TEST #3:</u> The effects of halftone screened areas was evaluated from the red ink extraction performed on map #6. An interesting effect resulted from this test. In the visual analysis of this map sample in Section 2.1.3, it was noted that a slight change in the apparent tint of one halftone

FIGURE 2-14

REPLICA OVERLAY OF EXTRACTION TEST #1

See envelope inside back cover

FIGURE 2-15

ORIGINAL MAP-EXTRACTION TEST #1

See envelope inside back cover

area compared to another was due to a slight difference in dot size, which appeared to be caused by a difference in the amount of ink applied. The extraction results magnified this difference by approximately 50% making it more noticeable visually.

2.5.5 BASIC REQUIREMENTS FOR A FIVE COLOR MAP SEPARATOR:

From an evaluation of the program results, the multilogic approach to the five color map separation problem was extremely effective. A high degree of success was demonstrated in the areas of preprocessing spectral analysis, machine operational techniques, test equipment reliability, and extraction quality. Therefore, in establishing the basic requirements and parameters for a five color map separator unit, optimization of the present system approach was used as a basis for defining these specifications.

Our analysis involved (1) evaluation of the present test system capabilities, and (2) determination of realistic operational system parameters. For the sake of comparison, a map input having a 24 x 30 inch format size is assumed.

TEST SYSTEM CAPABILITIES

The multilogic circuitry, used in conjunction with the ARPA simulator, performed faultlessly during the extraction test phase of the program. The main problems exhibited by the test equipment were a direct result of the low system sensitivity and limited spectral bandwidth sensitivity of the ARPA simulator portion of the test system. These two factors restricted the test system resolution capability and the selection of efficient separation filters adequate for all five color map samples.

From an operational standpoint, the "on-line" preprocessing analysis appeared to be a feasible method for determining optimum machine set-up techniques. Based on the program tests, approximately one hour would be required for preprocessing of each map. In considering a 24 x 30 inch map, the present system would require 15 hours for the actual extraction of all five colors simultaneously.

OPERATIONAL SYSTEM PARAMETERS

Based upon the results and upon practicable improvements, the following system features are proposed. The level of development needed prior to final design in order to realize these features is indicated.

Type of Scan: Rotating drum facsimile scan is recommended. Object surface drum is to be 30 inches wide to accept maps up through 30 by 40 inches (although 24 by 30 inches will be used below as a typical size). Output would be in two forms: 1) a seven bit binary number indicating five colors plus white plus parity, together with digital X-Y coordinates for each optical channel, and 2) write-on a companion film drum of the five color separations. It is probably convenient to scale the film separations to 8½ by 11 inches or smaller. Development here would be primarily involved in the test and modification of the scanner once the machine has been fabricated.

Four Color Multilogic: The four color multilogic technique incorporated in the present machine has been proved to be adequate. Increased spectral bandwidth and resolution will enhance this capability. No further development required.

On-line Visual Monitor: The color separation machine should have means of visually monitoring the instantaneous field of view of each channel similar to that provided in the present machine. This permits on-line color analysis, verification of the decision adjustments, and optical alignments. No development is required.

Illumination Source Improvement: Resolution and scan rate of the present system are specifically limited by the limited spectral band and brightness of the map illumination source. A brighter source, much richer in the blue-violet region and a more efficient means of optically condensing the source output at the map are needed. Development here involves test and selection of a source, and design and test of source condensing optics.

Resolution Increase: To accommodate the full variation expected in line and detail dimensions of maps, the resolution (instantaneous field of view) should be increased from the present 0.004 inches diameter to 0.002 inches diameter. No development other than that of improved source required.

Multiple Channels: The present machine separates a single instantaneous field into four colors for analysis and decisions. Scan rate can be substantially increased if several adjacent instantaneous fields are scanned in parallel. As an example, the present machine can be converted to a four channel (four line) scan by changing the field stops and adding four color separation means and detectors to each channel. Other than a verification of the color splitting means, no development is required.

Increased Scan Rate: The present instrument's electronics can accommodate scan rates up to ten times the present scan. With the improved broader spectral band and brighter source, sufficient radiant signal for this increased scan rate is available. The following factors, therefore, can be applied to upgrading the present scan time of 15 hours for a 24 by 30 map:

Feature	Factor (improvement)
Ten times data rate/channel	10
Twice the resolution (0.002")	0.5
Four channels in parallel	4
Net improvement	20

Scan time: 45 minutes

Additionally, features such as optimizing adjustments and controls for operator's convenience and effectiveness are to be incorporated.

3.0 DISCUSSION OF RESULTS:

3.1 TEST EQUIPMENT, MATERIALS, AND PROCEDURES:

Since the ARPA simulator was originally designed to perform quite similar tasks to those required on this program, the importance of being able to utilize it as an analytical and operational tool during the performance of this study, cannot be too heavily emphasized.

The equipment has demonstrated a very high degree of operational reliability and measurement repeatability throughout the investigations performed. Variations in spectral response measurements due to equipment contributions were continually monitored during the program and found to not exceed 1.0%. The main limitation imposed by the equipment capability was in the area of system sensitivity. The combination of photomultiplier spectral sensitivity, illumination energy, filter transmission characteristics, and resolution requirements, resulted in reduced measurement level capability in the areas at both ends of the visible spectral region.

3.2 IR SPECTRAL RESPONSE CHARACTERISTICS:

Although the IR spectral response characteristics, obtained from the S-1 sensitive photomultiplier tests, were of technical interest, no special characteristics, other than the high blue ink spectral response on three maps, was found.

The use of a photomultiplier, such as the S-1 with its extended spectral range, would have been more desirable from a system standpoint, in that a larger number of spectral samples could be obtained. The S-1 PMT, however, has very low sensitivity compared to the S-10 PMT, which precluded its use in the program.

3.3 SPECTRAL RESPONSE VARIATIONS:

The intensity variations found to exist were considerably larger than had been anticipated. An evaluation of the test data shows that the map paper and the black ink intensity variations are reasonably linear spectrally. However, the remaining colors and combinations exhibit varying degrees of intensity variations and nonlinearity in the spectral region evaluated.

Analysis shows that the major factor in intensity variations and resulting color ratio shifts is due to the poor ink application quality. Where light or spotty ink adherence occurs, the highly reflective white paper base contributes energy, with a resultant increase in signal over the entire spectral region. Depending on the amount of background contribution, the results of the tests indicate a larger proportional intensity increase in the normally low or nontransmitting filter regions for a particular color. Since a given color normally reflects the most energy through a filter of the same color or one of a closely adjoining spectral region, the proportional change is much smaller, intensity wise, than the low reflectance areas when the map background contributions increase.

3.4 COMPUTER ORIENTED APPROACHES TO FILTER FUNCTION OPTIMIZATION:

THEORETICAL CONSIDERATIONS

The computer oriented theoretical approach, Section 2.4.1, represents the original concepts proposed for the development of a five color map separation technique and indicates the direction toward which the main technical effort was expended at the start of the program.

INFLUENCE MATRIX INVESTIGATION

Investigation showed that the "influence matrix" derived from the data (which is the information used in the minimization program) frequently leads to oscillating solutions, and it must be concluded that the merit function is so extremely nonlinear that the least square approach is inappropriate.

ITERATIVE VARIATIONAL COMPUTER INVESTIGATION

The conclusion here must be that this one-dimensional ordering of color response is not satisfactory, and that a multidimensional approach is necessary.

3.5 MULTILOGIC DECISION CIRCUIT APPROACH:

3.5.1 THEORETICAL CONSIDERATIONS:

The theory of the multidimensional approach to the color extraction objective of this program was developed specifically to overcome the spectral intensity variations which were found to be a major stumbling block to the computer optimization approach. Equipment limitations, however, also created problems. The spectral sensitivity of the ARPA system in the blue region of the spectrum was very low. The spectral bandwidth, for adequate signal strength, was thus reduced to the green and red spectral regions for the most part. The reduction in the number of spectral samples attainable was also detrimental to optimum results being obtained by "matrix optimization" techniques.

