NBSIR 84-2924(R)

Color Calibrator for RRWDS Radar Remote Weather Display System

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U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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FOREWORD

This report covers the status of work by the National Bureau of Standards (NBS) on the Radar Remote Weather Display System (RRWDS) Color Calibrator. The NBS work was supported by the Federal Aviation Administration (FAA) under Modification No. 0001 of FAA/NBS Interagency Agreement No. DTFA01-83-Y-20592.

ACKNOWLEDGMENTS

The authors wish to acknowledge with thanks the technical advice and consultation provided by Drs. Gerald Howett and James Worthey of NBS, the RRWDS maintenance support provided by Mr. Nick Donato of Electrodynamics, and the active encouragement and support provided by the FAA government technical representative Mr. Armand Maillet.

DISCLAIMER

Certain commercial equipment, instruments, or materials are identified in this report to specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Bureau of Standards nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

ACRONYMS AND ABBREVIATIONS USED IN THIS REPORT

B	CRT brightness control
BITE	Built-in test equipment
C	CRT contrast control
CCA	Circuit card assemblies
CRT	Cathode Ray Tube
EPROM	Erasable and programmable read only memory
FAA	Federal Aviation Administration
GaAsP	Gallium, Arsenide, Phosphide (a type of photodiode)
NBS	National Bureau of Standards
nit	A unit of luminance equal to one candela per square meter
NWS	National Weather Service
RAM	Random addressable memory
RGB	Red, Green, Blue (designating the colors of the three phosphors and the three electron light guns used in the CRT and the filters incapsulated in the three photodiodes used in the color calibrator
RRWDS	Radar Remote Weather Display System
S/N	Serial number
TBD	To be determined
TDL	Test digital level (refer to footnote 3, page 4 for details)
WIL	Weather intensity level

1. OBJECTIVES AND TECHNICAL APPROACH

The Federal Aviation Administration (FAA) uses a color Radar Remote Weather Display System (RRWDS) to display regional weather patterns of importance to various flight operations. The display presents six levels of weather intensity, using combinations of three colors and two lightness levels.

To determine the accuracy of the color combinations representing the different weather intensity levels (WIL) for an individual display, the FAA commissioned the National Bureau of Standards (NBS) to design, fabricate, and evaluate an engineering development model of a low cost, portable color calibrator for field use.

The objectives of this project were:

1) To design, fabricate, and evaluate an engineering development model of a low cost (about $100 in quantity) color calibrator capable of objectively determining whether the chromaticities and luminances of six colors, (i.e., light and dark green, light and dark yellow, and light and dark red) are within specified limits. These six colors are used to display areas of increasing weather intensity levels, respectively, on the Radar Remote Weather Display System cathode ray tube display (CRT).

2) To prepare a draft specification for use by FAA in procuring production prototype model color calibrators for field evaluation.

The basic tasks were to: (1) select the major components and combinations thereof (e.g., photocells, color filters, and electronic circuitry) for a simple, reliable and inexpensive color calibrator; and (2) evaluate these combinations under laboratory conditions in order to recommend a practical model to the FAA for field evaluation.

The results from the design, fabrication, and evaluation of the color calibrator model are reported in the following sections. In addition, some results relevant to the operation and calibration of the RRWDS are also presented. Evaluation of the color calibrator revealed some unexpected luminance and chromaticity changes on the RRWDS as well as some other system-related problems which should be considered in developing any set of field-calibration procedures and calibrator procurement specifications.

2. COLOR CALIBRATOR DESIGN

2.1 COMPONENTS

The color calibrator model consists of four parts: a sensory head, quick disconnect cable, power supply, and a digital voltmeter. The color calibrator sensing head itself consists of three photocells, each having a red, green, or blue (RGB) encapsulated filter corresponding to the RGB phosphor colors of the cathode ray tube (CRT) of the RRWDS. Tests were made on selected combinations of photodiodes and light filters to select optimum combinations for the color calibrator. The photodiode types included GaAsP and silicon; the filter types included Wratten narrow-band, medium-band and wide-band; and dichroic. Table 1 gives a detailed description of the combinations that were procured. A schematic circuit diagram is shown in figure 6.

The amount of light impinging on each photodiode is a function of the viewing distance, the radiance of the light source, and the transmittance of the filter. Each filtered photodiode predominantly responds to the light energy being emitted by its corresponding phosphor. Thus, the color calibrator measures the relative irradiance contribution [1/] of each phosphor to the WIL colors rather than measuring the chromaticity of each WIL. [2/]

2.2 RECOMMENDED SELECTION CRITERIA

Five criteria were used to evaluate the relative merits of the different types of photodiodes or photodiode/color filter combinations used in the color calibrator.

The photodiode selection criteria were:

1. Extended response out to UV to achieve a fairly strong color calibrator response for the blue phosphor.

2. Cut-off in red region at about 750 to 800 nm to eliminate response from infrared radiation.

The criteria for evaluating the photodiode/light filter combinations were:

3. A different numerical response by each of the three filtered photodiodes to provide suitable discrimination among the various RGB and WIL colors.

1/ When the viewing distance and geometry are specified, the resulting measurement is in terms of relative irradiance or simply radiant flux. With appropriate calibration which involves the V(λ) weighting function, the color calibrators could be made to measure luminance. The spot photometer and spectroradiometer both take V(λ) into account, and hence, were used to make illuminance measurements in candelas per square meter (c/m^2) or nits. Since the present color calibrator model is not so calibrated, the color calibrator simply reflects the relative radiances of each phosphor.

2/ Further refinement and development of the current approach has the potential for resulting in a true CRT colorimeter; i.e., a device whose output would be the CIE chromaticity coordinates for a particular set of phosphors.

Table 1. Photodiode/Color Filter Combinations

Item No.	Item Type	Quantity	Photodiode Type	Photodiode Mfgr.	Photodiode Model No.	Light Window (Infrared Filter)	Mfgr.	Model No.
1	Red narrow band Wratten	2	Silicone 1/	Vactec	VTB 5048	Two 0.5 mm layers of Schott glass 3/	Eastman Kodak	#26
2	Green narrow band Wratten	2	(")	(")	(")	(")	(")	#61
3	Blue narrow band Wratten	2	(")	(")	(")	(")	(")	#98
4	Red medium band Wratten	2	(")	(")	(")	(")	(")	#22
5	Green medium band Wratten	2	(")	(")	(")	(")	(")	#55
6	Blue medium band Wratten	2	(")	(")	(")	(")	(")	#47A
7	Red broad band Wratten	2	(")	(")	(")	(")	(")	#86
8	Green broad band Wratten	2	(")	(")	(")	(")	(")	#66
9	Blue broad band Wratten	2	(")	(")	(")	(")	(")	#CC80A
10	Red narrow band dichroic	1	GaAsP 2/	Hamamatsu	G1118	- 4/	Optical Coating Laboratory, Inc.	5/
11	Green narrow band dicroic	1	(")	(")	(")	(")	(")	5/
12	Blue narrow band dichroic	2	(")	(")	(")	(")	(")	5/

1/ Very low leakage P-N diode.

2/ Planar diffusion type P-N diode with SiO_2 coating on junction surface.

3/ The RG-18 Schott glass has a transmission range of about 310 to 760 nm.

4/ The G1118 diode has a spectral response range of 300 to 680 nm and does not require an infrared filter.

5/ No catalog number designated.

4. Capable of detecting differential light level changes equal to or less than one test digital level (TDL) [3/] increment or decrement of a light gun.

5. Off-the-shelf component availability.

2.3 EVALUATION

2.3.1 Test Color Display

The color displays were generated by three RGB guns on an FAA Radar Remote Weather Display System (RRWDS) manufactured by Electrodynamics and composed of Weather Processor Type FA9901/6, S/N 0101, Weather Display Type FA9901/7, S/N 0071, interconnecting cabling (shortened to ten foot lengths),[4/] and special EPROM circuit boards. After installation at NBS, the RRWDS system was calibrated by a representative of Electrodynamics.

2.3.2 Test Instrumentation

The principal instruments used in taking measurements of the chromaticity and luminance of the RRWDS and the color calibrator included:

- Chromaticity Measurements--Photo Research Model PR-703A Spot Spectroscan Rapid Scanning Spectroradiometer, S/N 1022.
- Luminance Measurements--Pritchard Model 1980 OP PL Photometer, S/N 214 (as well as the above radiometer).
- Color Calibrator Linearity Measurement--Spindler and Hoyer Optical Bench.
- Voltage Measurements

  1. Data Precision Model 2480R Digital Voltmeter, S/N 7499.

  2. Tektronix Oscilloscope Model TM506, Option 2, S/N B011387.

[3/] See appendix A section entitled, RRWDS Color Calibrator Test Mode, for a description of the test digital change capability for altering the DC signals from the Weather Processor to the volatile memory in the Weather Display, afforded by the addition of special erasable and programmable read only memory (EPROM) boards.

[4/] Replacement of the typical 100 ft coax cables interconnecting the RRWDS processor and display units with 10 ft cables greatly improved the high frequency video signal-to-noise ratio experienced when operating the system in the NBS laboratory environment.

3. RESULTS OF COLOR CALIBRATOR EVALUATION

The results obtained to date point to the following preliminary conclusions:

3.1 DEMONSTRATION OF FEASIBILITY

The technical feasibility of the color calibrator concept (using amplified voltage outputs from three independent RGB-filtered photodiodes) was demonstrated for single-step test digital changes. Feasibility remains to be demonstrated for the complex analog changes expected in the field and for meeting the hardware cost objectives.

The color calibrator was tested for linearity of output voltage by showing agreement with the inverse square law of radiation. The results plotted in figure 1, page A-15, show that the output characteristic of the color calibrator is linear over the illuminance range of interest (2 to 20 fc). (This indicates that the observed nonlinearities in measured data from the RRWDS CRT can be attributed to the RRWDS, and not to the color calibrator).

3.2 RECOMMENDED PHOTODIODE/FILTER COMBINATION

A critical aspect of the NBS evaluation was a determination of photodiodes/filters for the sensing head of the color calibrator. The combinations of photodiode/filter under consideration for the color calibrator were:

(a) silicon vs GaAsP diodes,
(b) Wratten vs dichroic filters, and
(c) if Wratten, then whether narrow-, medium-, or wide-band color filters.

The basic recommended sensitivity criterion is that at least one of the filtered RBG photodiode channels be capable of detecting differential light level changes equal to or less than one TDL increment or decrement in one of the guns, for each of six WILs. For example, WIL #1 is specified as R=06, B=02, and G=12. Based on this criterion, a unit TDL change (increment/decrement) in the R gun shall be detectable by at least one of the R, B or G photodiodes, preferably the R diode. A similar change in the G gun shall also be detectable by at least one photodiode, preferably the G diode. An exception to this criterion will occur any time any one of the RBG guns is decremented from TDL #02 or less as in WIL #1 and WIL #2 (B=02 in WIL #1 and #2 and R=01 in WIL #2)--and may occur when a gun is incremented from TDL #02 (or even from TDL #03 in some cases). Unit increments/decrements from these low digital level settings are not detectable by the color calibrator, the spectroradiometer, or the human visual system.

Based upon the procedures used in determining the feasibility of the color calibrator approach, two combinations have been demonstrated to be feasible. They are the silicon diodes with narrow-band Wratten filters, and GaAsP diodes with dichroic filters. The use of silicon diodes with wide-band Wratten filters has been ruled out because they fail to meet the preferred criterion stated in the previous paragraph. Specifically, the red channel responded strongly to stimulation by any one of the three RGB phosphors, and there was little or no difference between the responses of the blue and green channels for various levels of the green phosphor stimulation.

Time and resources available did not permit testing of other possible combinations such as silicon diodes with dichroic filters or GaAsP diodes with narrow-band Wratten filters. Other technical issues identified in this report appear to have first priority.

The GaAsP diodes are produced overseas and the color filters can only be incorporated into the diode housing by the diode manufacturer. For reasons of ease and timeliness of procurement, and probably the least cost, the silicon diode/narrow-band Wratten filter combination is recommended.

The long term stability of the Wratten and dichroic filters is unknown. The gelatin Wratten filters, which are especially degradable by UV exposure, are sandwiched between two pieces of BG - 18 Schott glass and encapsuled in the photocells during manufacturing. This process increases their stability. However, the color calibrator head (quick-disconnect) should be stored in the dark when not in use.

3.3 MEASURED COLOR CALIBRATION DATA

To validate the feasiblity of the color calibrator concept, NBS employed six special EPROMs (provided by the manufacturer) and an extra set of RGB memory planes in the RRWDS. The EPROMs provided the means of addressing the WIL random access read and write memory (RAM) locations from the display numeric entry board. Memory Plane B (three RGB circuit card assemblies (CCA)) provided a means of storing information for later comparison with incoming information (for example the WIL color wedges from a digitizer's built-in test equipment BITE) or with information stored in Memory Plane A. The EPROMs were used to make all digital level changes in the 14.7 inch diameter solid color background whereas the Memory Planes were used to make brightness and contrast checks of the original WIL colors. The color changes were all made on the WIL background (i.e., 14.7 in. diameter circle). This procedure eliminated the reflections or spillover present when there were adjacent color areas.

Spectroradiometric measurements of the chromaticities of the WILs provided by the vertical bars from the processor's BITE and the wedges from the digitizer's BITE indicated color reflections or spillover from adjacent areas. No effort was expended to determine if the color calibrator would yield similar results.

Measurements of filtered photodiode output voltages were made for each of the three RGB guns using the six special EPROMs. The luminance of each color phosphor was incremented by unit test digital level (TDL) steps from 00 to 15 (16 steps) and the color calibrator's response was plotted. Color calibrator response changes were noted as a function of performance degradation changes in the console's video amplifier board and high voltage block (Part No. 7030051), and changing from power supply No. 1 to No. 2. The color calibrator responses were plotted and the results for silicon photodiodes with narrow-band Wratten filters are shown in figures 2A-C (pp. A-17 through A-19), medium-band filters in figures 3A-C (pp. A-27 through A-30) and wide-band filters in figures 4A-C (pp. A-38 through A-41). The results for GaAsP photodiodes with dichroic filters are shown in figures 5A-C (pp. A-50 through A-53).

Measurements were also taken of unit digital level increments/decrements from the TDL specified for each gun for each of the six WILs using the narrow-, medium-, and wide-band filtered silicon diodes and the dichroic filtered GaAsP diodes. The color calibrator responses were plotted and the results are shown respectively in figures 2D-I (pp. A-20 through A-26), figures 3D-I (pp. A-31 through A-37), figures 4D-I (pp. A-42 through A-49) and figures 5D-I (pp. A-54 through A-60). The results indicate that:

a. The color calibrator can detect a unit test digital level change in chromaticity (the smallest change available from the vendor's EPROM).

b. The color calibrator (and the rapid scanning spectroradiometer) cannot detect the absence of TDL 02 blue in WIL #1 or #2, nor TDL 01 red in WIL #2.

Item b. appears to have no practical impact on the project, since NBS observers also cannot visually detect any change in color under similar circumstances, except when dark adapted in a very dark room. (NBS has previously reported on the nonlinear (or zero) chromaticity changes experienced with the RRWDS system at low test digital levels).

3.4 DETERMINING NEED FOR FRESNEL LENS AND LIGHT TUBES

A more stable voltage reading was obtained from the color calibrator if the detector head was moved away from the CRT screen. However, at distances approaching 6 feet the color calibrator no longer responded to the dark WILs (i.e., #2, 4 and 6), unless a Fresnel lens and light tube (tunnel) were added. A preliminary study was done to evaluate the effectiveness of various Fresnel lenses in collecting more light and concentrating it on the photodiodes, thereby increasing the response and stability of the color calibrator voltage. Locating the color calibrator head in front of or behind the focal length of the Fresnel lens improved both the magnitude of the readout voltage and measurement stability However, the geometry has not yet been worked out for ensuring that each of the three photodiodes in the head is equally illuminated.

Whether or not a Fresnel lens and light tube will be required accessories for field use of the color calibrator depends on the method to be used in the field for generating the display colors. The following table identifies both preliminary recommendations and need for further work:

Method of Displaying Test Colors (assumes dark room)	Need For: Tube	Fresnel Lens
Weather Processor BITE--bars (near distance only)	Yes	TBD (To be determined)
Digitizer BITE--wedges (near or mid-distances only)	Yes	TBD
EPROMS--solid color		
o Near distance	No	No
o Three feet	TBD	TBD
o Six feet	Yes	Yes

If a Fresnel lens is to be used, more work needs to be done to determine the proper off-focus distance needed to assure uniform light over all three RGB detectors. (Note that the data reported in appendix A was all measured without the use of a Fresnel lens or light tube.)

4. RESULTS OF RRWDS PERFORMANCE EVALUATION

4.1 COLOR CALIBRATOR AS DIAGNOSTIC TOOL

During the course of the laboratory evaluation of the color calibrator, a number of RRWDS equipment malfunctions were experienced. Examination of the color calibrator data taken prior to the malfunctions generally revealed a pattern. For example, when the tripler for Power Supply #1 failed, the data taken preceding the failure yielded a pattern of rapidly increasing shift in the chromaticities for each of the RGB channels. Switching from P.S. #1 to P.S. #2 resulted in a shift in the color calibrator output voltage readings approximately equivalent to changing EPROM settings by two TDL levels, depending on the color channel.

Color calibrator data taken prior to failure of the high voltage (HV) junction block revealed a somewhat different pattern. In this pattern the color calibrator output voltage reached a peak at around TDL = 1012, and then declined out to TDL = 15. Replacement of the HV junction block yielded a steadily increasing function up to TDL = 15 (refer to figures 2A-C, pp. A-17 through A-19). These findings suggest that the color calibrator might be a useful diagnostic tool (once verified in the field). It should be noted that no systematic changes were introduced into the system to verify these findings.

4.2 OBSERVED RRWD SYSTEM CRT CHARACTERISTICS

During the evaluation of the color calibrator, the RRWDS CRT console exhibited the following characteristics which may affect the ability of the operator (meteorologist) to discriminate between adjacent or nearly adjacent areas delineating differing weather intensities.

4.2.1 Background

A properly adjusted background generally minimizes, but does not eliminate visual discrimination problems when the Brightness and Contrast (B/C) controls are varied over their full range. A properly adjusted background is a (dim) medium grey that is neutral in color when the B/C control positions are at their maximum settings. As their names imply, the B/C controls permit individual operators to make minor adjustments in both chromaticity and light-dark contrasts to accommodate for individual preferences, particularly under different lighting conditions. However, extreme settings of these controls should be avoided as they may produce significant changes in chromaticity of the weather intensity levels (WILs).

Using a properly adjusted background, photometric and spectroradiometric measurements confirmed that even small changes in the B/C controls resulted in chromaticity and luminance changes in both single EPROM-derived colors or in WIL colors. Chromaticity changes in the WIL colors were more complex than for a single color. Most of these small changes in luminance and/or chromaticity are not discriminable by the human visual system except under conditions of direct comparison; i.e., when seen side-by-side. (Large changes in the B/C control settings were visually discriminable.)

A slightly misadjusted background can also present significant visual discrimination problems. Under this condition the effects of the B/C settings appear to be magnified. For example, a "bright" grey background tends to diminish light-dark contrast at high settings of the B/C controls. A color-tinged background distorts color contrasts significantly. Experiments with changing the adjustment of the background and changing the settings of B/C controls for a live weather display resulted in:

(1) WIL #5 (bright red) and WIL #6 (dark red) becoming virtually indistinguishable.

(2) WIL #2 (dark green) and the background becoming virtually indistinguishable.

(3) A requirement that the background and the B/C be kept constant in order to properly evaluate the color calibrator.

During early phases of this project, one problem was variability in both luminance and chromaticity data. One component of this variability was target size. Target size was varied from an individual RGB phosphor dot, to a pixel (RGB color triad), to a number of pixels, and to a circular area of about 2 inches in diameter. Increasing target size decreased variability in both photometer and spectroradiometer readings by averaging out the effects of refresh rate and the decay rates of the medium persistence phosphors.

4.2.2 Bright-dark Contrast

Under certain weather conditions and with a properly adjusted background, the weather intensity represented by the brighter color of a color pair fills a larger portion of the display than the darker color. The luminance provided by these bright colors then dominates the human visual system such that the darker member of a color pair cannot be discriminated from the background. Two such conditions have been observed on live weather displays:

(1) Where WIL #1 (bright green) predominated, WIL #2 (dark green) became indistinguishable from the background.

(2) Where WIL #5 (bright red) predominated, WIL #6 areas (dark red) became indistinguishable from the background.

In both situations the more intense weather condition was located within or directly adjacent to broad areas of the less intense but more luminous weather condition.

These situations may increase the operator workload required to detect the more intense (darker) weather intensity. For example, increasing the settings of the B/C controls may be used to improve the brightness contrast between the darker WIL and the background but at a cost of undesirable chromaticity and color contrast changes. Other Menu options, e.g., BLINK, may be used to decrease operator workload. Blink, however, is primarily useful for attention-getting and not continuous observation. Momentarily "masking" out the brighter WIL areas of lesser intensity is another option.

Excessive use of menu items (e.g., maps, range rings, azimuth lines, etc.) on the RRWDS may add unwanted luminance, especially if the line intensity is set to the maximum value (i.e., 07). This unwanted brightness diminishes the ability to distinguish bright-dark contrasts. Specular reflections and veiling glare from poorly designed room lighting also may seriously degrade a console operator's ability to make both color and bright-dark contrast discriminations.

4.2.3 Quasi-hysteresis Effect

A hysteresis-like effect in the RRWDS was observed in measurements made with both the color calibrator and the spectroradiometer. This effect consisted of different functions, one for an ascending series (TDL=00 to TDL=15) and one for a descending series (TDL=15 to TDL=00).

This effect is believed to be caused by RRWDS system drifts. The effect on developing a color calibrator procedure is that the type of color pattern to be used, the direction of the TDL changes, and the elapsed time for warm up and conduct of each step, may have to be specified in a way that is unrelated to the daily operational function of the display (i.e., the test conditions will be arbitrarily specified and not necessarily represent typical operational conditions).

4.2.4 System Drift

System drift in the RRWDS is a complex phenomenon which alters primary colors (single phosphors) and WIL colors differentially. If the weather background area is filled with a single color of a high level (e.g., TDL = 15, RED), and monitored over time, the luminance (and to some extent chromaticity) changes. Initially, luminance starts high, drops over the next one-half hour, and then begins to climb back up. However, even after 8 hours, luminance usually does not reach its initial value.

On the other hand, if the same weather background area is filled with a WIL then something different happens. After 15 minutes, bright WILs (#1, #3, #5) show a decrease in luminance, but dark WILs (#2, #4, #6) show an increase in luminance. Thus, the combination of system drift and the hysteresis-like effect means: a) the effects of a one TDL increment is not necessarily the same as a one TDL decrement, b) the effects of a one TDL change depend on the phosphor color and its contribution to a WIL, and c) possible interactions between color channels. The net result is that a unit TDL change in a particular gun means something slightly different for each WIL.

Perceptually most unit TDL changes are not discriminable. However, except for very low levels of a RGB color (e.g., as in WILs #1 and #2), unit TDL changes are discriminable when the changed and unchanged WILs are simultaneously viewed adjacent to one another.

4.2.5 Effect of Digital Level Changes

Although changing the TDL levels of a given color gun normally would not be expected to cause chromaticity to change, the chromaticity does shift on the RRWDS system at NBS. The shift is indicated by spectroradiometric data. For example, with the guns energized to green level #15, blue level #00, and red level #00, then as the TDL level for green is reduced, the CIE color coordinates as measured on the spectroradiometer remain constant down to about #07. Below TDL #07, the CIE coordinates change.

RCA, in their own lab and on the same model CRT, applied current to one gun only (the other two guns were de-energized) and found that the CIE coordinates did not shift as a function of decrease in current to the color gun under test. In the RRWDS system the RGB guns are always energized. The authors conclude that the observed chromaticity shifts are due to RRWDS system effects (interactions between the color channels).

4.2.6 Measurement Effects Due to Power Supply Degradation

Using RRWDS display power supply No. 1, measurements of photodiode voltage vs TDL setting showed severe saturation at and above certain TDL settings, even to the extent of complete reversal of the slope of the curve. The Contrast Control was originally set on +0.5V DC and the Brightness Control on -150V DC (there are no index marks on these controls). Switching to power supply No. 2 and then changing the Contrast Control setting to + 1.5V DC eliminated the slope reversal, greatly reduced saturation, and restored the original color (the latter based on subjective judgement). Changing the Brightness Control over a range of -225V to -125V produced little noticeable effect from a single WIL so the Brightness setting was left at about its original voltage. Subsequently, when a new voltage tripler was installed by FAA, the original Brightness and Contrast voltage settings proved satisfactory.

4.3 COLOR SPLOTCHES

Apparent thermal warping of the shadow mask is believed to be the cause of visible shifts in color in "splotch-like" areas covering perhaps 20 to 30 percent of the face of the CRT. It takes a fraction of an hour for such effects to appear. The impact on the pending calibration procedure is similar to that mentioned in section 4.2.4 above, plus the necessity to avoid the splotch areas when using the color calibrator.

Although the RRWDS CRT incorporates PERMA-CHROME, a temperature-compensated shadow mask, the MANUAL DEGAUSS button on the CRT console and the grounded console shielding appear to eliminate both magnetic and electrostatic warping as the sources of the color "splotching", leaving only thermal warping as the apparent source.

4.5 SYSTEM LIMITATIONS ON OBJECTIVES

If the operational anomalies of the RRWDS system used for NBS laboratory measurements are typical of other sets produced of this make and model, the overall purpose of achieving objective RRWDS color calibration in the field is attainable only under a predetermined and restricted set of operational conditions.

5. RECOMMENDATIONS

At this stage of the work, several recommendations regarding the color calibrator and RRWDS are offered for FAA consideration.

5.1 DESIGN OF THE COLOR CALIBRATOR AS A COLORIMETER

FAA may wish to consider future work to convert the color calibrator to a "true" CRT colorimeter by the addition of a low-cost microprocessor. Preliminary theoretical considerations and mathematical formulations have established the feasibility of a three-photodiode colorimeter. The hardware/software implementation of the colorimeter has not been attempted. The microprocessor would permit determination of the International Commission on Illumination (CIE) coordinates (x,y) of any given color on the screen, for a particular set of phosphors. These coordinates would be reproducible for use as evidence in court proceedings whereas the current color calibrator determines whether the WIL colors produce photodiode voltages that are within certain specified limits.

5.2 USE OF THE COLOR CALIBRATOR

5.2.1 Development of Field Calibration Procedures

Pursuit of the color calibrator approach requires a decision about how the WILs on the RRWDS should be calibrated in the field; i.e., (a) EPROMs + Memory Plane B, (b) vertical bars from the processor, or (c) wedges from the digitizer. Supplementary or alternative techniques to the use of a light tube with Fresnel lens as a means of reducing/eliminating color bleed-through for (b) and (c) above would have to be explored. These might include removing the glass safety shield during field maintenance or modifying the CRT.

Depending on FAA decisions on the recommendations in this report, additional work may need to be done to resolve such issues as color reflections or spillover, luminance specifications, Fresnel lens/color calibrator geometry with respect to the CRT screen, EPROMS, etc. In addition, the impact of room lighting (as in FAA Flight Service Stations) or darkened room conditions (as in Air Route Traffic Control Centers) on detectability of WILS and on RRWDS calibration procedures needs to be assessed.

Still another area which must be resolved before field calibration procedures are implemented is a determination of the replicability of color calibrator measurements. The following possible causes for perturbations in photodiode voltage measurements using the color calibrator should be checked under differing conditions:

a. Investigate whether light reflections between the surface of the CRT and the protective glass and/or the Fresnel lens are causing the spill-over of color from one color segment to another (of the multicolor digitizer's wedge or the processor's bar type display), even when a multicolor (RGB) calibrator head is constrained by a tube to viewing only one color segment of the display.

   Alternatively, use only single-color displays for color calibration purposes.

b. Check for the possible presence in the NBS laboratory of electro-magnetic interference (EMI) or conducted electrical interference that may be causing extraneous spectral power spikes to show up in the output of the rapid scanning spectroradiometer at low chromaticity test digital levels (the RRWDS lab is directly above the CBT computer facility room).

5.2.2 Chromaticity Drift

Resolve issues as needed for development of an initial working draft calibration procedure. Until the RRWDS chromaticity shifts over time are essentially eliminated, develop:

a. A method of restricting the area of the solid color display to be checked (e.g., visually staying away from the splotches of obviously shifting chromaticity).

b. An arbitrary specification of the timing and sequence in which the calibration color patterns are displayed.

5.2.3 Color Calibration Tolerance

Specification of the photodiode voltage equivalent of a plus or minus unit TDL change is recommended as the interim maximum acceptable limit for gun drift in the field. This recommendation is based on the fact that a unit TDL change is visually detectable (except at TDL 01 and 02), is measurable by instrument, and is the smallest luminance that can be produced with a vendor furnished EPROM.

If absolute color calibrator voltage readings are to be used to set tolerance limits for the WIL colors, some fixed distance from calibrator head to protection screen/CRT face should be determined from field measurements.

5.3 DESIGN OF RRWDS

5.3.1 Operation of RRWDS to Maintain Calibration

If the present WIL color scheme for the RRWDS is to be retained by FAA, then in order to deal with problems listed under section 4 it is recommended that:

a. If the FAA does not find it practical to relocate the Brightness and especially the Contrast Control to the inside of the display unit, some other sort of restriction should be placed on the range of the Contrast Control setting or a cautionary placard should be added to inform the operator. For example:

> "CAUTION--Changing the Contrast Control setting (Ref +0.5VDC) can change the colors appearing on the Weather Display," and

b. External voltmeters should be added to indicate Contrast and Brightness voltages so that these adjustments can be included in the daily operating procedure and the technician's color calibration procedure, or

c. External jacks should be added for convenient connection of voltmeters to indicate Contrast and Brightness voltages to the technician during the color calibration procedure.

5.3.2 Visual Detectability

Another problem is the discriminability of certain WILs by meteorologists having slight color-vision anomalies. NBS recommends that the WIL colors be reevaluated to establish WIL chromaticities and luminances that would maximize color discrimination by persons having slight color vision defects. This reevaluation would also consider selection of luminance levels to permit all observers to distinguish the dark WIL colors from both the background and the corresponding bright colors. At FAA's option the basic FAA color scheme of bright and dark red, yellow, and green could remain unaltered. Only minor changes in the CIE coordinates for several of the WILs would be recommended.

5.3.3 Possible Revision of Objective

Because of chromaticity and luminance changes due to system drifting, power supply degradation over time, and manual manipulation of external controls, the strategy of using occasional field calibration in order to hold colors constant appears to be only partially effective. Perhaps in future work the feasibility of a modified strategy should be explored; namely maintaining specified degree(s) of contrast between WILs while substantially loosening the limits on the absolute colors. This would require a microprocessor-controlled version of the color calibrator. Note that future modifications to the RRWDS system might make unnecessary such a change in objective, which NBS regards as being of secondary desirability.

5.3.4 Recommended Inclusion of Luminances in WIL Color Specifications

The effects described in sections 4.2.1 and 4.2.2 make clear that the purpose of achieving six highly discriminable WIL colors cannot be achieved by control of chromaticity alone. Some minimum ratio of luminances between the light and dark colors of each pair must be maintained to ensure adequate discriminability. Moreover, the need to discriminate the even-numbered (dark) WILs from blackness (the background) necessitates setting minimum absolute luminances for those colors. As a consequence, it is strongly recommended that the final FAA specifications for the WIL colors include luminances as well as chromaticities.

If the color calibrator is used in the absolute mode, with a fixed measuring distance and a single table of acceptable ranges of the diode voltage outputs, then the luminance aspect is automatically controlled, along with the chromaticities.

5.4 NEED FOR FIELD OR LABORATORY ANALOG TESTING

One of the previously stated criteria for sensitivity of the filtered photodiodes (see No. 4 in section 2.2) is intended for use with test digital level changes in chromaticity. A feasibility demonstration of that objective is not the same as demonstrating the suitability of the engineering model color calibrator for such analog changes as are expected to appear in the field. Analog changes could be due to such factors as changes in gun bias voltages, changes in grid potentials (especially G2), video amplifier board replacement, or high voltage block or tripler replacements in power supplies. This distinction is crucial because a unit TDL change affects only the WIL being tested and not other WILs. In the field, any analog change (especially in the RG guns) is expected to affect all WILs, but not necessarily proportionally. Because of the potential complexity of in-the-field analog changes, NBS's demonstration of the feasibility of the color calibrator cannot be generalized to cover analog changes in the field without further testing.

6. CONCLUSIONS

In conclusion, the research reported here demonstrates the feasibility of the color calibrator. The engineering model of the calibrator was used successfully to measure differences between WIL levels on the RRWDS at NBS. The data suggest that the initial objective of designing, fabricating, and evaluating a color calibrator has been met.

Additional field testing at selected FAA facilities is recommended to verify the feasibility of field use of the color calibrator, develop calibration procedures, assess room illumination effects, and finalize recommendation for chromaticity/luminance specifications on operational RRWDS Systems. This research would result in recommendations for the tolerance limits (in terms of chromaticity and luminance) for the colors used to indicate weather intensity, calibration procedures for using the color calibrator with the RRWDS, and a range of lighting conditions for RRWDS operations.

Appendix A

COLOR CALIBRATOR TEST PROCEDURES AND RESULTS

INTRODUCTION

The project objectives, technical approach, test articles, selection criteria, instruments used and general results are described in the main report. The laboratory evaluation objectives and detailed experimental procedures and results are described in this appendix.