3.5.2 APPLICATION OF SPECTRAL RESPONSE DATA:

Although the four filter combinations selected were not the most effective for every case, they offered the best compromise out of the six filters evaluated. In almost every case, more than one color or combination was found to meet the intensity range conditions of the wanted color for a given filter channel. The choice of filters was necessarily made by having only the wanted color meet the intensity range requirements of all four channels. In some overprint color instances this was found to be impossible or border line, which resulted in making an additional extraction pass necessary.

Theoretical results show that four out of the six "five color" maps could be extracted in five passes. Map #1, which as six pure colors plus overprints, also could be done in a minimum number of passes. These results were extremely gratifying considering the small number of filter samples used and the equipment limitations on the spectral bandwidth available for evaluation.

The results obtained were considered to be more than satisfactory for the intended scope of the program. A more complete evaluation, using a larger variety of wide band filters in addition to the narrow band interference filters, would more than likely offer even better results than those obtained.

3.5.3 MULTILOGIC DECISION CIRCUIT DESIGN AND OPERATION:

The static operation of the system, utilizing the multilogic circuitry, was deemed highly successful in that few checkout problems occurred and the maps evaluated gave every indication of good extraction success.

The limitation to the input signal intensity range was found to be of no consequence, since two volts was completely adequate for operation. The expansion of the spectral intensity ranges for individual channels did not cause any problems for the sample maps tested statically. However, analysis of predicted ranges on all maps indicates the possibility of multiple extractions, in some instances, where color response ratios are very similar.

3.5.4 PHOTOGRAPHIC EXTRACTION TESTS:

The contract for this program called for the attempted extraction of only one map color, to be selected by the government, on the ARPA simulator. The original thought was that the ARPA simulator would not produce extraction results adequate enough for evaluation purposes, other than for filter function analysis, since the machine and its related electronic circuitry were not basically designed for the intended purposes of this program. In addition, the machine was being used on a loan basis from ARPA/ONR, and could not undergo any major modifications that might be considered necessary. The multidimensional approach, developed during the course of the investigations, however, showed that the use of the multilogic circuitry did not require major equipment modifications and that the results obtainable would be much more adequate than anticipated. Also, the simplicity of the machine oriented approach required very little added technical effort. The extra machine extractions made provided an immeasurably better base for the evaluation and establishment of requirements for the prototype separation unit, than the originally planned theoretical analysis.

In general the overall photographic extraction test results were considered to be excellent. Extraction success for completeness of separation was only limited by the resolution capability of the test equipment in resolving the fine detail. The theoretical analysis performed compared quite closely to the actual results as can be seen on the intensity range graphs in Appendices #3, #6, and #7. The machine oriented "on line" operational techniques worked out very well. They showed that a reasonably competent operator could set up for an extraction of one color in about 10 minutes.

The problem noted, whereby the black-white boundary is extracted in some cases along with the desired color, would not be of too much consequence in normal printing ink reproduction processes, since the black printer would cover up the errors produced. The answer to solving the problem lies with having a better intensity separation of the input signals which would be provided by a more effective set of analysis filters. The large intensity range variations, such as produced by the poor ink application quality of Map #7, also resulted in pulling unwanted colors. This problem, too, would be solved by a more effective filter set.

The effect resulting from halftone screened areas, that occurred on Map #6 tests, is similar to that reported in the red extraction for Map #3. An analysis of the basic machine scanning techniques will show that the normal tendency is to slightly reduce the size of lines and spots. This effect is generally not noticeable for the larger object scene portions, but in situations where the scene element size is near the resolution capability of the system and registration is critical, the effect is more apparent. Line widths can be widened photographically by exposure control on the output films. This, however, is not the case with halftone screened areas that vary at different portions on the format.

3.5.5 BASIC REQUIREMENTS FOR A FIVE COLOR MAP SEPARATOR:

The proposed system parameters and requirements, presented in Section 2.5.5, reflects a realistic approach to the capabilities that could be attained in the development of a prototype five color map separation unit. The feasibility of the multidimensional approach, developed during the program, has been demonstrated by the results.

With some minor development and mechanical modification, the present ARPA system approach would be able to perform the required quality of extraction functions. In considering an operational system, however, the slow throughput time of the present system would be generally unsatisfactory. Therefore, in specifying areas requiring further development, the main consideration was of improved extraction rates, rather than extraction quality. The reduction from a 15 hour throughput time to less than one hour is considered to be a reasonable and achievable design goal.

4.0 CONCLUSIONS AND RECOMMENDATIONS:

Specific uses for the color map separation system developed during this program have been generally undefined, except in the area of military intelligence, where reproduction of enemy maps would be desirable. The proposed system would be readily adaptable to field operations, due to the simplicity of operation, relatively nonrestrictive environment and minimum operational tolerance requirements. The photographic materials used are high contrast graphic arts films which require minimum processing control. The only restrictive requirement for the system is that the input power to the illumination and chopper motor must be voltage controlled to within 1%.

The main conclusions that can be drawn from the results of the program are summarized:

1. The "one dimensional" computer matrix optimization program, initially considered at the onset of this investigation, is not an effective approach to the map color separation problem. The only merit of this approach would be in working with idealized colors having minimum spectral variation.

2. The multidimensional logic system approach will provide an effective extraction technique for all but the poorest quality multicolor map inputs. Although only five and six color maps were considered during this program, the technique should work equally well with more complicated map materials.

3. The "on-line" preprocessing analysis and operational techniques of the multidimensional approach eliminates the need for any time consuming data acquisition and computer optimization functions prior to the extraction process. The simple operational procedures required can be performed by a person having normal skill in photographic equipment operation.

4. The electronic, optical, and mechanical design configuration of the operational five color prototype separator proposed would be relatively uncomplicated and have a high degree of operational reliability.

Conclusion 4 leads to the recommendation that since no large uncertainties exist nor large developmental investigations are required for an operational version of the five color separation system, a follow-on program could be immediately directed toward the design and fabrication of a prototype machine. This machine would comply, with the possible exception of environmental testing, with the set of interface and operational specifications established by ETL.

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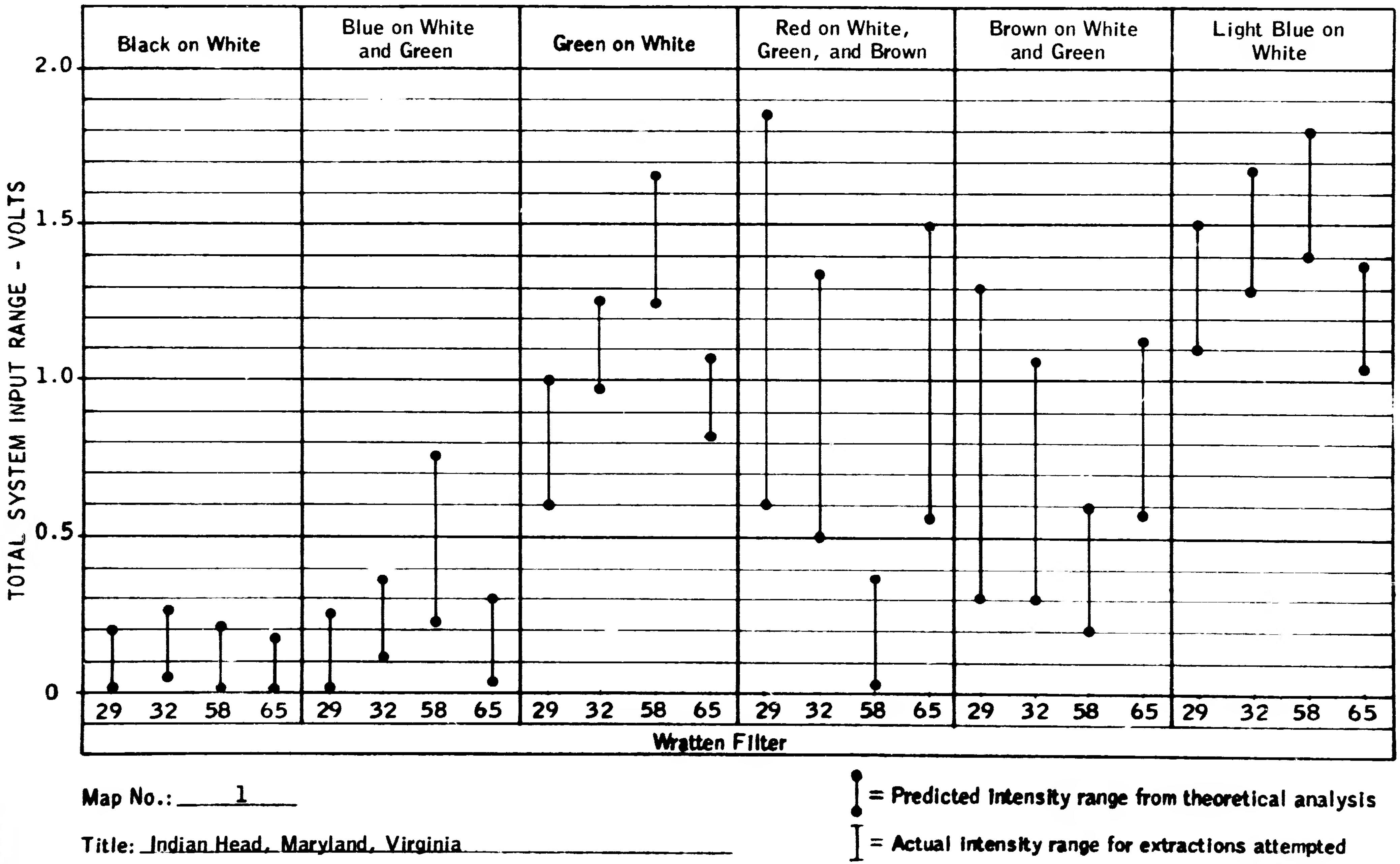
2. Spatial and Spectral Optical Processing, The Te Company, Report No. 2002, March 1965, prepared under Contract No. Nonr-4570(00), ARPA Order No. 369, dated 3 April 1964.

3. Target Enhancement and Extraction by Optical Processing, The Te Company, Report No. 2003, December 1966, prepared under Contract No. Nonr-5050(00), ARPA Order No. 369, dated 5 February 1965.

APPENDICES

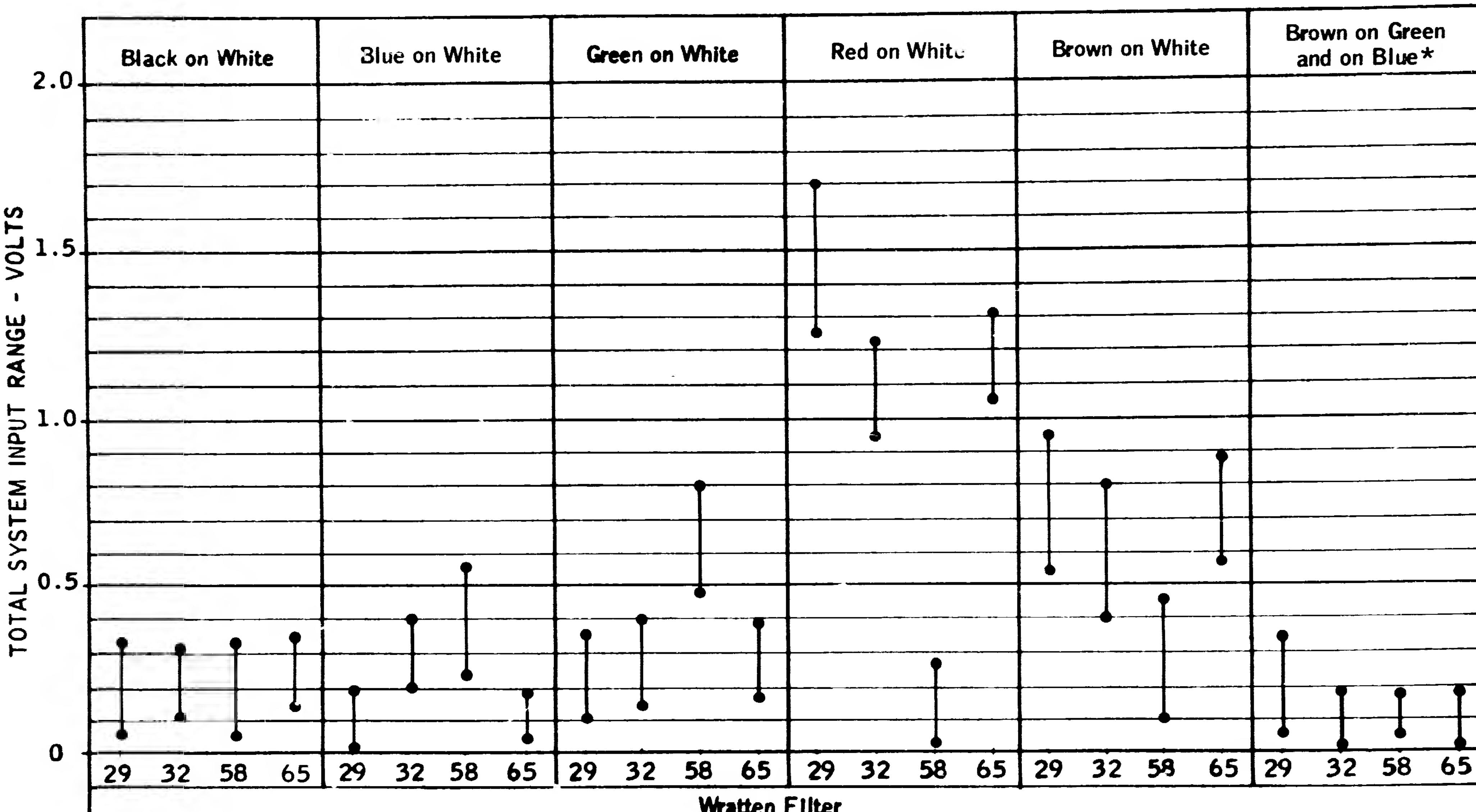


Map No.: 1

Title: Indian Head, Maryland, Virginia

INTENSITY RANGE GRAPH

Appendix No. 1 Page 1



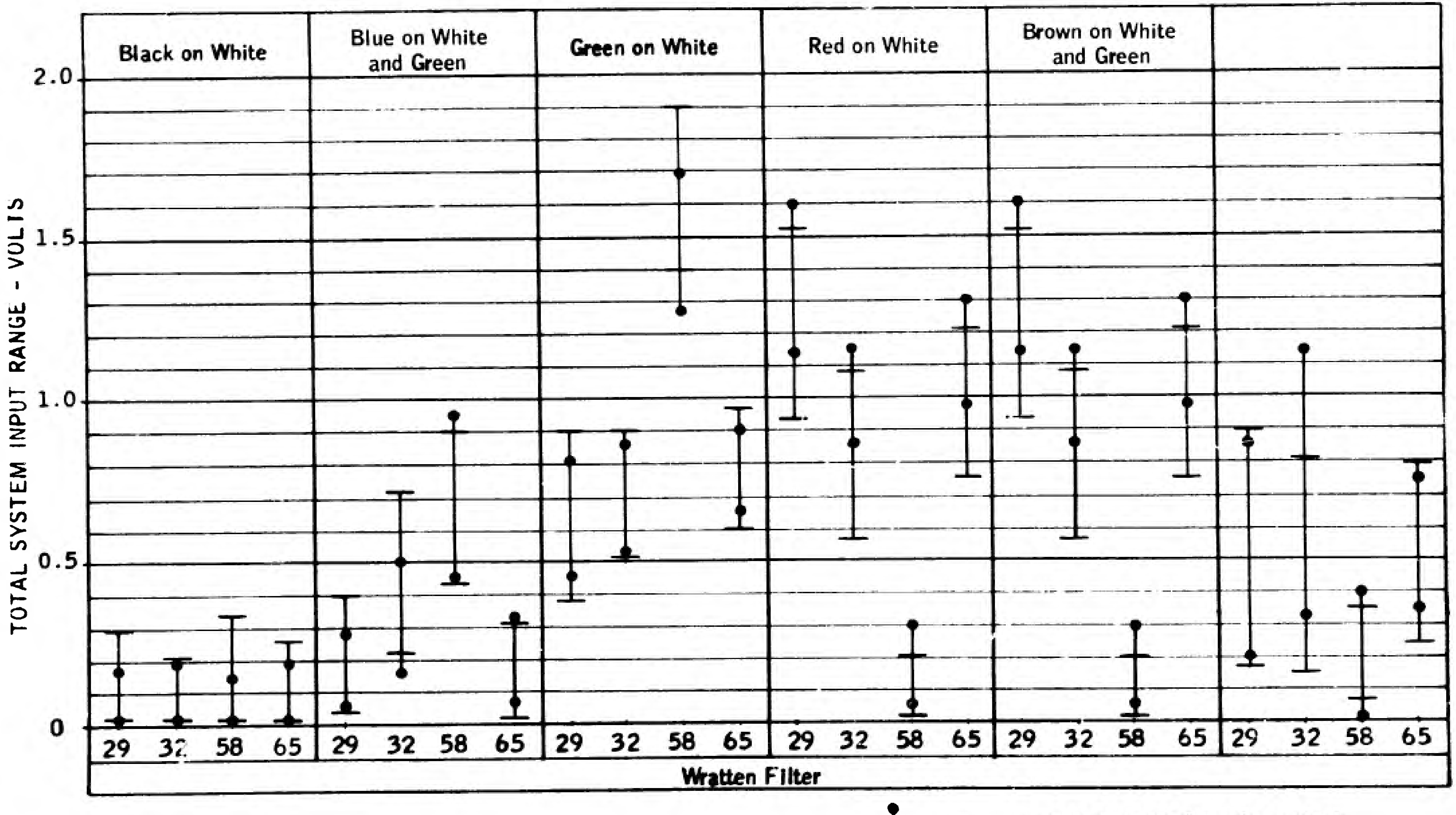
* Will probably pull Black as well