LABORATORY EVALUATION OBJECTIVES

The three principal objectives of the laboratory evaluation were to:

1. Verify that the color calibrator responds linearly over the luminance range of the RRWDS CRT display.

2. Determine that the color calibrator has enough sensitivity and discrimination to detect a specified amount of relative change in the contribution of any RGB color gun/phosphor to the specified chromaticity of any of the six WILs.

3. Determine the best photodiode/light filter combination for detecting relative changes in chromaticity for each of the six WILs.

PRELIMINARY RRWDS CRT MEASUREMENTS

A raster-scan (digital) CRT has certain known non-homogeneities, e.g., non-convergence at the perimeter, color shadow mask warping due to magnetic/ heating effects, and sloping lines with the "jaggies" to mention a few. Some of these non-homogeneities are due to the color CRT, such as color "splotching" which may be due to either magnetic or thermal warping. Other observed non-homogeneities may be due to systems effects which result from engineering trade-offs to meet system objectives, such as when the CRT anode voltage is upped to 30 KV from the manufacturer's recommended 25 KV. Therefore, one major concern of this project was to determine system effects on the color CRT's luminance and chromaticity characteristics.

Photometric measurements indicated that: a) the luminance of a single phosphor dot averaged over several scans showed both temporal and spatial (dot-dot) variability, b) the averaged luminance of the smallest digitized area (approximately 7 to 9 pixels) showed somewhat less temporal and spatial variability, and c) use of large viewing areas for measurement provided spatial averaging and showed the least amount of spatial variability. On the other hand, the large areas did reveal a significant luminance variation as a function of the time that the target had been displayed.

Time-sampled spectroradiometric measurements with calculated summary outputs verified the luminance variability detected by the photometer. In addition the spectroradiometric measurements indicated that there are small chromaticity changes concurrent with the luminance changes associated with a single phosphor color, i.e., with only a single color displayed on the CRT. Since the results of the RCA tests show that chromaticity should not change as a function of a single phosphor's luminance change, a system effect or interaction apparently caused these results. Changes in system components, e.g.. voltage triplers, high voltage junction blocks, or video amplifiers also produced changes in WIL chromaticity. Changes in the Brightness Control (B) and especially the Contrast Control (C), produced both luminance and chromaticity changes. Although the photometric and spectroradiometric data are not included in this report, they were used to develop a standard set of conditions under which all color calibrator measurements were taken. These standard conditions were used to reduce some of the nonhomogeneity and variability detected by the spectroradiometer.

RRWDS COLOR CALIBRATOR TEST MODE

The RRWDS was converted to the color calibrator test mode by replacing the standard 2708 EPROMs on the Display CPU/Interface circuit card assembly (i.e., CCA #N3NB#A1) with a set of color test EPROMs provided by the Electrodynamics Corporation. These color test EPROMs allow entry through the console keyboard to the WIL color and background RAMs. The programs written into the EPROMs allow each color gun to be changed by 16 digital levels as entered from the keyboard, i.e., from 00 to 15. In addition, a Memory Plane B was added to the Weather Processor to provide RGB memory boards for storing the six WIL color wedges from a Digitizer located at an FAA/NWS radar site. This permitted a choice of two modes for testing the color calibrator: a) filling the weather display background with a single color and eliminating the alphanumerics, thus avoiding color interference, and b) changing adjacent WIL wedges for side by side comparisons. The latter test mode was used to determine if a unit TDL change could be visually detected. For the bright WILs (i.e., #1, #3, #5), a unit TDL change cannot be detected visually. For the dark WIL's (i.e., #2, #4, #6) a unit TDL change can sometimes be visually detected with the room lights off but it appears to the observer as more of a brightness change than a chromaticity shift.

On a live weather display, the B and C Controls can be manipulated such that it is extremely difficult to distinguish between the light and dark WILs (e.g., WIL #5 vs WIL #6) depending on the size of the areas involved, or between a dark WIL (e.g., WIL #2) and the CRT background color. In order to establish standard conditions for setting these controls, a number of live weather displays were examined while adjusting the B and C controls and recording the B and C voltages with the room lights off. The B and C controls were manipulated so as to:

1. Minimize weather display background.

2. Maximize light-dark contrast between weather display and display background.

3. Maximize color contrasts between WILs.

4. Maximize light-dark contrasts between WILs.

The final Brightness and Contrast settings resulted from the subjective interpretations of the investigators. Other operators using different CRTs may arrive at different settings. Nevertheless, by keeping these settings constant throughout all data collection, a common reference point was obtained. The final values used throughout this study were B = -150 VDC and C = +0.50 VDC. The color calibrator is sensitive to color changes resulting from B and C voltage changes so that the same set of B and C voltage conditions should always be used. However, it should be noted that the B and C control voltages necessary to maintain the same color calibrator outputs may change due to switching from Power Supply #1 to Power Supply #2 or to the normal performance degradation of a power supply over time.

According to the manufacturer, the chromaticity of a CRT phosphor does not change over time. However, the display may show chromaticity changes as the CRT ages. These shifts in chromaticity are due to electrode erosion reducing the accuracy of the beam control, thereby producing unwanted stimulation of adjacent phosphors. Usually the red and green color guns erode first. When the chromaticity of a WIL shifts beyond the equivalent of two TDLs, the CRT tube (or the guns) probably should be replaced. Gun replacement requires special facilities. Chromaticity changes in the six WILs have been noted when other components fail, e.g., the video amplifier CCA, high voltage junction block, or the voltage triplers for the power supplies. In several cases CRT luminance changes noted with the color calibrator have forecast or signaled a component failure.

COLOR CALIBRATOR LINEARITY TEST

Objectives:

It is highly desirable that the output voltage of the color calibrator be a linear function of the input irradiance. One way of checking this linearity is to confirm the inverse square law of illuminance from a point source, at least up to the illuminance level produced by the RRWDS display at short range. Linear response simplifies the interpretation of the color calibrator data and is almost a requirement for practical field applications. The objectives of this test were to:

1. Verify the linear characteristics designed into the color calibrator.

2. Remove the color calibrator as a possible cause of nonlinear characteristics observed in measurements of the Weather Display Test Digital Levels.

Procedure:

The inverse square law of illuminance is represented by:

$$E = kI/S^2$$

where: E = illuminance falling on detector from a point source,

I = luminous intensity of the point source,

S = distance from lamp to detector (e.g., color calibrator head),

k = proportionality constant (depends on measurement units).

The inverse square law holds accurately as one backs off from a small lamp, beyond a certain minimum distance. Hence a plot of E 1/ against $1/S^2$ should give a straight line.

Step #1--A Weston foot-candle meter was used to measure the illuminance provided by the RRWDS CRT. The following conditions were established:

(a)	Digital gun settings:	R=15 B=13 G=15	Manufacturer's white
(b)	Brightness Control:	-150 VDC	
(c)	Contrast Control:	+0.5 VDC	
(d)	Cosine correcting lens of meter:	Touching glass protective screen. Centered on cursor's home position	
(e)	Extraneous Light Sources:	All room lights - OFF Console lights - Covered Other RRWDS Indicator lights - ON	
(f)	Result:	The Weston foot-candle meter set at the low light scale, yielded a reading of 20 fc 2/	

1/ The color calibrator voltage should in the general case be proportional to irradiance, but by using a lamp of fixed spectrum, illuminance can be used instead, since they are then proportional. Alternatively, simply interpret E and I in the inverse square law as irradiance and radiant intensity.

2/ The 20 fc reading does not represent the maximum illuminance that the RRWDS is capable of providing at the protective screen; rather it represents the illuminance resulting from the reference voltage values selected for this project for the Brightness and Contrast Controls.

Step #2--The next step was to check the linearity of the color calibrator on the Spindler and Hoyer Optical Bench. The point source used was a 12 VDC lamp (auto taillight). Power was supplied by a precision AC to DC converter that supplies ripple-free 12 VDC irrespective of AC line voltage fluctuations. The long axis of the lamp filament was placed orthogonal to the length of the light bench. The photometer was placed on the optical bench and moved away from the filament until 20 fc was obtained (487 mm). This distance from the filament was the starting point for the color calibrator check.

The color calibrator was installed on the optical bench and readings taken at various distances until a point was reached when the photometer measured 2 fc. The red narrow band filtered photodiode (combination No. 1) was used for this test because the 12 VDC incandescent lamp was a convenient low wattage lamp with ample energy in the red region of the spectrum. Since there is no difference between the RGB silicon photodiodes except for the type of Wratten filter, there was no need to check the green and blue filtered photodiodes.

Results:

As shown in figure 1, a plot of the voltage output of the calibrator against $1/S^2$ yields a straight line over the illuminance range of 2 to 20 fc. Hence, since things linearly related to the same thing are linearly related to each other, the test established that the calibrator voltage output is linearly related to E. In fact, the line very nearly passes through the origin ($E = 0$, $1/S^2 = 0$). At an infinite distance S, $1/S^2 = 0$ and E should be zero, assuming that the dark current (ID) has been nulled out. Since the voltage is very nearly zero there, this means that there is little or no output from the calibrator when no light strikes it. Thus the voltage output is actually directly proportional to the illuminance, within a reasonable tolerance.

Conclusion:

The nonlinear results obtained from color calibrator measurements of the CRT display are attributable to RRWDS/CRT system effects.

OBSERVATIONS OF SYSTEM EFFECTS

Five types of non-uniformities or system effects have been observed and will be described in detail:

1. CRT display drift/Quasi-hysteresis effect

2. Heat warping of shadow mask

3. Refresh rate

4. Color reflections

5. System interactions

1. CRT Display Drift/Quasi-hysteresis Effect

Certain CRT display anomalies were noted during preliminary investigation of the RRWDS color display. These CRT display anomalies are associated with the test methodology used to identify them and appear to be interrelated through some overall system effect(s). These effects occur during continuous RRWDS operation so intermittent operation of the RRWDS was not a factor in these observations. These effects/anomalies are:

a. CRT Display Drift--At the start of an 8 hour test period, a white (TDL of R = 15, G = 15, B = 13) was keyed into the RAM location for the (WIL) background and the alphanumerics erased. Spectroradiometer samples were taken at appropriate intervals throughout the 8 hour test period. The (spectroradiometer-calculated) luminance values (nits), when plotted over time indicated that the luminance dropped considerably during the first one-half hour, slightly fluctuated around a median value for the next one-half hour, and then steadily increased. However, at the end of the 8 hour test period, the luminance was still less than the initial value.

   The above procedure was replicated with each of the individual RGB colors in turn at a TDL = 15 while the remaining two colors were at TDL = 00. Although the luminance values were correspondingly lower, the forms of the functional relationships between CRT luminance and time were similar to those obtained for the white background. Further replications using a TDL = 05 for each of the individual RGB colors produced a different functional relationship. For these replications, there was a slow steady increase in luminance over the first 2 hours and then a leveling off, with minor fluctuations, out to 8 hours.

   Chromaticity changes calculated by the spectroradiometer were noted in conjunction with the luminance changes. Since the calculated CIE (x,y) value changes were in the fourth and third decimal places, a correlational analysis relating chromaticity shifts to luminous changes was not attempted.

b. Quasi-hysteresis Effect--Preliminary checks were made to determine if measurements of RRWDS display characteristics using individual RGB colors should be made in ascending (from 00 to 15) or descending (from 15 to 00) order of TDL. Luminance measurements were made at an approximate time interval of 15 minutes.[3/] For ascending TDLs it was observed that the curve of luminance (nits) against TDL was significantly displaced (to the left and above) the curve for descending TDLs. Due to time constraints a full set of measurements was not completed for the descending series. The ascending series approach was adopted as a basis for evaluation of the color calibrator.

   As a point of information, the investigators considered and then rejected the possibility that the variable spectroradiometer lapsed-time measurement characteristics [3/] might have contributed to the observed quasi-hysterisis effect, since brief checks using other instruments not affected by time factor considerations indicated that the effect was caused by the RRWDS.

Comment--The changes in luminance and chromaticity recorded by instrumentation were not generally discriminable by the investigator. However, in a split-screen display with simultaneous cross-comparisons, such changes may be discriminable by the human visual system.

2. Heat Warping of Shadow Mask

Apparent heat warping [4/] of the thermal-compensated, color shadow mask was most clearly noticeable under two conditions. The white color vertical bar from the processor's BITE showed extensive warping of the mask because the bar was near the perimeter of the 14.7 inch diameter display area and the RBG guns were set at high heat producing levels (R = 15, B = 13, and G = 15). Another instance of heat warping occurred when B = 15, R = 00, and G = 00. After approximately 20 minutes a purplish area appeared in the lower left quadrant of the Weather Display. Using 10 to 20x magnification, a red "pimple" was observed next to the blue phosphor. This appeared to be caused by mask warpage resulting in some of the electrons from the blue gun striking a portion of the red phosphor dot. This heat warping may be a function of the particular CRT in the test Weather Display.

3. Refresh Rate

Spectroradiometric measurements on a single phosphor dot were quite variable when manually limited to short integration times but became steadier as the integration was extended to the spectroradiometer's maximum integration time of 32 seconds. Spectroradiometric measurements of WILs taken over larger areas near the center of the display area showed large chromaticity differences from measurements taken near the perimeter of the display area. This result was expected because convergence is best controlled for the center of the display area.

3/ Luminance measurements were taken approximately every 15 minutes to keep the TDL-on time constant. [The spectroradiometer automatically adjusts its sampling time as a functon of an initial luminance measurement. Hence, at low CRT luminances, sampling time is long (~ 10 minutes) while at high luminances it is short. Thus, measurements for the higher luminance TDLs were taken closer to the end of the 15 minute TDL-on time than was the case for the lower luminance TDLs.]

4/ Electro-magnetic and electro-static effects are eliminated by the MANUAL DEGAUSS button as well as the magnetic shielding of the console. Electro-static effects on RAM may change the pattern being displayed.

4. Color Reflections

All calibration tests of the color calibrator were performed by filling the 14.7 inch diameter display area with a single phosphor color or a WIL color. If instead the vertical WIL bars from the processor were to be used, the color calibrator would require a "light tube" and a Fresnel lens (planar) to focus equally over all three photocells in the color calibrator.

Tests to date indicate different readings obtained using the color bar technique than from those resulting from flooding the whole screen. The chief suspected cause is reflected light from adjacent color bars bouncing back and forth between the CRT face and the protective glass screen. That such reflections occur may be deduced from the fact that measured chromaticity changes for dark WILs having adjacent bright WILs are greater than for bright WILs having adjacent dark WILs. Another problem in using the vertical bars is the small target area available for measurement.

Light reflections from adjacent WILs can be significantly reduced if test wedges from the digitizer are used, assuming the digitizer is properly calibrated. Here, the best approach to minimizing reflections is to put the console display in the ZOOM and Cursor ON mode and move the wedge until the appropriate WIL covers the maximum area of the display circle.

5. System Interactions

In calibrating WILs, all six WILs should be checked even if only one gun is suspect. For example a unit TDL decrement in the red gun is not the same for WIL #5 (R = 15, B = 00, G = 00) and WIL #3 (R = 15, B = 00, G = 15). The explanation for this effect is twofold. First, there appears to be a complex system interaction whenever more than one gun is on at a time. Second, the effect of a unit TDL increment/decrement varies as a function of the luminance levels associated with each gun. Later in this report, plots of luminance as a function of TDL are described. Associated with these plots is a time to stabilize system drift at a given TDL of a single gun. Roughly, the higher the TDL for a given color gun the longer it takes to stabilize the luminance reading.

SINGLE COLOR TEST

Objective:

The objective of the Single Color Test was to evaluate the ability of different types of color calibrator heads to discriminate the various levels of an individual RGB phosphor by using one gun at a time (the other two guns are energized but set to TDL = 00).

Procedure:

Four types of color calibrator detector heads were tested. A summary description is given in table 1. Each head incorporated three (RGB) channels. Head Nos. 1, 2, and 3 used silicon photodiodes, with Wratten filters of the narrow-, medium-, and wide-band type, respectively. Head No. 4 used GaAsP photodiodes with dichroic filters. Because of the high cost and the time required for hand manufacturing of the photodiode/filter assemblies, other possible combinations of GaAsP photodiodes with Wratten filters and silicon photodiodes with dichroic filters were not procured or tested. Thus, a) the measured data is for combined characteristics of the GaAsP photodiode and dichroic filter and these are not separable given the available data, and b) no data was obtained on whether a silicon or GaAsP photodiode is best for the color calibrator application.

The Single Color Test involved filling the display screen using a single gun at a time; starting at TDL = 00 and proceeding to TDL = 15. All lights were OFF or covered over, including the alphanumerics, Power ON light, etc. The dark field currents (ID) of the photocells were nulled out using the variable resistors in the color calibrator head. The null potentiometer on the power supply was set to give approximately equal values for the RGBs. The sensitivity potentiometer on the power supply was set to 10.00. The color calibrator head was then placed on a tripod at a distance of 12 inches from the glass protective screen, with the plane of the detector head parallel to the plane of the protective screen and centered on the Cursor HOME position. Both console and processor were continuously energized (except for equipment failure).