Map No.: 2

Title: Bien Hoa, Vietnam

INTENSITY RANGE GRAPH

Appendix No. 2 Page 1

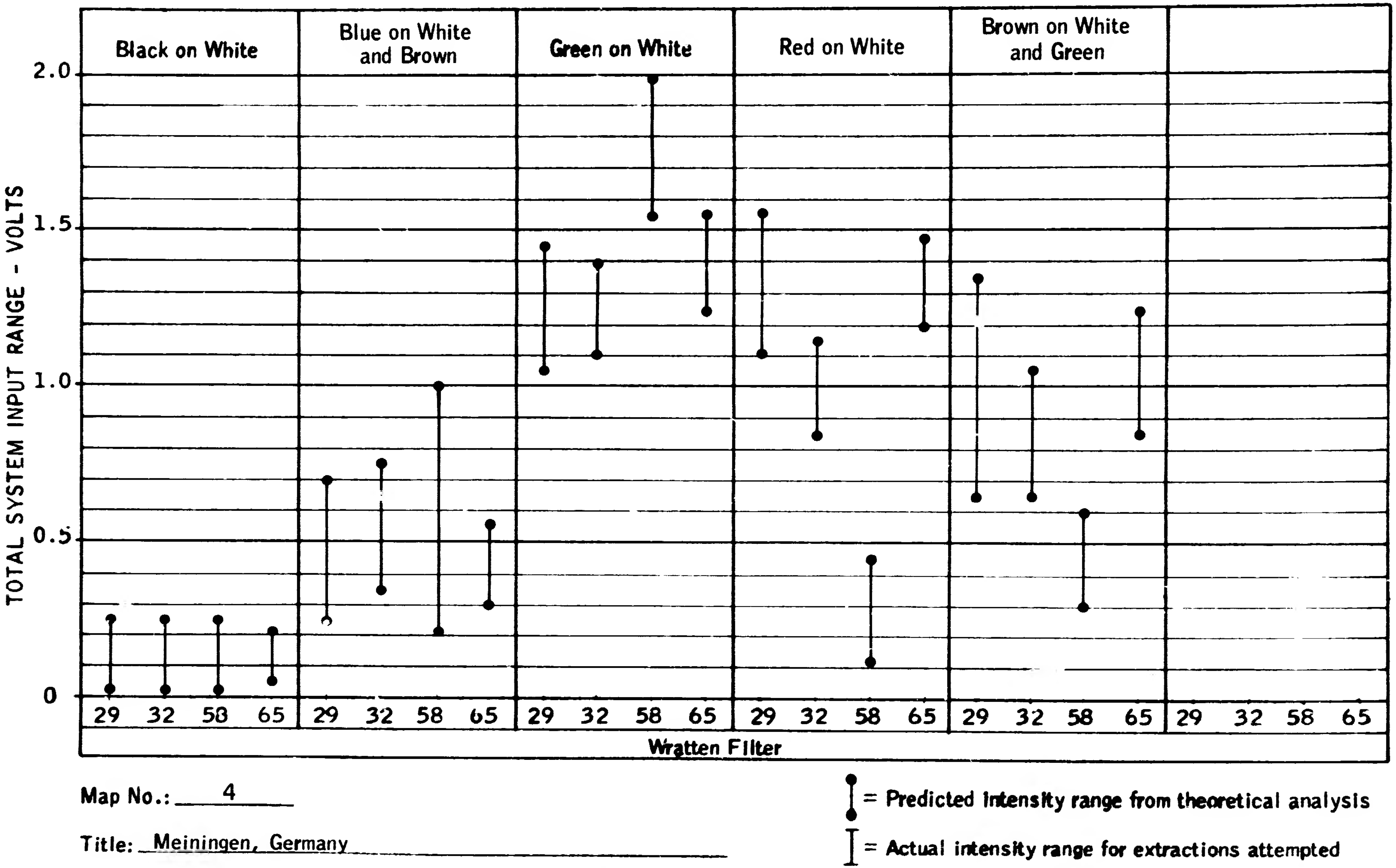


Map No.: 3

Title: Port Royal, Virginia

INTENSITY RANGE GRAPH

Appendix No. 3 Page 1

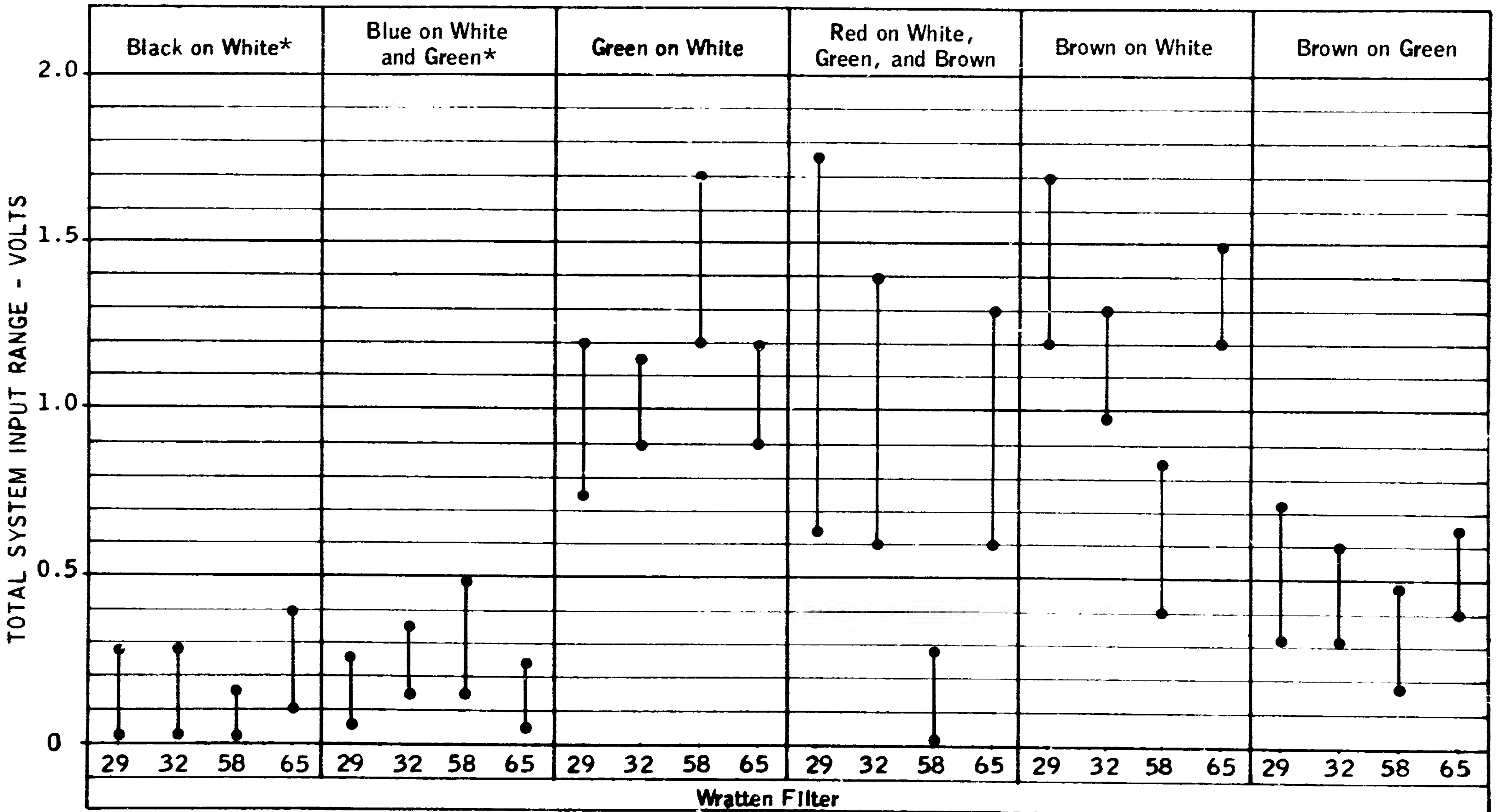


Map No.: 4

Title: Meiningen, Germany

INTENSITY RANGE GRAPH

Appendix No. 4 Page 1



*Blue and Black will probably separate together.