The Single Color Test procedure was to insert the TDLs, starting at 00, and record voltage readings for each RGB photocell. This procedure was used for all four color calibrator heads for all three color guns.

Results:

The results for each of the four color calibrator heads are shown in figures 2A-C, 3A-C, 4A-C and 5A-C. Examination of these figures demonstrate the following:

1. Each filtered photodiode was capable of detecting a unit TDL increment of its respective RGB color. This was true for all four detector heads.

2. The narrow-band Wratten-filtered photodiodes, and to a slightly lesser extent the dichroic-filtered photodiodes, responded selectively to their respective RGB colors. The medium- and wide-band Wratten filter photodiodes responded weakly but still differentally.

3. The R-filtered wide-band photodiode reponded more than the G and B photodiodes to all three colors. Further, the G- and B-filtered photodiodes yielded nearly identical values for the G-phosphor color.

4. On the basis of NBS's criteria, the narrow-band and dichroic filters provide the best fit for the color calibrator.

Examination of color calibrator data taken to explore the limits of the RRWDS CRT display revealed some interesting effects (data not included in this report). One such effect appeared to result from a breakdown in the potting material used in the high voltage power supply triplers and high voltage junction block. The effect, detected by the color calibrator and verified with the spectroradiometer, is that when a high level TDL was further increased in the system produced an unexpected decrease rather than an increase in the luminance of a given RGB phosphor. For example, prior to replacement of the triplers, the red phosphor reached peak luminance at TDL = 11 and steadily decreased thereafter. Under somewhat similar conditions, the luminance of the blue phosphor reached saturation at TDL = 09 and remained more or less constant up to TDL = 15. Under more typical operating conditions the red phosphor reached a peak at R = 15, whereas the blue phosphor reached its peak luminance at B = 13 with no further luminance increase for B = 14 or B = 15.

WIL COLOR TEST

Objective:

The objective of the WIL Color Test was to evaluate the ability of four different color calibrator heads to discriminate small changes in the pattern of stimulation of the RGB phosphor when WIL colors are used.

Procedure:

The same four test articles and the same standard set of conditions and procedures were used in this test as for the Single Color Test, except for the way the TDLs of the guns were changed. In the WIL Color Test, a WIL was entered on the Weather Display background and allowed to stabilize for one-half hour. Then a given RGB gun was decremented one TDL step, and the readings of the RGB photocells recorded. The WIL was returned to its initial condition. After a 10 to 15 minute wait the same RGB gun was decremented by two steps and RGB readings recorded. After each RGB gun had been decremented one at a time by one and two TDL steps (except for B = 00 as in WIL's #3, #4, #5, #6) the same procedure was applied by incrementing the RGB guns one and two TDL steps. This procedure was necessitated by system drift; i.e., the color calibrator readings after returning to the initial WILs were usually different from the original readings. Thus, the recorded calibrator values were voltage differences which, to some extent, obscured system drift. This same procedure was used for all four color calibrator detection heads.

The numerical portion of the figure label (i.e., 2-5) represents filter type whereas the alphabetical portion (i.e., D-I) represents WILs #1 to #6, respectively. These figures graphically present color calibrator voltage differences. The horizontal lines represent the original WIL TDL value for each RGB gun. The vertical bars represent the color calibrator voltage differences as a function of one- or two-TDL step decrements/increments for each of the RGB guns.[5/] Thus, for each color calibrator detection head there are six WILs depicted in six figures. These figures indicate the complex interaction between the RGB channels when a single one- or two-TDL step is made in just one of the RGB guns. No data was collected on multiple gun changes.

5/ Reading left to right the colors represented by each set of three bars are, in order, red, green, and blue.

Results and Conclusions:

The above figures reveal several interesting characteristics and some interaction effects:

1. The presence of (RGB) TDLs from 01 to 04 was not detectable by the color calibrator, and TDLs from 01 to 03 were not detectable by the spectroradiometer. Fully dark adapted human observers sometimes detected luminance at TDL = 02 and color at TDL = 03 for each of the RGB guns. This finding suggests that the R=01 in WIL #2 and the B=02 in WIL #1 and WIL #2 may be contributing little or nothing to the visual recognition of these WILs.

2. A unit TDL step decrement does not necessarily yield the same color calibrator voltage change as a unit TDL increment. This characteristic is a function of at least three variables:

   a. The location of the original WIL RGB values on the characteristic curve.

   b. The TDL levels for the other two guns for a given WIL.

   c. The elapsed time that the WIL has been displayed.

   These three phenomena appeared to be caused by a system interaction between the electrical current levels of the three RGB guns, since all three guns were always energized. The largest such effect involves the G gun since it is also used to "paint" the alphanumerics.

   As a consequence, if an analog change in the bias voltage of a given RGB gun occurs, the change will likely affect all WILs (but do so differentially). This means a technician, in correcting for a change or drift, may have to evaluate his correction as it affects all six WIL's and not just one.

   The color calibrator tests were performed using special EPROMs to make TDL step changes. In the field both analog and digital effects may occur. Hence, it is not possible to confidently generalize from digital-based laboratory tests to unknown field conditions, although the above generalizations should still hold true.

3. Figures 2A-I present the results of the Single and WIL Color Tests using narrow-band Wratten-filtered silicon photodetectors. The Single Color Test clearly indicated that the narrow-bands responded very selectively to their appropriate RGB guns, e.g., the R filters responded strongly to the R gun while the G and B filters responded weakly. Comparing the results of the narrow-band Single Color Test with the medium-band Single Color Test illustrates two points: (a) at Brightness (B) and Contrast (C) settings of -150 VDC and +0.50 VDC, respectively, the RGB guns were not driven to saturation, except for a slight leveling off of B at B = 10; and (b) when the RRWDS CRT display is functioning

normally, the above B and C settings are effective in preventing RGB gun saturation.

The WIL Color Test indicated that all four color calibrator heads could detect a unit TDL change in any RGB color gun setting for any of the six WILs with certain exceptions. These exceptions, cited earlier, are: (a) very low TDL settings of a RGB gun in a multi-gun WIL and very high TDLs of a single gun in a single gun WIL (e.g., WIL #5).

As expected, the responses of the broad-band detectors, figures 4A-I, were too wide, especially the red filter. The red-filtered photocell yielded the largest voltage of the RGB photocells for all three RGB colors (figures 4A-C). The G- and B-filtered photocells yielded about the same voltages with the G gun ON (figure 4C), i.e. no discriminability between G and B. Thus, for the purposes of the present study, the broad-band filters did not provide sufficient discriminability.

The medium-band filtered silicon photodiodes and the dichroic-filtered GaAsP photodiodes yielded moderate discriminability but the measured data for both are confounded with RRWDS component failures. Figures 5A-I represent color calibrator voltages using head No. 4. Figure 5D shows a break in the data at TDL=12 for the G gun. The break in the data is due to the failure of the voltage tripler for Power Supply No. 1. The automatic switch over to Power Supply No. 2 produced a significant drop in luminance. To compensate for this apparent drop in G luminance the Brightness control was changed to -145VDC and Contrast to +1.50VDC. The remainder of this graph was obtained at these new B and C settings. Later the tripler for Power Supply No. 2 and the high voltage junction block failed. Just prior to complete failure, the color calibrator voltages for the medium-band Wratten-filtered silicon photocells were rapidly changing as the display got smaller and then larger.

Data for the medium-band Wratten-filtered photodetectors were taken shortly after replacement of the failed components, i.e., with the B and C set at the previous Power Supply No. 2 values. From figures 3A-C, it can be seen that under these B and C settings, the RGB guns were driven to saturation at lower TDL's; thereby reemphasing the need to set standard (constant) values for the B and C controls.

Following the Single Color and WIL Color Tests using the medium-band filtered photodetectors, the entire series of test was redone. The new settings (subjectively about the same backround of dim gray) for the B and C controls turned out to be the same as the old, i.e., B = -150 VDC and C = +0.50 VDC--an interesting result that should be explored in the field. That is, the color calibrator should be investigated as a means of detecting RRWDS degradation as part of the regular preventive maintenance program.

Superimposed on figures 3A-B are the differences in color calibrator voltage readings occuring when a TDL = 15 of the gun under test is:

a) first entered on the CRT display, and b) after this RGB display has been on for 30 minutes. Ideally each TDL from 00 to 15 for each RGB gun should be measured for drift over an 8 hour time-base. Practically, such a procedure would be too time consuming.

SELECTION OF PHOTODIODE/FILTER COMBINATION

As shown in the aforementioned figures, the main difference observed among the detector heads tested was in the magnitude of voltage change caused by a unit change in TDL. The selection of the "best" combination from among the four tested depends upon how the device will be used in the field. Two alternative approaches will be described here: a) the colorimeter (theoretically ideal) approach, and b) the color calibrator approach.

The colorimeter approach is based upon calculation of the CIE x and y color coordinates, where the normalized spectral power distributions of the three phosphors and the transmittances of the filters are known. These calculations are complex but not formidable. In fact, the addition of a microprocessor and associated hardware in the color calibrator would convert it to a true colorimeter which could readout the CIE color coordinates. Here the requirement for the photodetectors (i.e., filtered photodiode) is simply that each RGB photodetector yield a unique or different value for any given color; i.e., if the voltage outputs of two photodetectors are precisely the same value for a given color, then discrimination is not possible. This requirement eliminates the wide-band Wratten filters used in this study. Thus, either the medium-band Wratten filters or the dichroic filters would be acceptable. Since the colorimeter approach requires discrete, measurable outputs from all three photodetectors, the narrow-band Wratten filters appear barely acceptable. The reason is that the color channels other than the one matching the phosphor color being examined have low voltage outputs that are near the noise level, so observed differences may not be real.

The color calibrator approach is based upon the assumption that the field technician need only determine whether the luminance produced by each RGB gun falls within specified limits relative to reference calibrator values, to be determined in some way. Among those tested, the "best" photodetector, in this case, would employ silicon photodiodes with narrow-band Wratten filters.

In one method of determining reference values, for example, reference color calibrator voltages and spectroradiometric measurements could be logged, as part of the RRWDS site-acceptance procedure. The resulting table of the relative luminances (color calibrator voltages) for each RGB gun for each of the six WILs could then be referenced during preventative maintenance to detect changes in relative luminance. No data is presently available on acceptable voltage deviation limit values for each RGB gun in a given RRWDS system, or the range of such values across all field sites. Field testing would be needed to provide this information. It is possible that a single table of voltages vs WIL levels may suffice for all RRWDS sites. However, the information in

Constantine's paper[6/] suggests that such a table may turn out to be site specific.

POSSIBLE TROUBLESHOOTING APPLICATION

It appears that, with sufficient field testing of RRWDS failure modes, the color calibrator could also be used as a general trouble shooting instrument for certain Weather Display malfunctions. For example, if one of the grid or screen voltages on N3NC1 CCA changed (particularly G2) this could be detected using the color calibrator by looking at all six WILS. The reason is that a DC shift in one of the RGB guns for the Weather Display background would show up equally in all WIL bars from the processor. On the other hand a malfunctioning resistor in an RGB ladder function of the processor's video amplifier might eliminate the red level six in WI1 #1 but not affect any other WIL because no other WIL uses a R = 06. Although these two examples may not be precisely correct, they should serve to illustrate the potential utility of the color calibrator if tested further under field conditions.

CONCLUSIONS

From the data presented in this report, it is concluded that the color calibrator--

1. Is a linear (and proportional) measuring instrument.

2. Can detect a unit TDL color increment or decrement except where the color TDL in a WIL is less than 03 (or in some cases 04), or a decrement in very high TDLs of a single gun in a single-gun WIL (i.e., WIL #5).

3. Has potential for greater utility than originally anticipated, especially for troubleshooting.

4. Has potential for improvement by incorporating a microprocessor and associated hardware to convert the relative luminance color calibrator into a true colorimeter (for a specified set of phosphors).

RECOMMENDATIONS

For an interim (at least) calibration tool and a means of developing needed field application data and experience, NBS recommends that FAA procure sufficient prototype color calibrators to field test the instrument and to gain experience in developing and applying the calibrator voltage vs WIL level tables.

FAA may also wish to consider additional opportunities to more fully develop the potential utility of the color calibrator or colorimeter.

[6/] Constantine, John M. Jr, Electron Optical Techniques for an Ultra High Resolution Color Film Recorder, Society of Photo Optical Instrumentation Engineers, 1984.

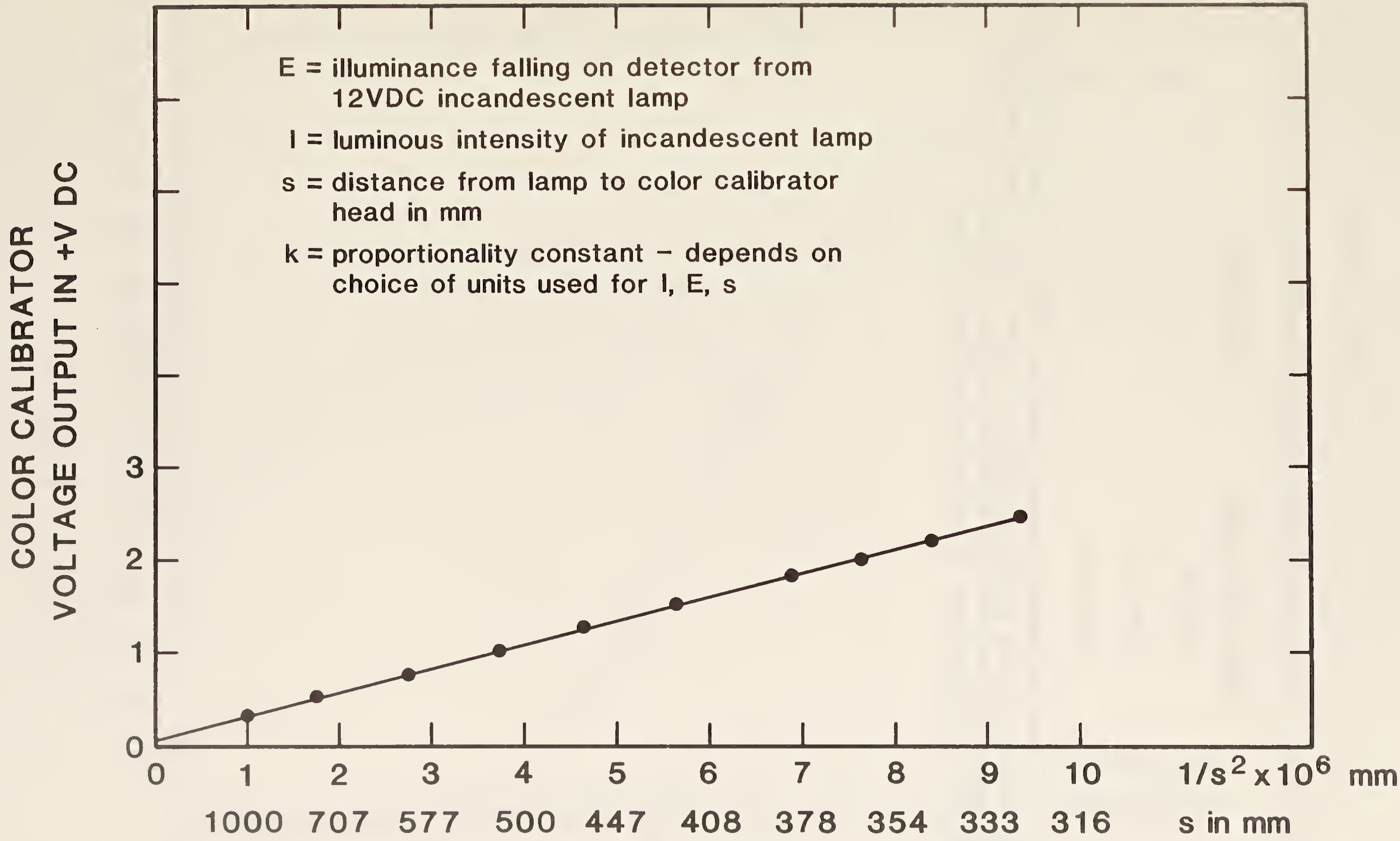

Figure 1. Test of color calibrator linearity by agreement with the Inverse - square Law of Radiation (i.e., $E = kI/s^2$)

Figures 2A-C. Silicon Photodiodes With Narrow-Band Wratten Filters

Single Color Tests	Figure No.
Red (R)	2A
Blue (B)	2B
Green (G)	2C

Description -- Color calibrator voltage readings (mVDC) for each test digital level (TDL) setting for the R gun (figure 2A), B gun (figure 2B), and G gun (figure 2C), starting from TDL = 00 to TDL = 15 (i.e., 16 steps), for each of the three RBG photodetectors in the color calibration hed.