Map No.: 5

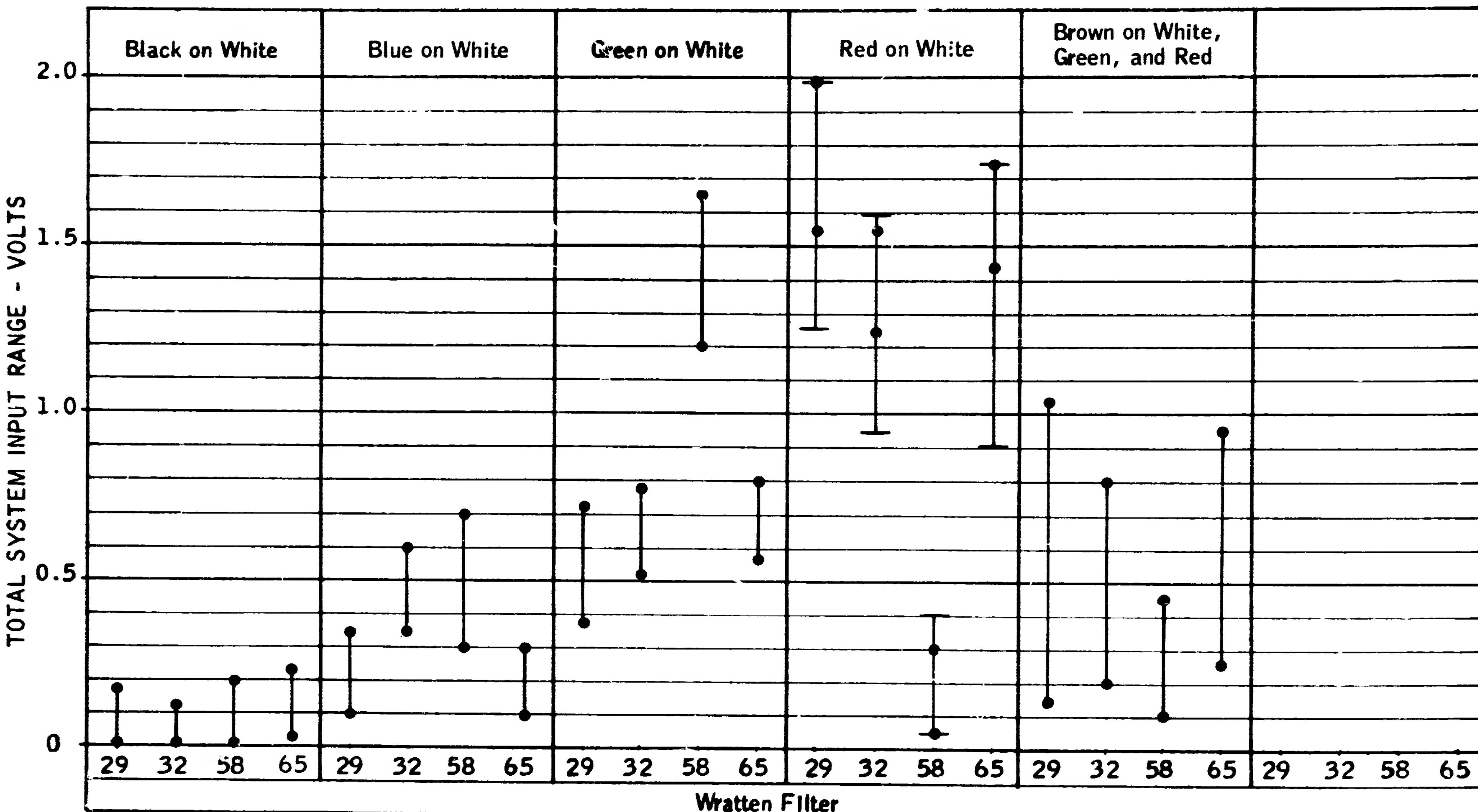
Title: Mount Vernon, Virginia

= Predicted intensity range from theoretical analysis

= Actual intensity range for extractions attempted

INTENSITY RANGE GRAPH

Appendix No. 5 Page 1



Map No.: 6

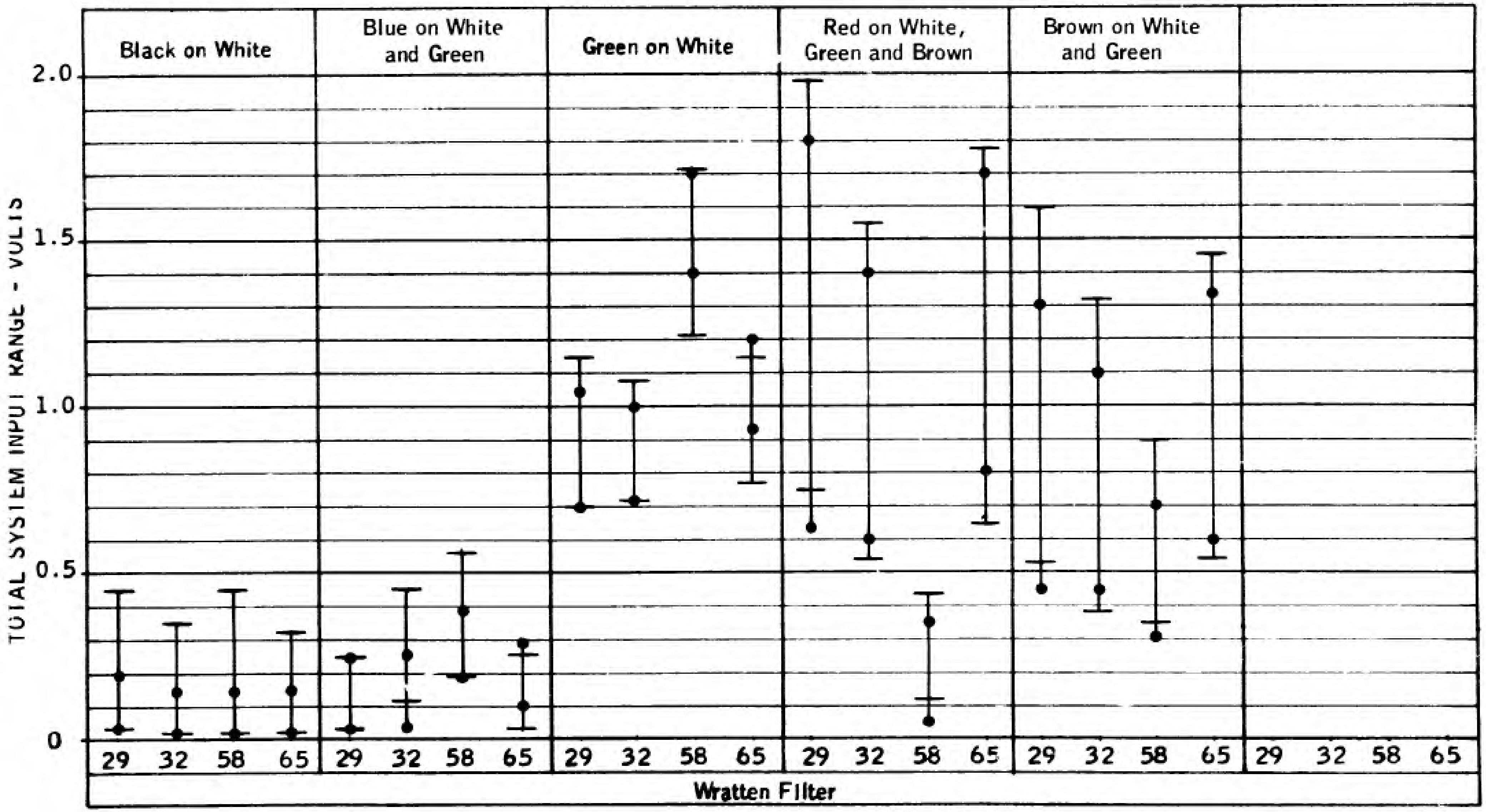
Title: Alexandria, Virginia

= Predicted intensity range from theoretical analysis

= Actual intensity range for extractions attempted

INTENSITY RANGE GRAPH

Appendix No. 6 Page 1



Map No.: 7

Title: Centre Hall, Pennsylvania

= Predicted intensity range from theoretical analysis

= Actual intensity range for extractions attempted

INTENSITY RANGE GRAPH

Appendix No. 7 Page 1

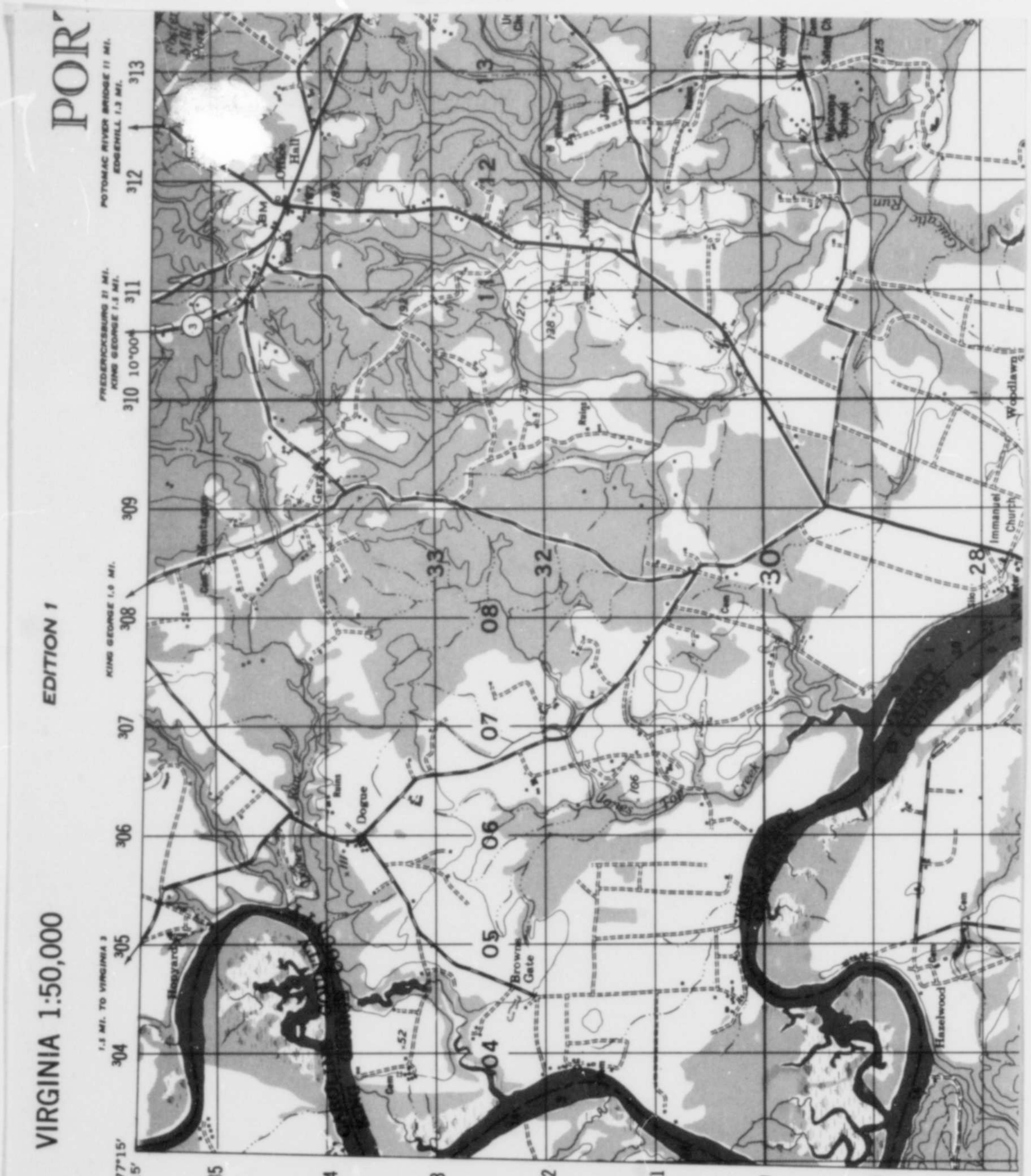
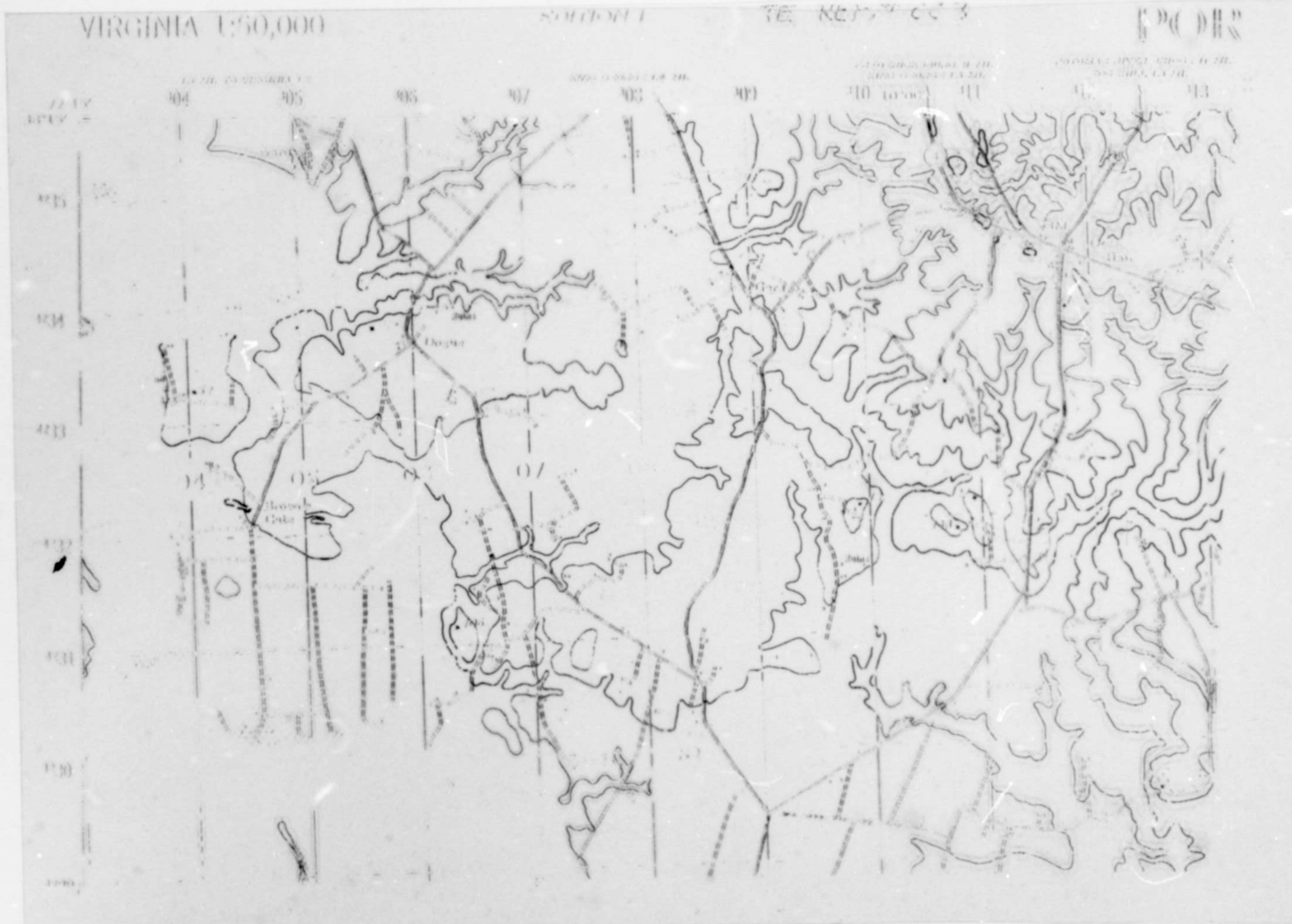