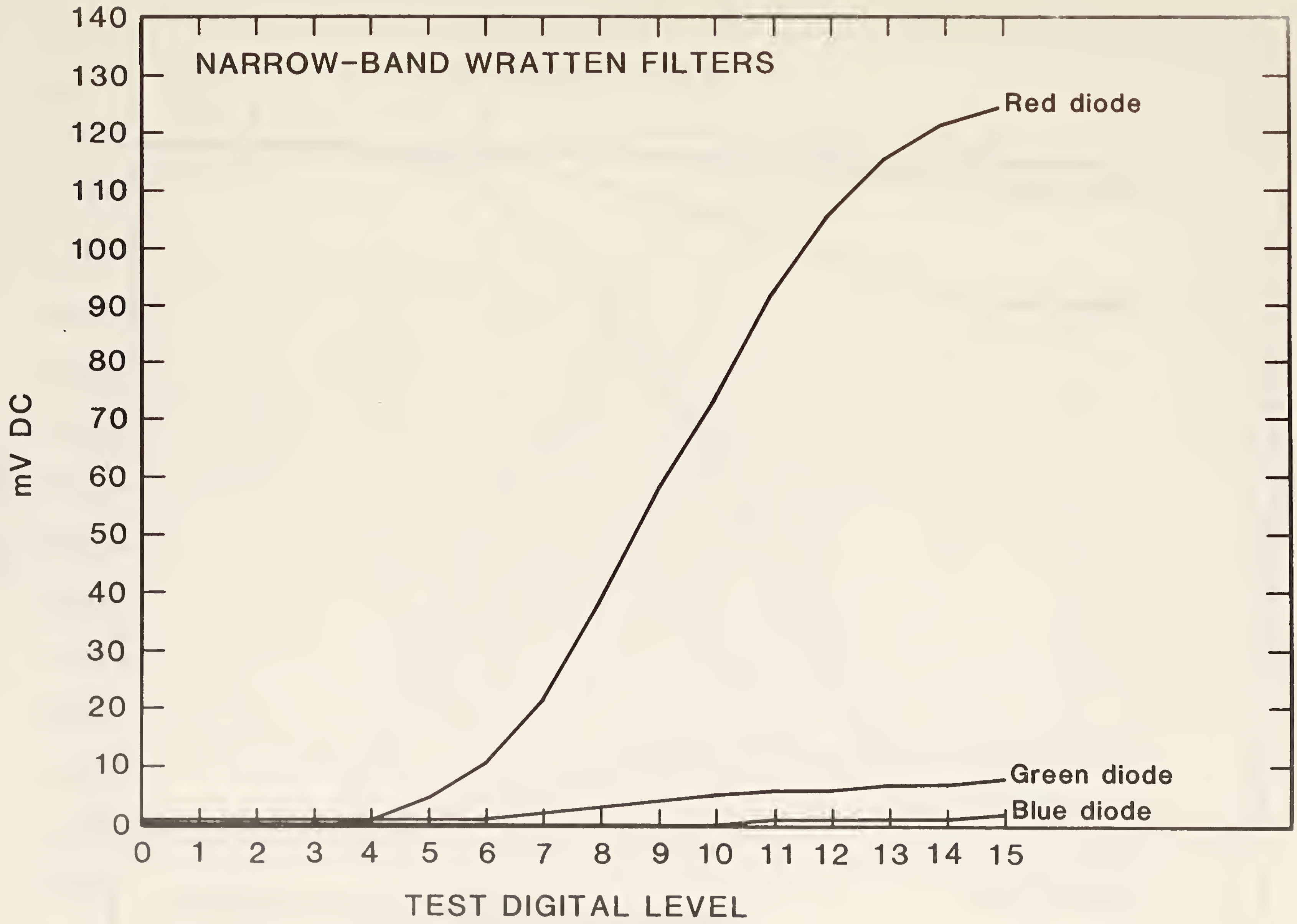

Figure 2A. Color calibrator voltage vs test digital level for CRT's red gun

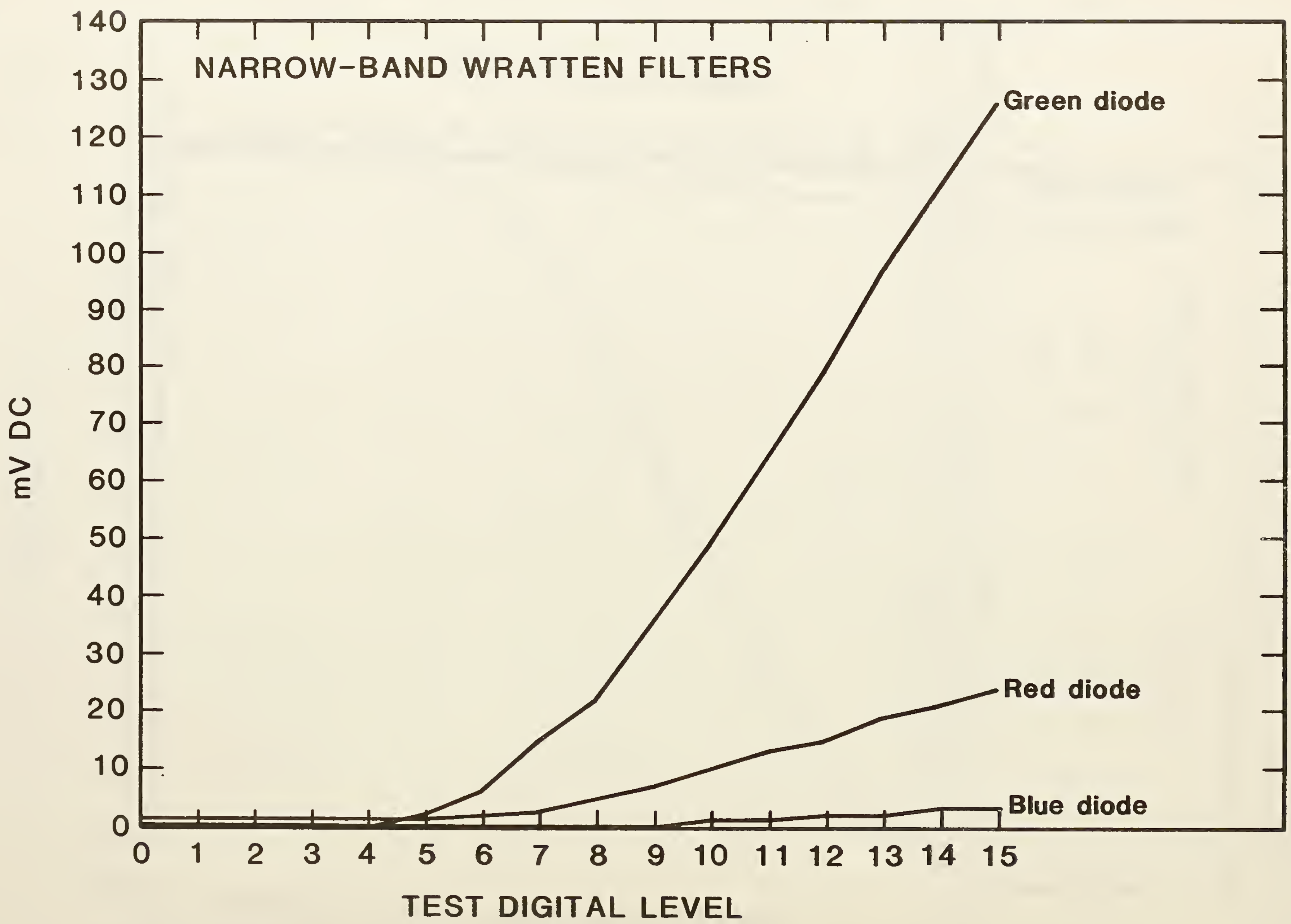

Figure 2B. Color calibrator voltage vs test digital level for CRT's blue gun

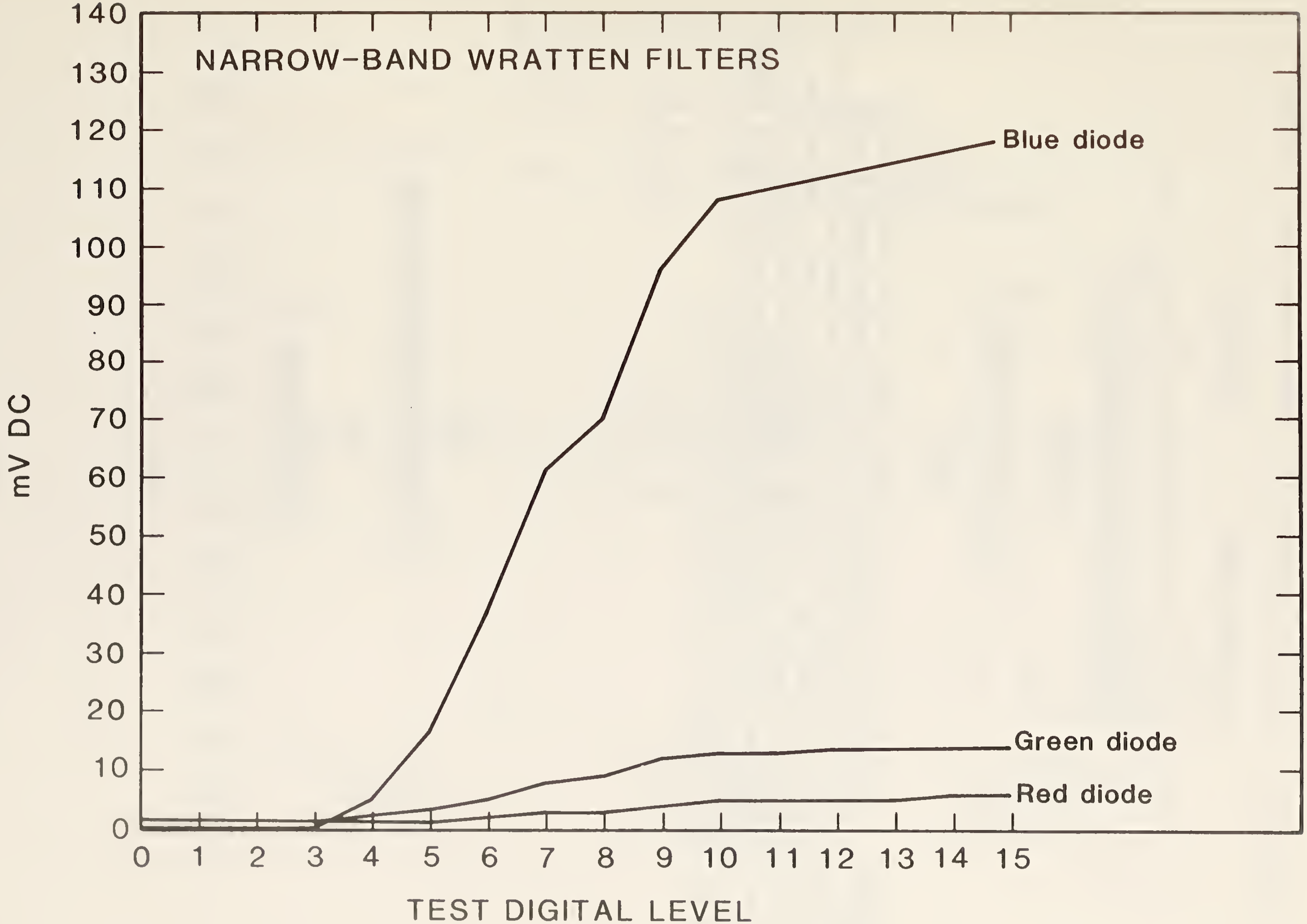

Figure 2C. Color calibrator voltage vs test digital level for CRT's green gun

Figures 2D-I. Silicon Photodiodes With Narrow-Band Wratten Filters

WIL Color Tests	Figure No.
WIL #1	2D
WIL #2	2E
WIL #3	2F
WIL #4	2G
WIL #5	2H
WIL #6	2I

Description -- Differential voltages (mVDC) between color calibrator RBG voltages: a) when TDLs for all RBG guns are set to manufacturer's color specifications for the WIL number, and b) when unit incremental or decremental TDL setting changes are made for each gun, one gun at a time. The abcissa represents condition (a) above and the RBG vertical bars represent condition (b). The vertical bars are read left to right in the order RBG. B is actually used only in WILs #1 and #2. Because of the complexity of these figures the reader may want to refer back to WIL Color Test, p. A-9.

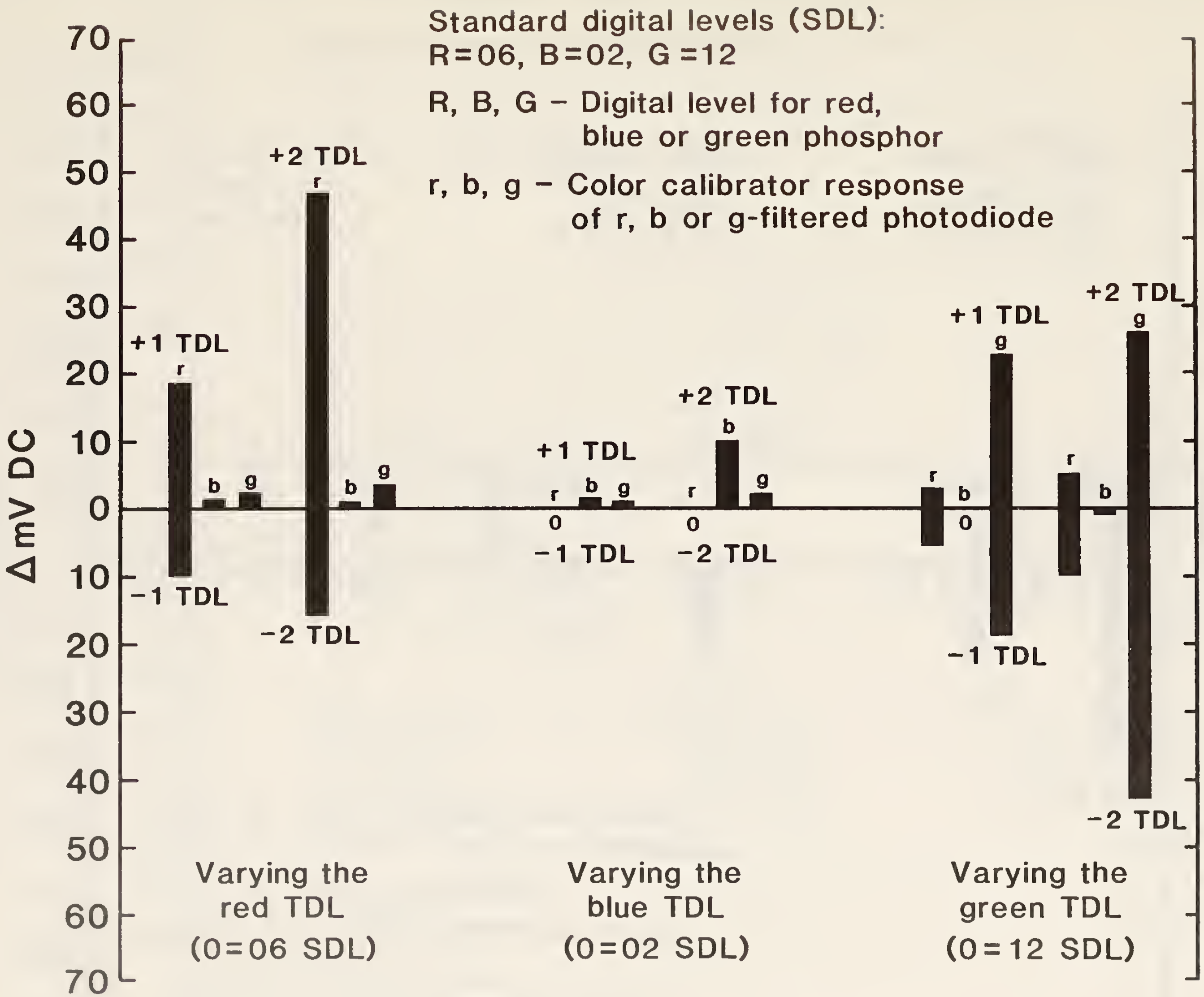

Figure 2D. Color calibrator difference voltages for each RBG color in WIL #1 using narrow-band Wratten filters