FIGURE 2-15

ORIGINAL MAP-EXTRACTION TEST #1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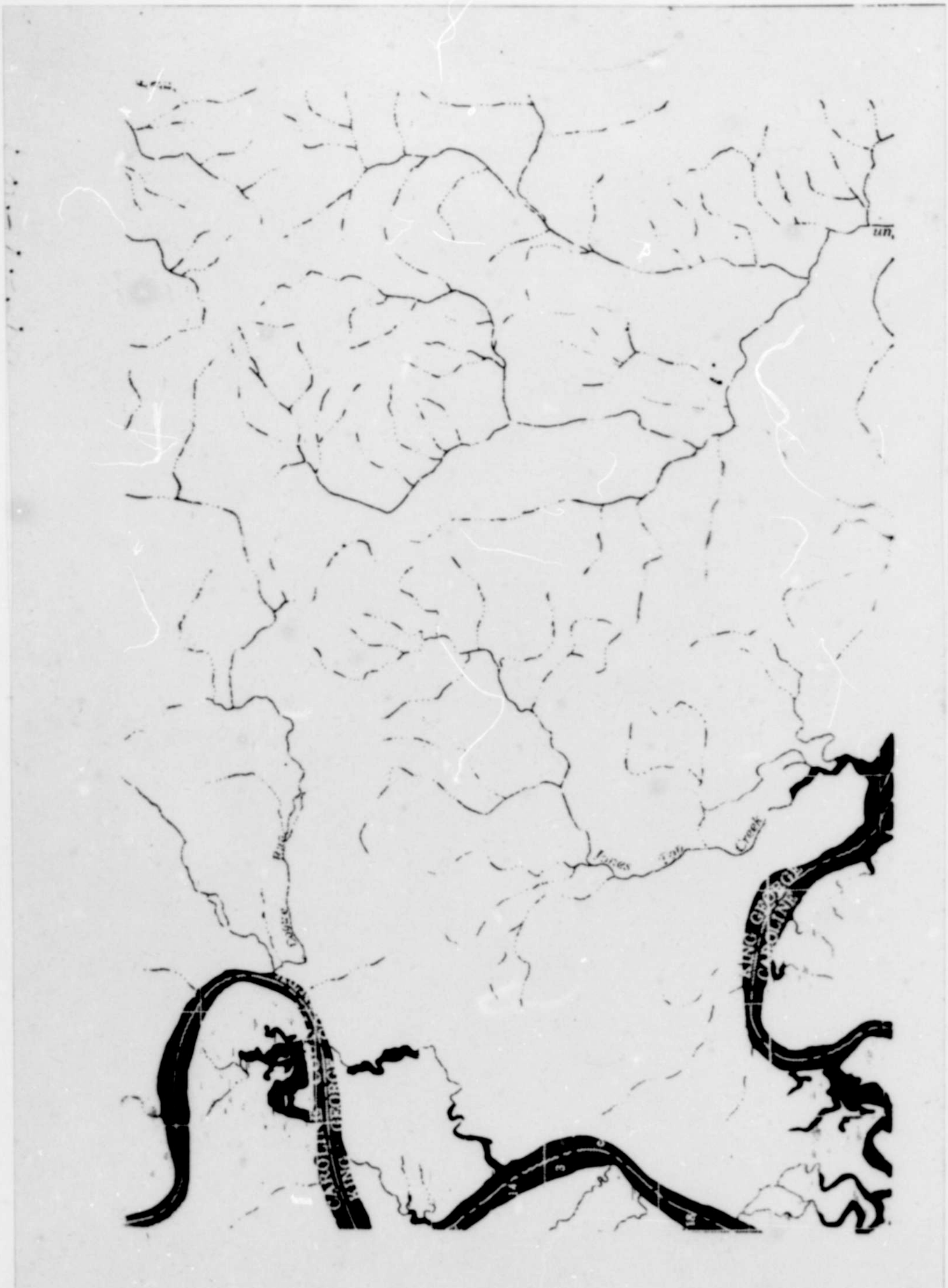
Depot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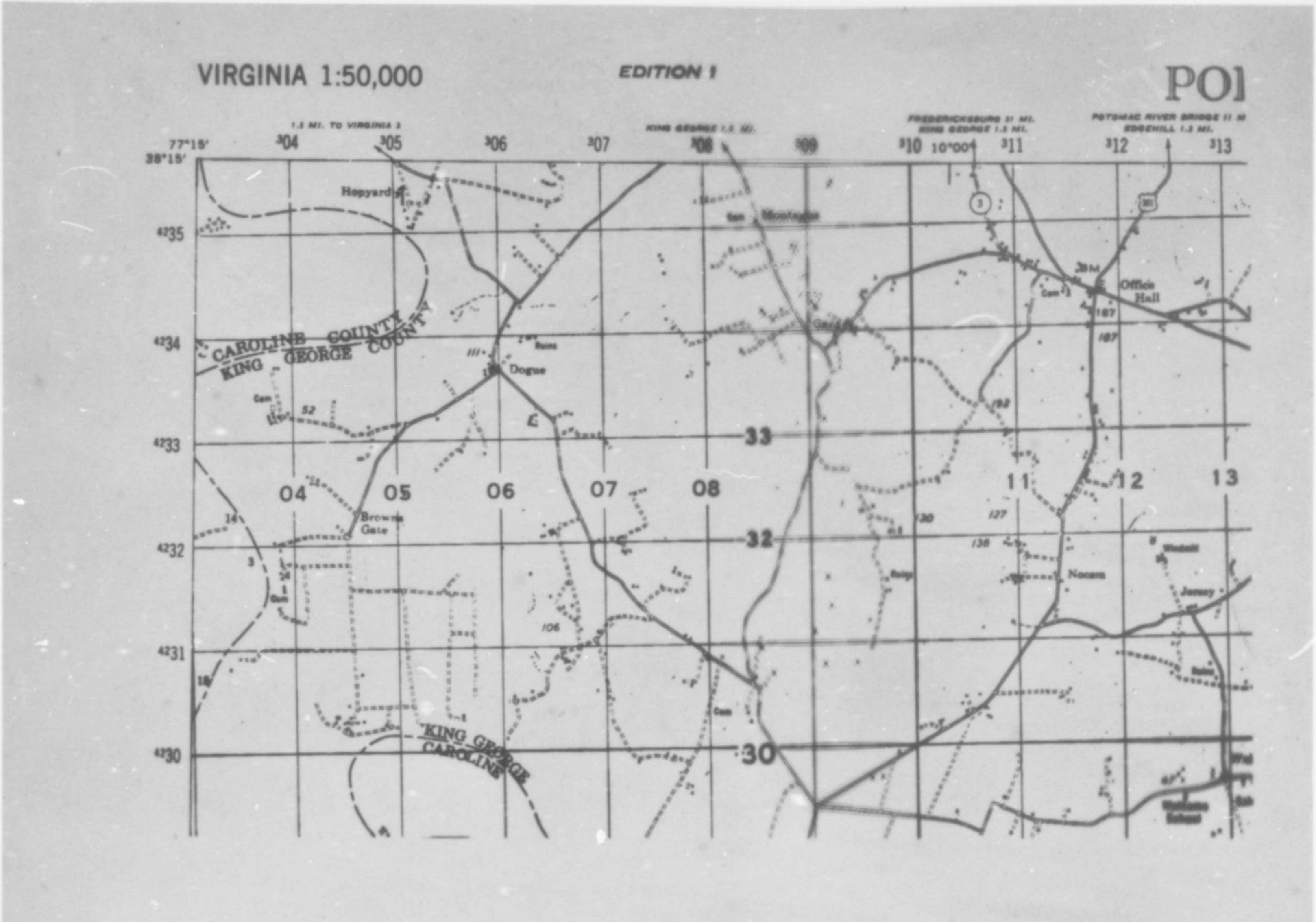
KING GEORGE
CAROLINE
CAROLINE
KING GEORGE