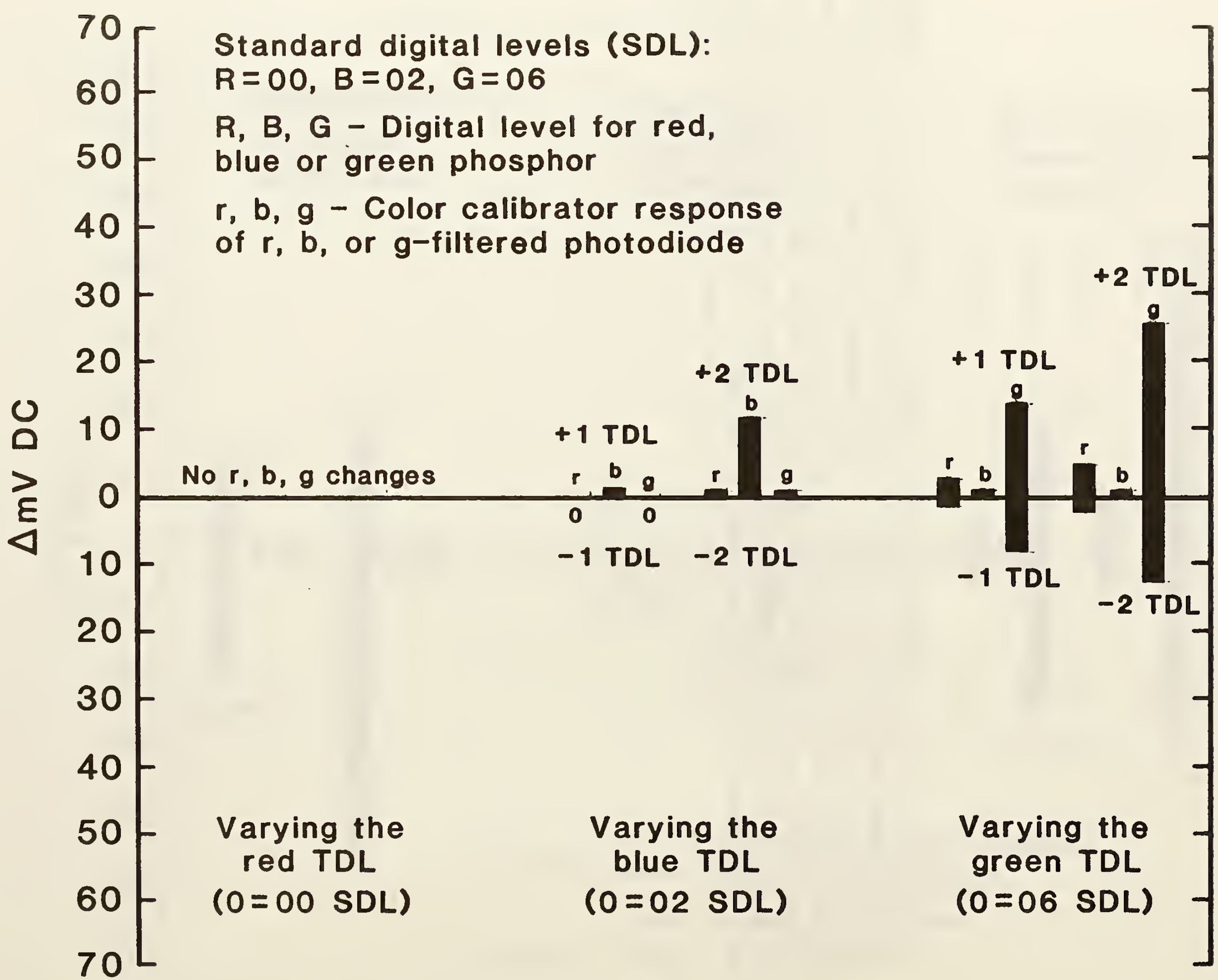

Figure 2E. Color calibrator difference voltages for each RBG color in WIL #2 using narrow-band Wratten filters

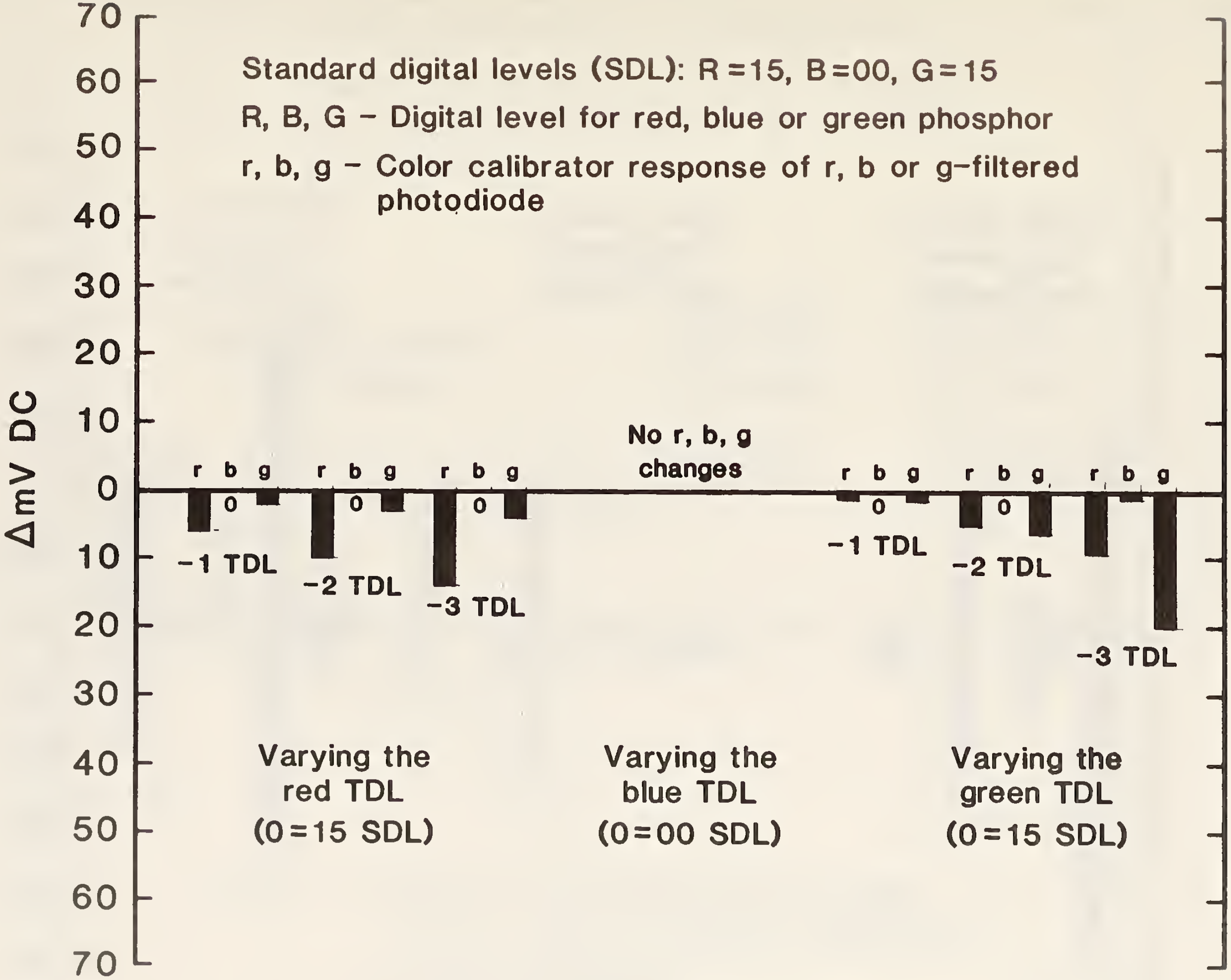

Figure 2F. Color calibrator difference voltages for each RBG color in WIL #3 using narrow-band Wratten filters

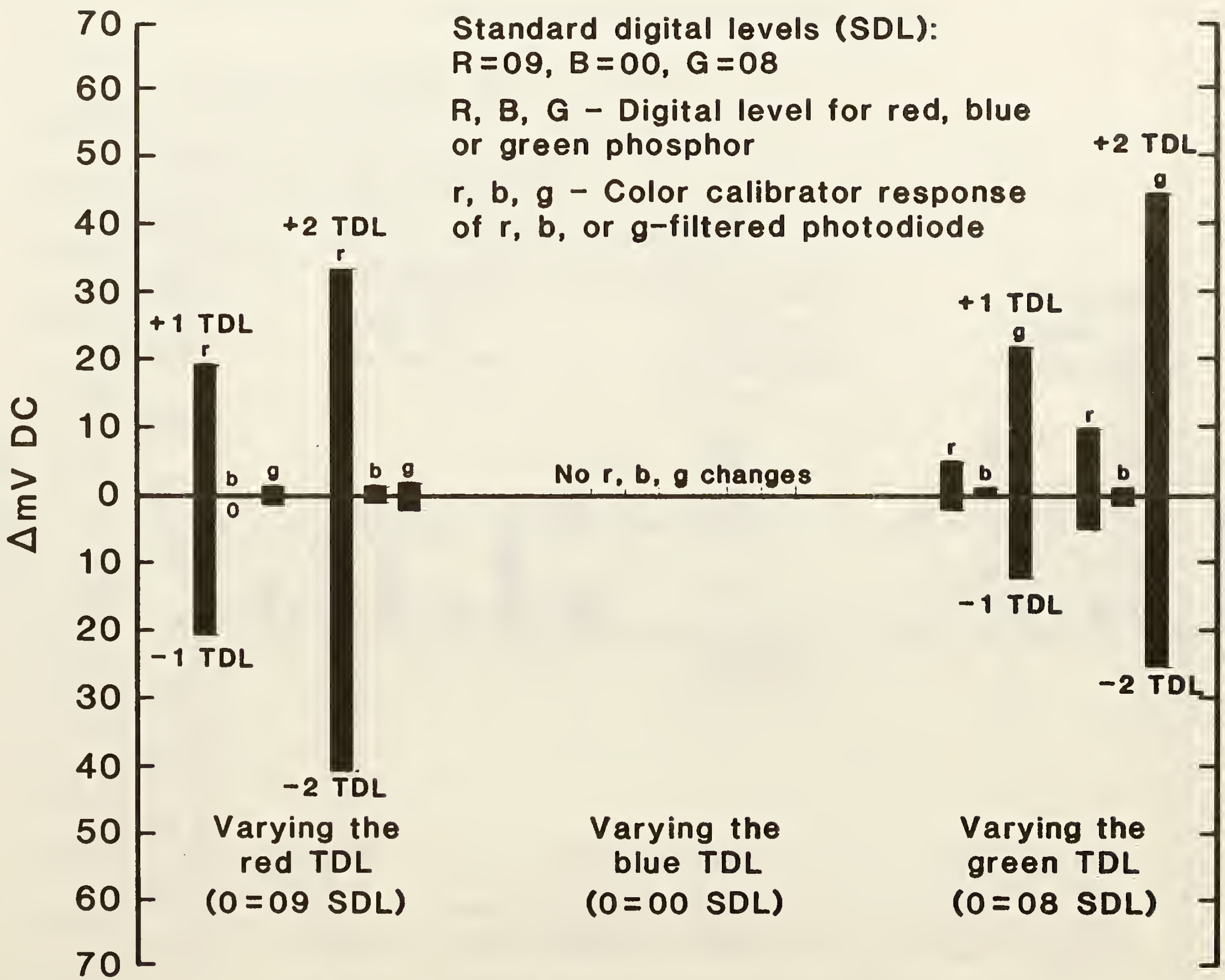

Figure 2G. Color calibrator difference voltages for each RBG color in WIL #4 using narrow-band Wratten filters

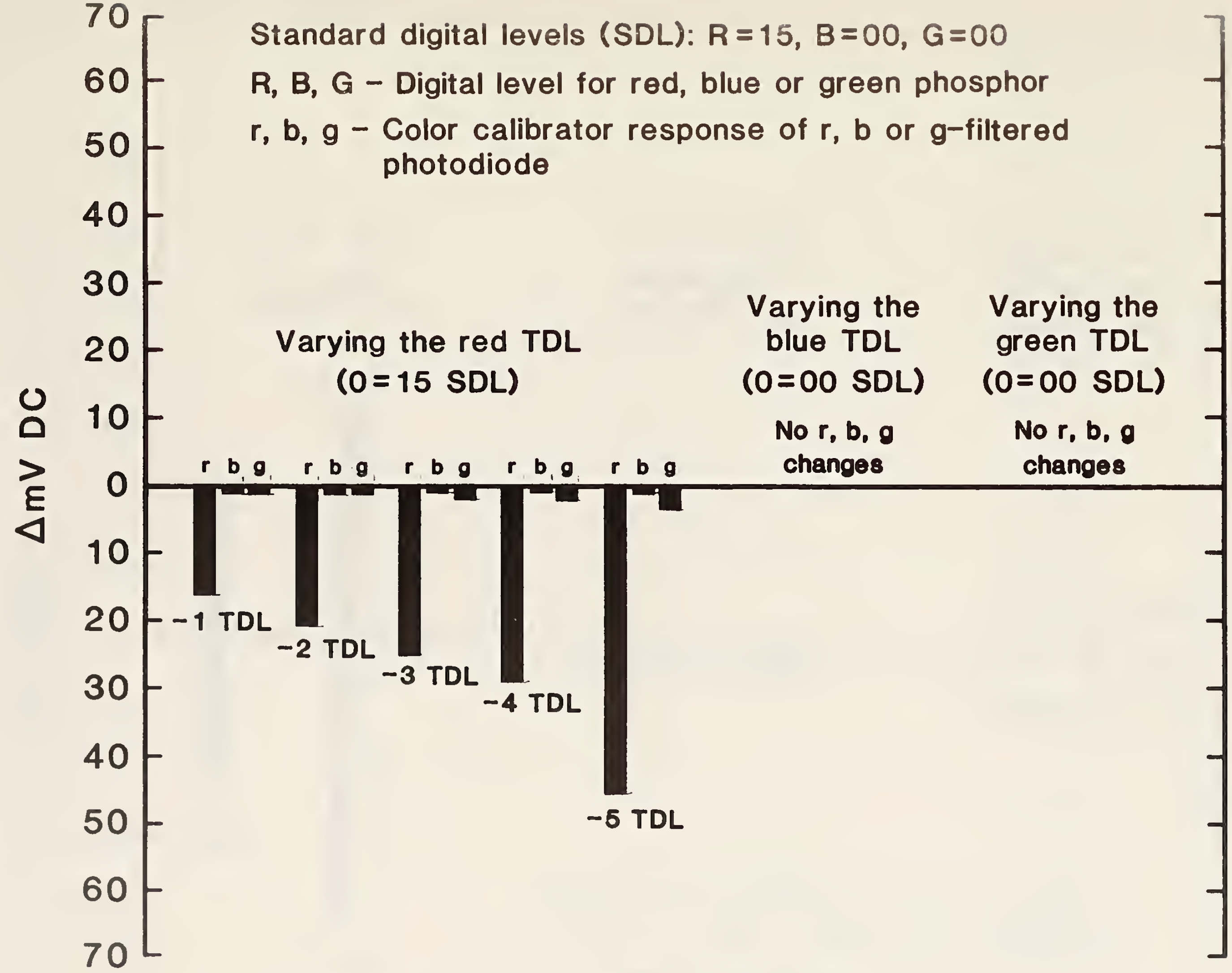

Figure 2H. Color calibrator difference voltages for each RBG color in WIL #5 using narrow-band Wratten filters

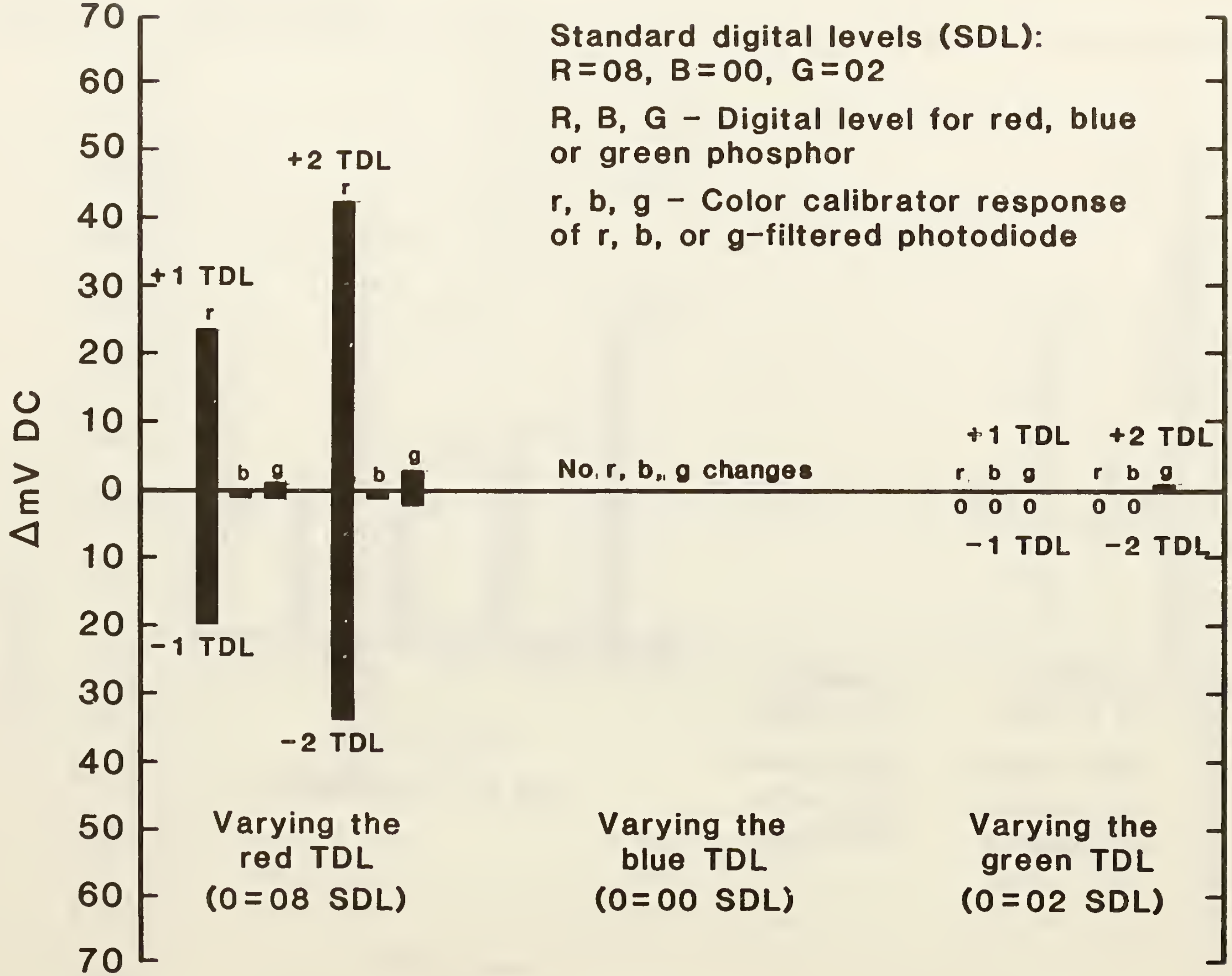

Figure 2I. Color calibrator difference voltages for each RBG color in WIL #6 using narrow-band Wratten filters

Figures 3A-C. Silicon Photodiodes With Medium-Band Wratten Filters

Single Color Tests	Figure No.
Red (R)	3A 1/
Blue (B)	3B 2/
Green (G)	3C

Description -- Color calibrator voltage readings (mVDC) for each test digital level (TDL) setting for the R gun (figure 3A), B gun (figure 3B), and g Gun (figure 3C), starting from TDL = 00 to TDL = 15 (i.e., 16 steps), for each gun of the RBG photodetectors in the color calibrator head.