VIRGINIA 1:50,000
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POI
FREDERICKSBURG 21 MI.
KING GEORGE 1.5 MI.
POTOMAC RIVER BRIDGE 11 MI
EDGEHILL 1.5 MI.
77°15'
38°15'
Hopyard
Montague
Office Hall
CAROLINE COUNTY
KING GEORGE COUNTY
Dogue
Brown Gate
Nocem
Jersey
KING GEORGE
CAROLINE
04
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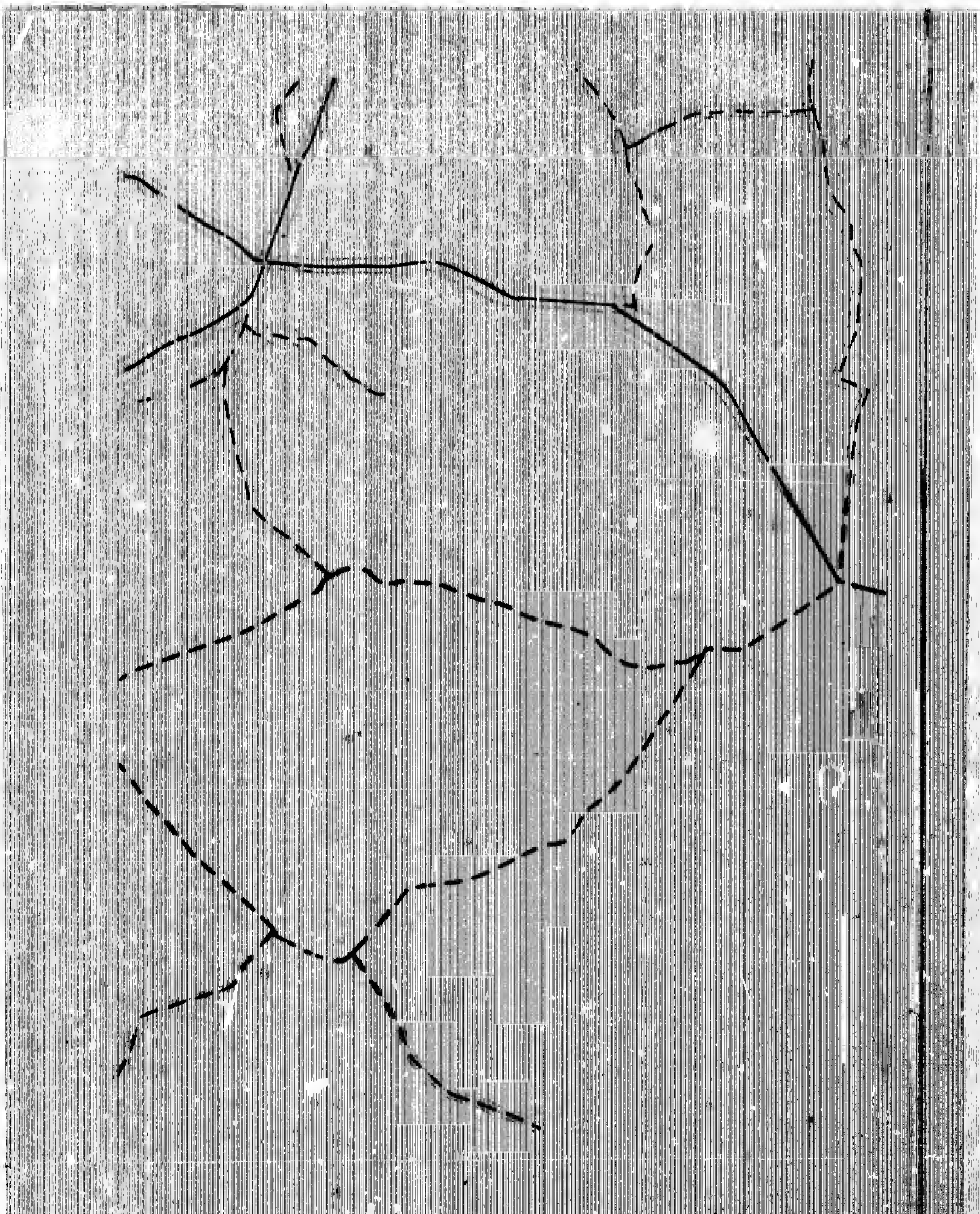

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1 ORIGINATING ACTIVITY (Corporate author) The Te Company 505 E. Montecito Street Santa Barbara, California 93103	2a REPORT SECURITY CLASSIFICATION Unclassified 2b GROUP

3 REPORT TITLE

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4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

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5 AUTHOR(S) (Last name, first name, initial)

Lierley, Charles R., and Harris, Clyde W.

6 REPORT DATE	7a TOTAL NO OF PAGES	7b NO OF REFS
September 1967	69	3

8a CONTRACT OR GRANT NO DAAK02-67-C-0172 b PROJECT NO c d	9a ORIGINATOR'S REPORT NUMBER(S) 6031 9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

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11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY U.S. Army Engineer Topographic Laboratories Topographic Systems Division, Reproduction Br. Fort Belvoir, Virginia

13 ABSTRACT

The purpose of this program was to determine the feasibility of extracting wanted single colors from multicolor maps. Unlike conventional three color graphic arts methods of color extraction, the approach utilized from four to twenty color sample analysis and analog and digital processing of the color data. The object map was line scanned, the resultant optical signal separated into color channels that in turn were converted to electronic signals, and these signals processed to produce a yes-no output recreating the wanted color line scanned on film. Both color matrix optimization and multilevel logic electronic processing functions were evaluated.

The results showed that color matrix optimization was not completely effective. The multilevel logic function, however, produced excellent results for several sample map sections tested. These maps included variations in print color, color overprinting, variations in substrate paper, and a wide variety of print geometries. The overlay of the resultant color extractions produced a faithful rendition of the original map, with the slight exception that fine detail such as halftone printing tended to be enhanced. Setup time to establish the logic extraction parameters for a given map was about 15 minutes for each color.

DD FORM 1 JAN 64 1473

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Optical Scanning						
Electronic Logic Functions						
Spectral Response						
Multicolor Maps						

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