1/ "Cold start" means entering an R = 15 TDL on the display at the start of a day and then measuring the same R = 15 TDL 30 minutes later.

2/ The 30 means that the B = 15 TDL was left on 30 minutes after the finish of the test and a remeasurement was then made.

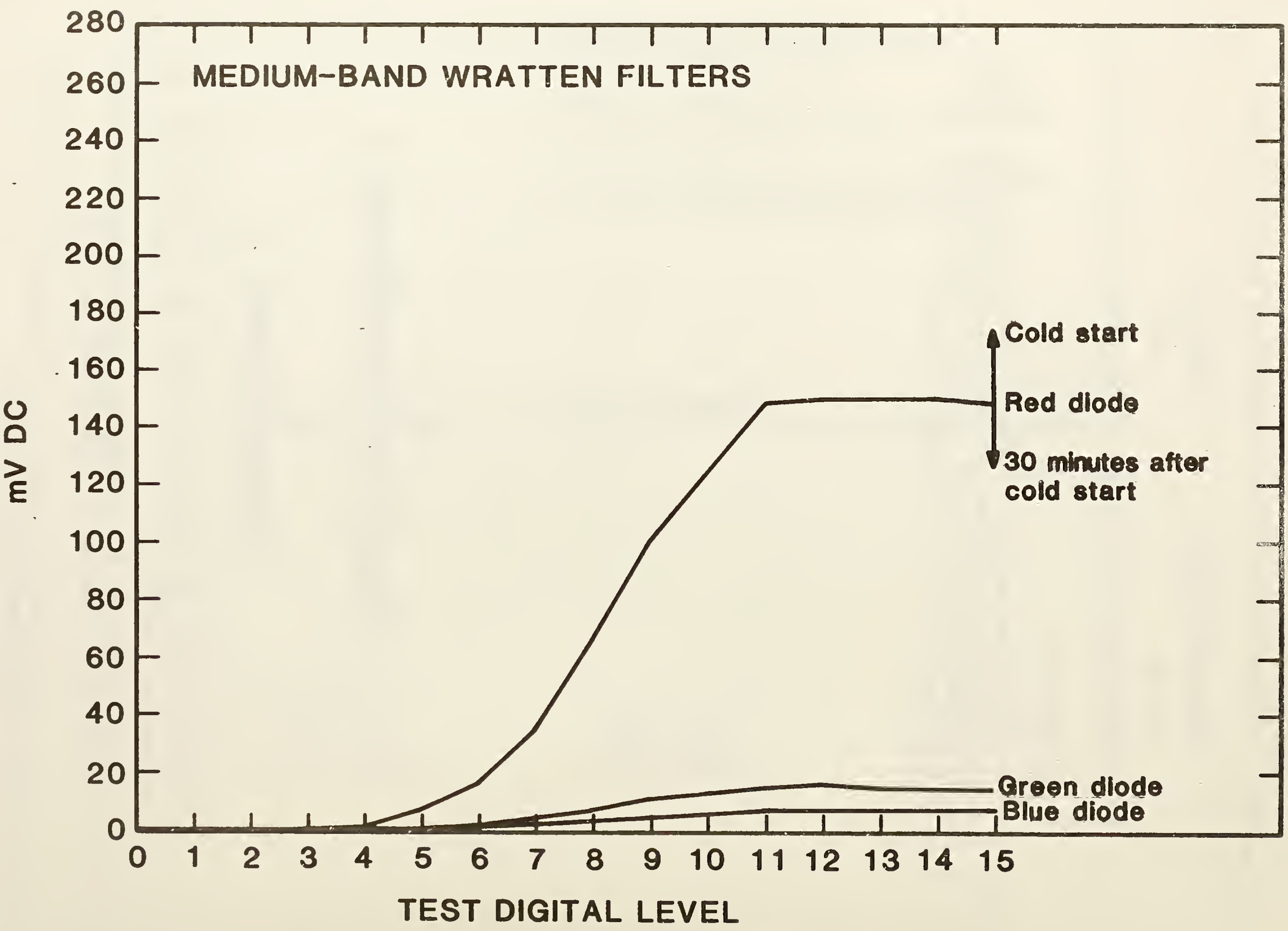

Figure 3A. Color calibrator voltage vs test digital level for CRT's red gun

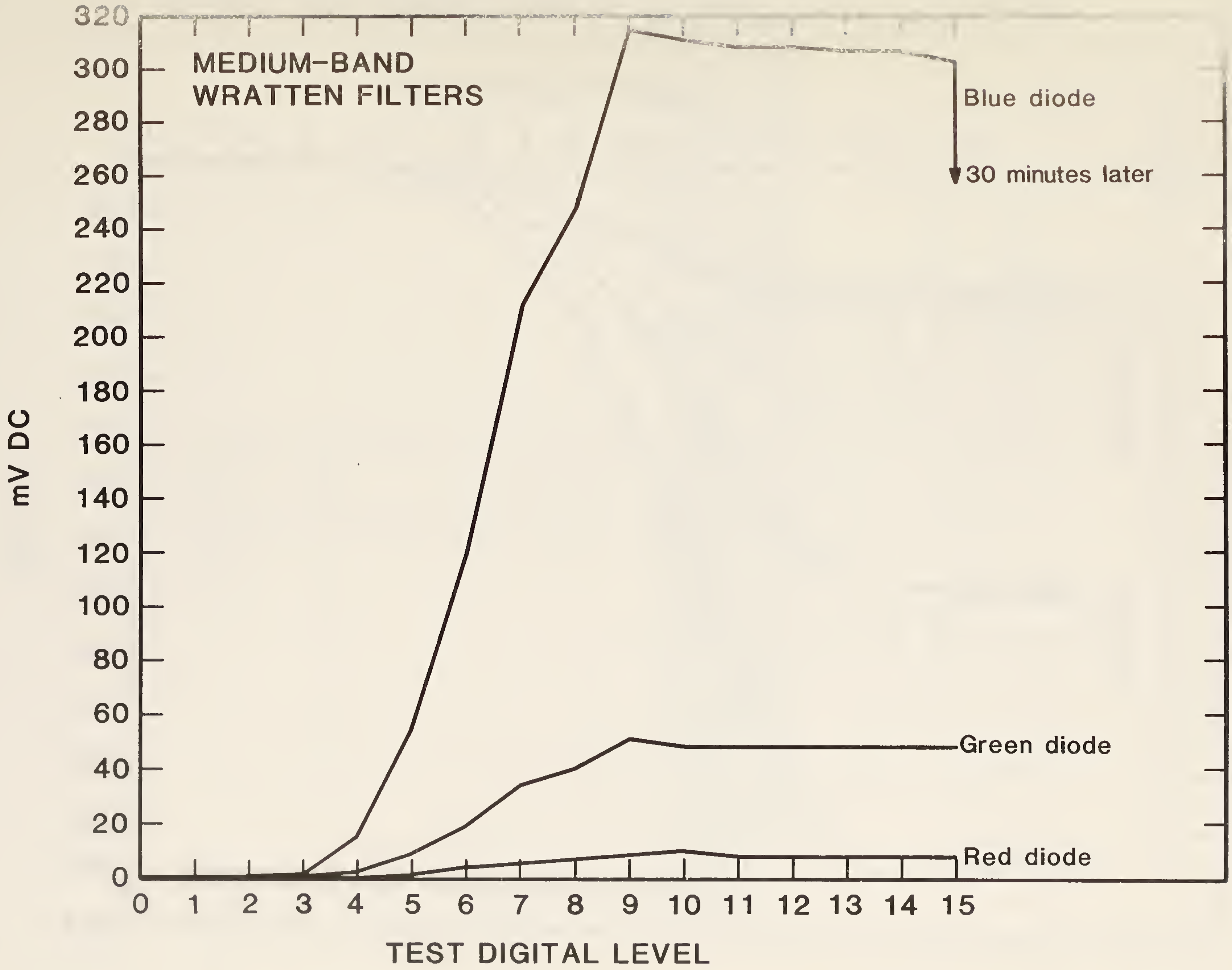

Figure 3B. Color calibrator voltage vs test digital level for CRT's blue gun

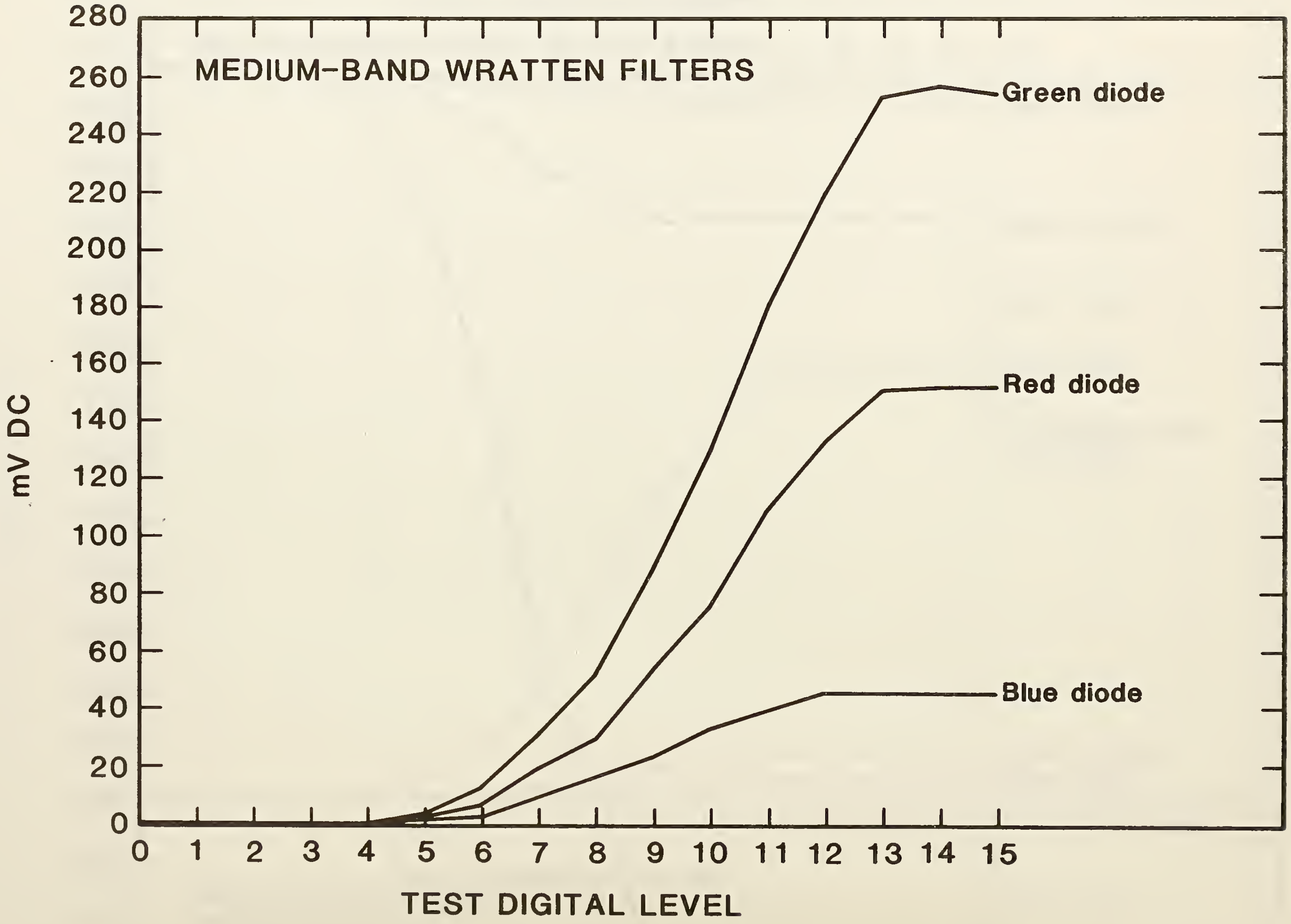

Figure 3C. Color calibrator voltage vs test digital level for CRT's green gun

Figures 3D-I. Silicon Photodiodes With Narrow-Band Wratten Filters

WIL Color Tests	Figure No.
WIL #1	3D
WIL #2	3E
WIL #3	3F
WIL #4	3G
WIL #5	3H
WIL #6	3I

Description -- Differential voltages (mVDC) between color calibrator RBG voltages: a) when TDLs for all RBG guns are set to manufacturer's color specifications for the WIL number, and b) when unit incremental or decremental TDL setting changes are made for each gun, one gun at a time. The RBG abcissa represents condition (a) above and the RBG vertical bars represent condition (b). The vertical bars are read left to right in the order RBG. B is actually used only in WILs #1 and #2.

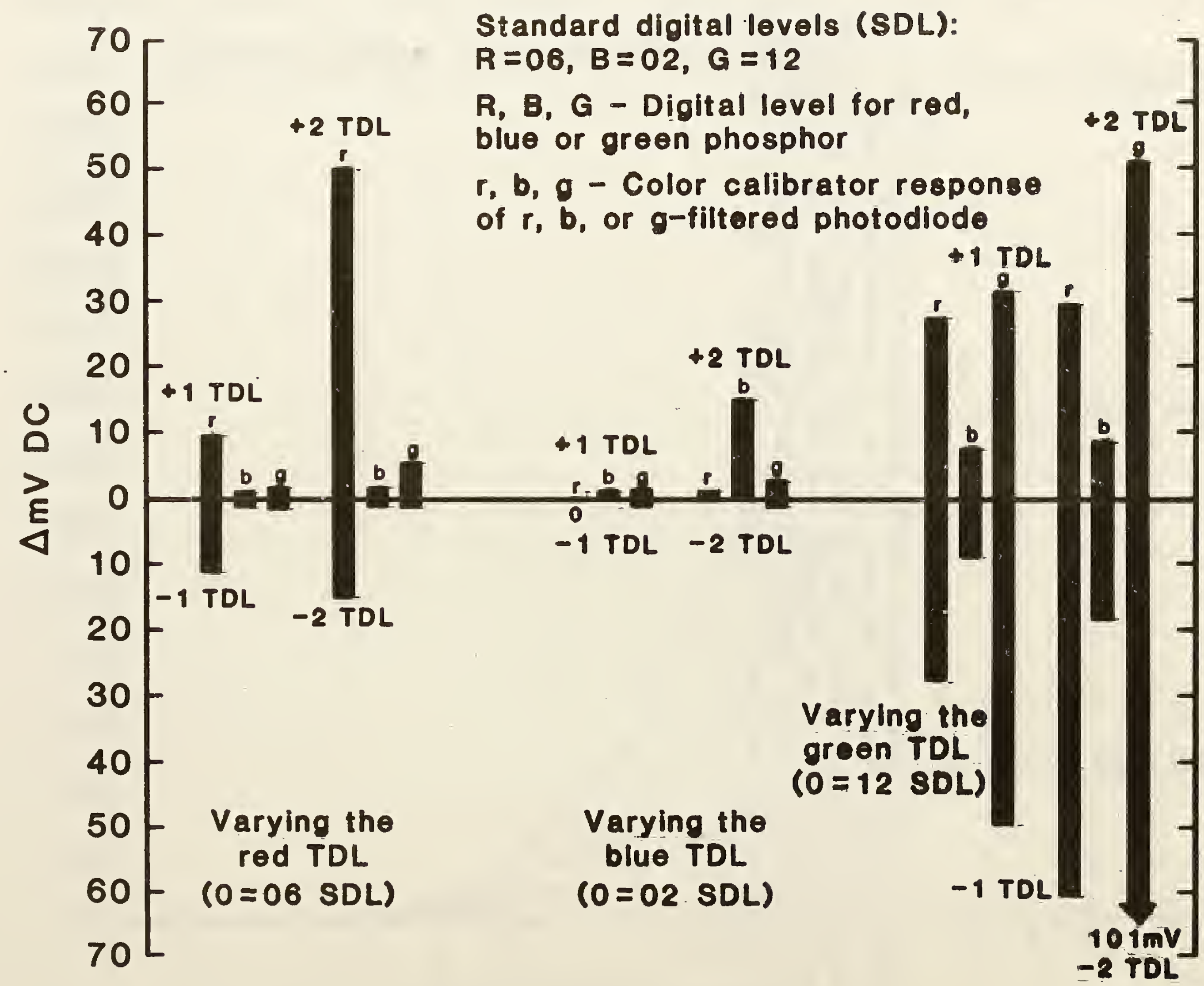

Figure 3D. Color calibrator difference voltages for each RBG color in WIL #1 using medium-band Wratten filters

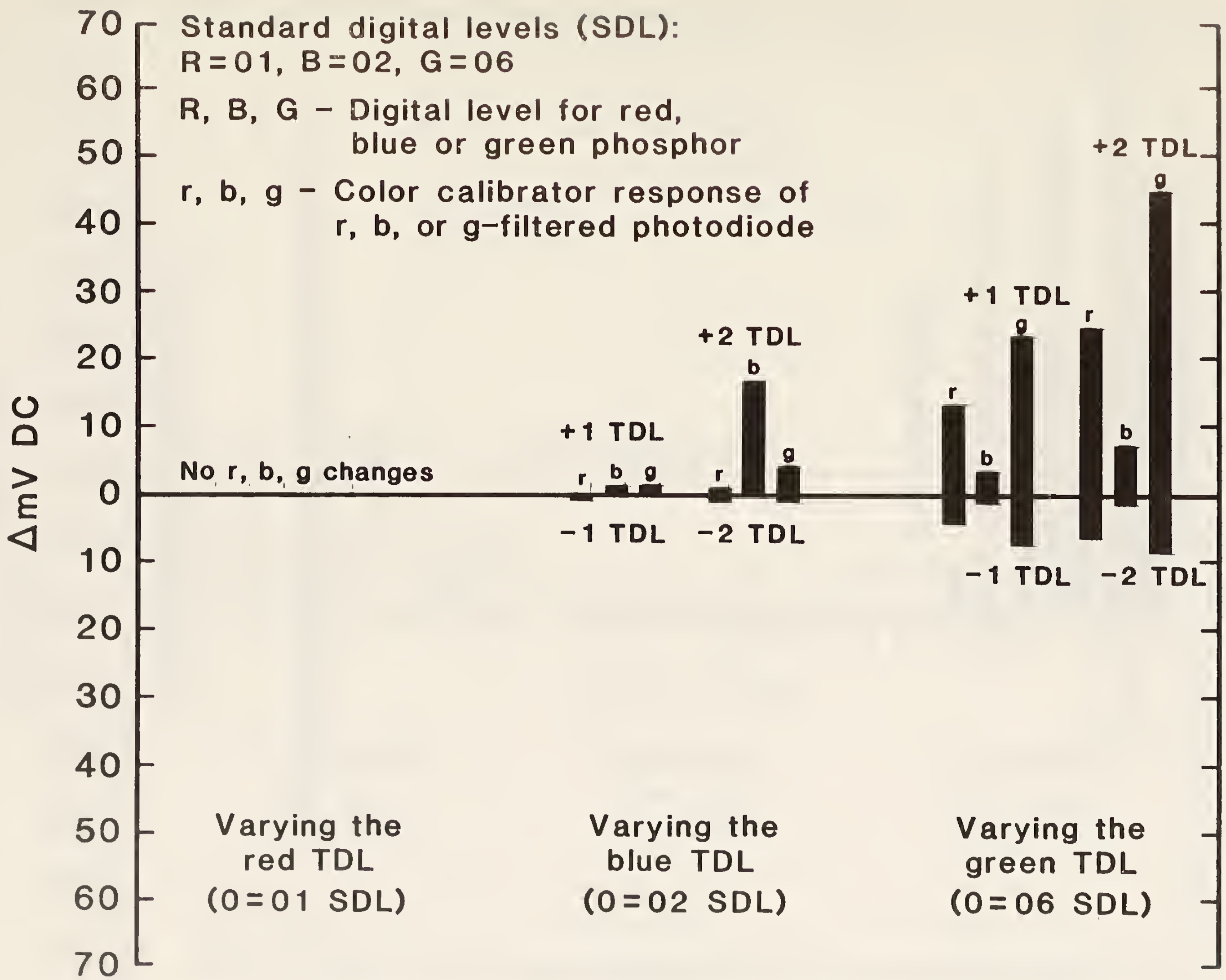

Figure 3E. Color calibrator difference voltages for each RBG color in WIL #2 using medium-band Wratten filters

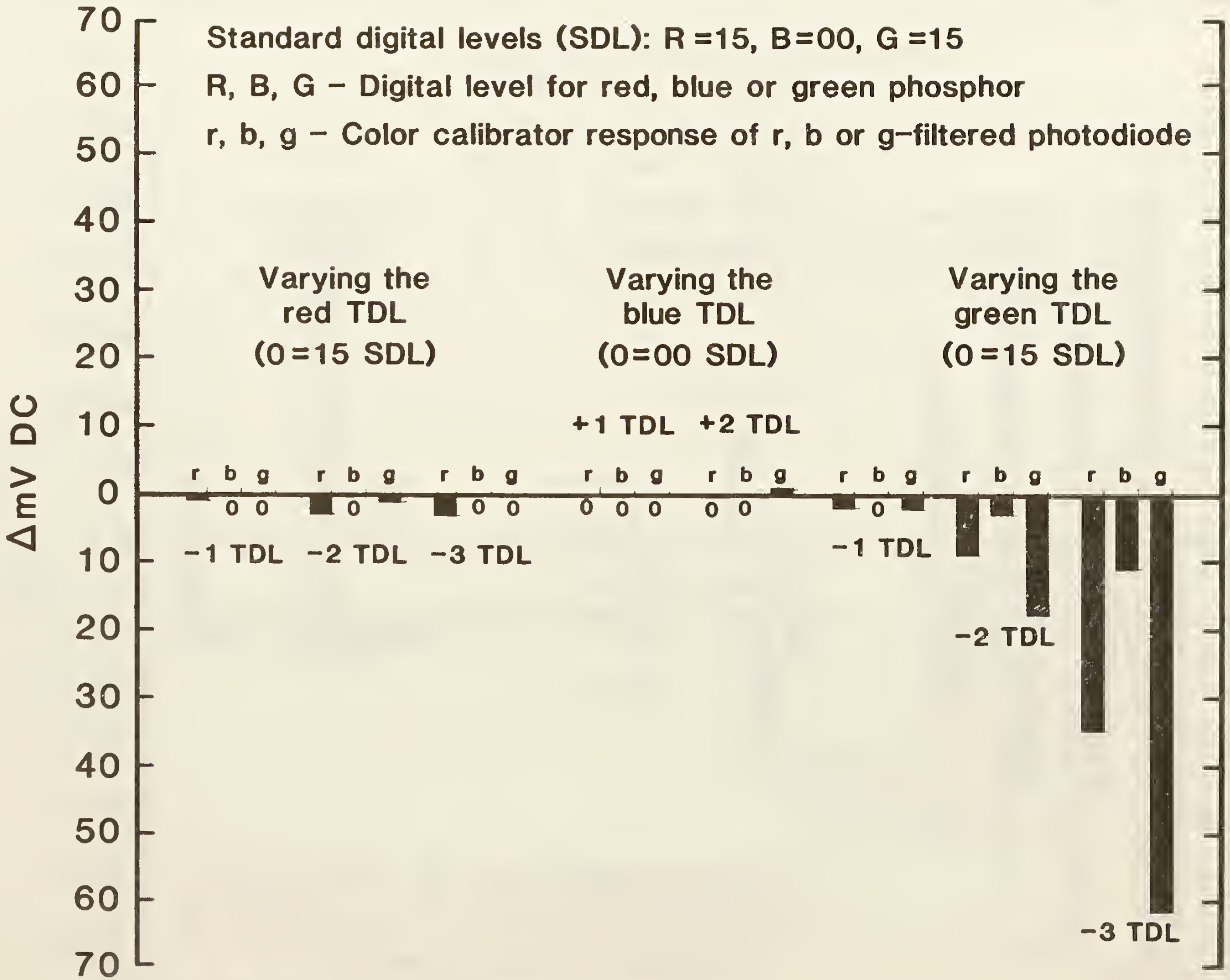

Figure 3F. Color calibrator difference voltages for each RBG color in WIL #3 using medium-band Wratten filters

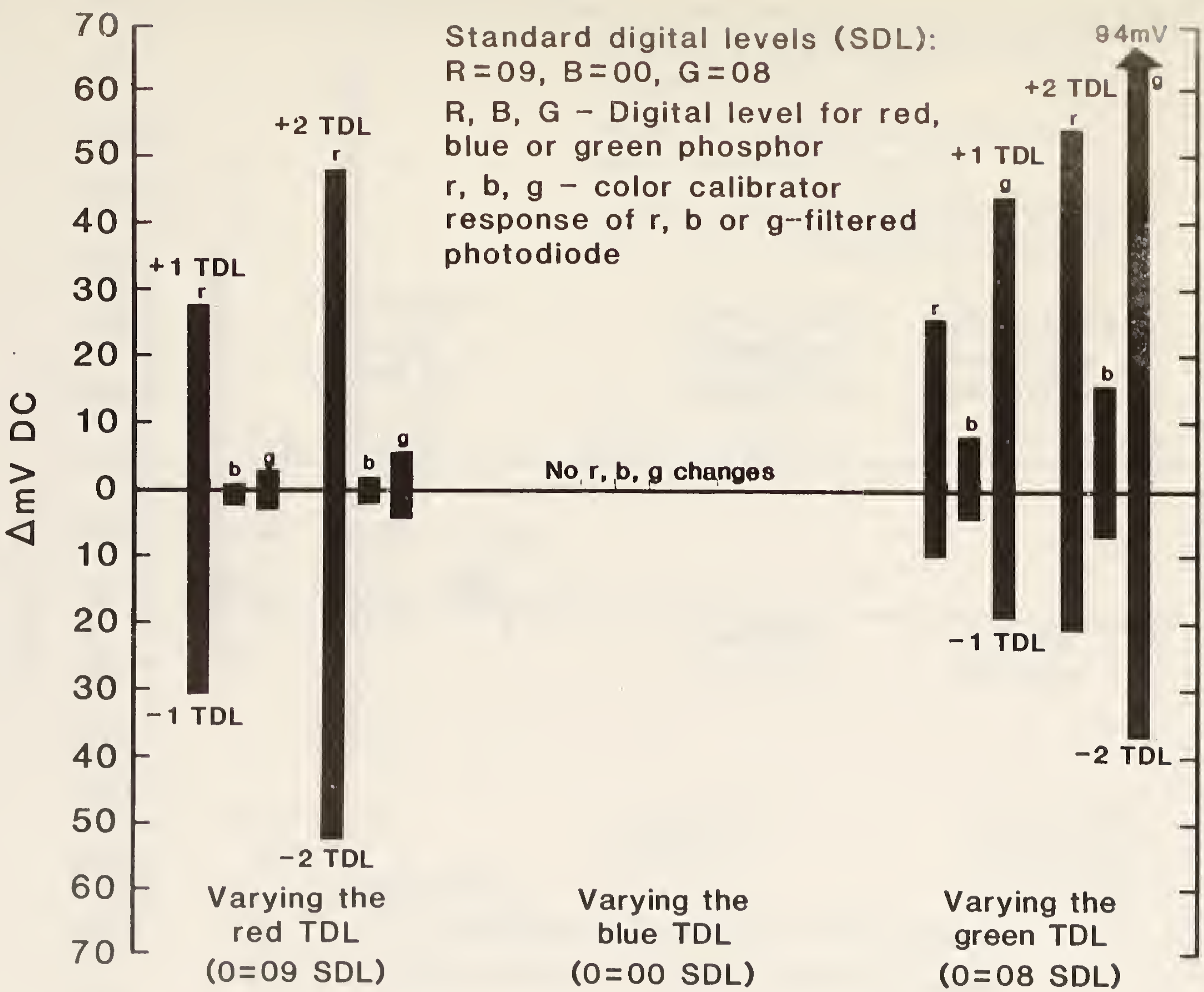

Figure 3G. Color calibrator difference voltages for each RBG color in WIL #4 using medium-band Wratten filters

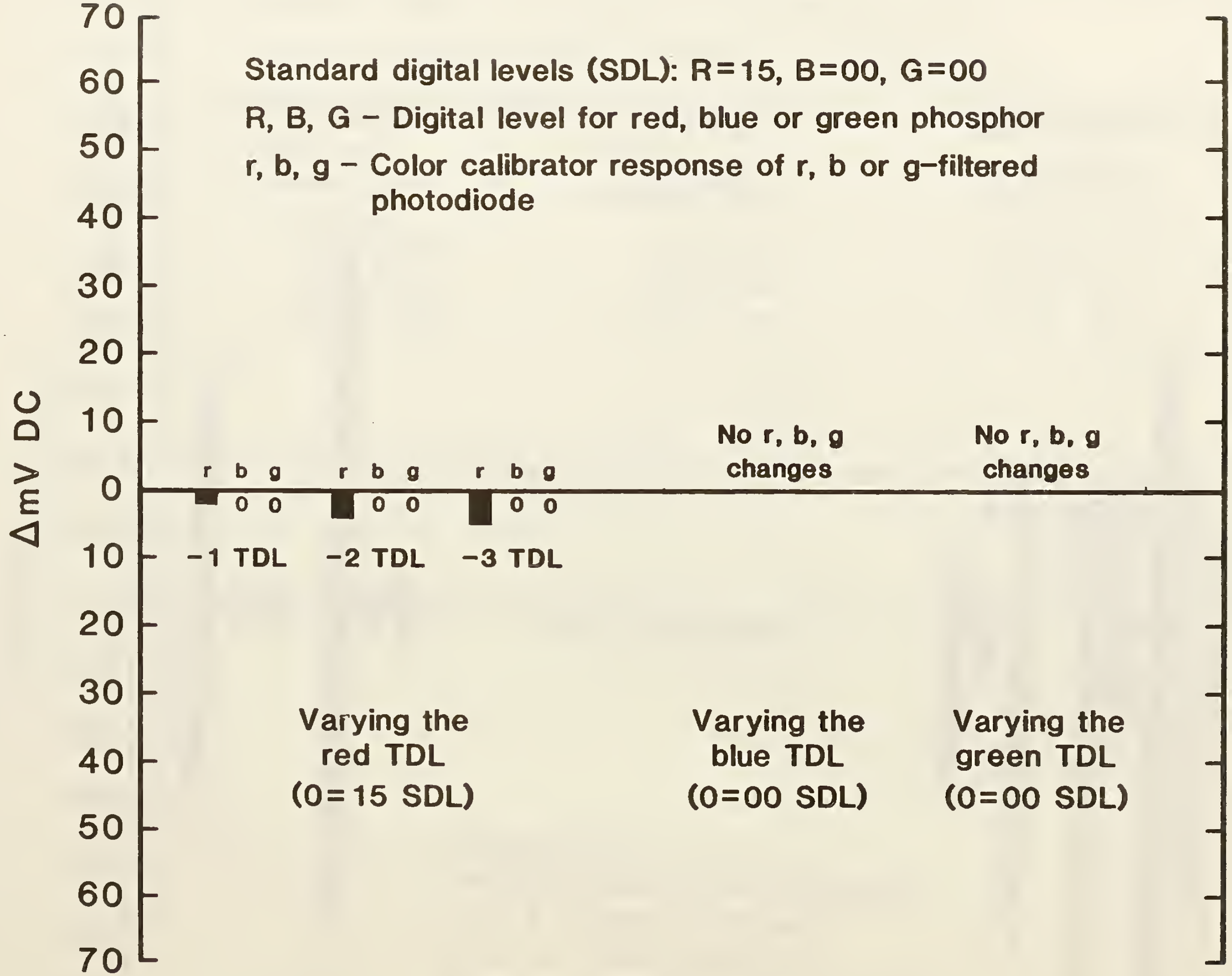

Figure 3H. Color calibrator difference voltages for each RBG color in WIL #5 using medium-band Wratten filters

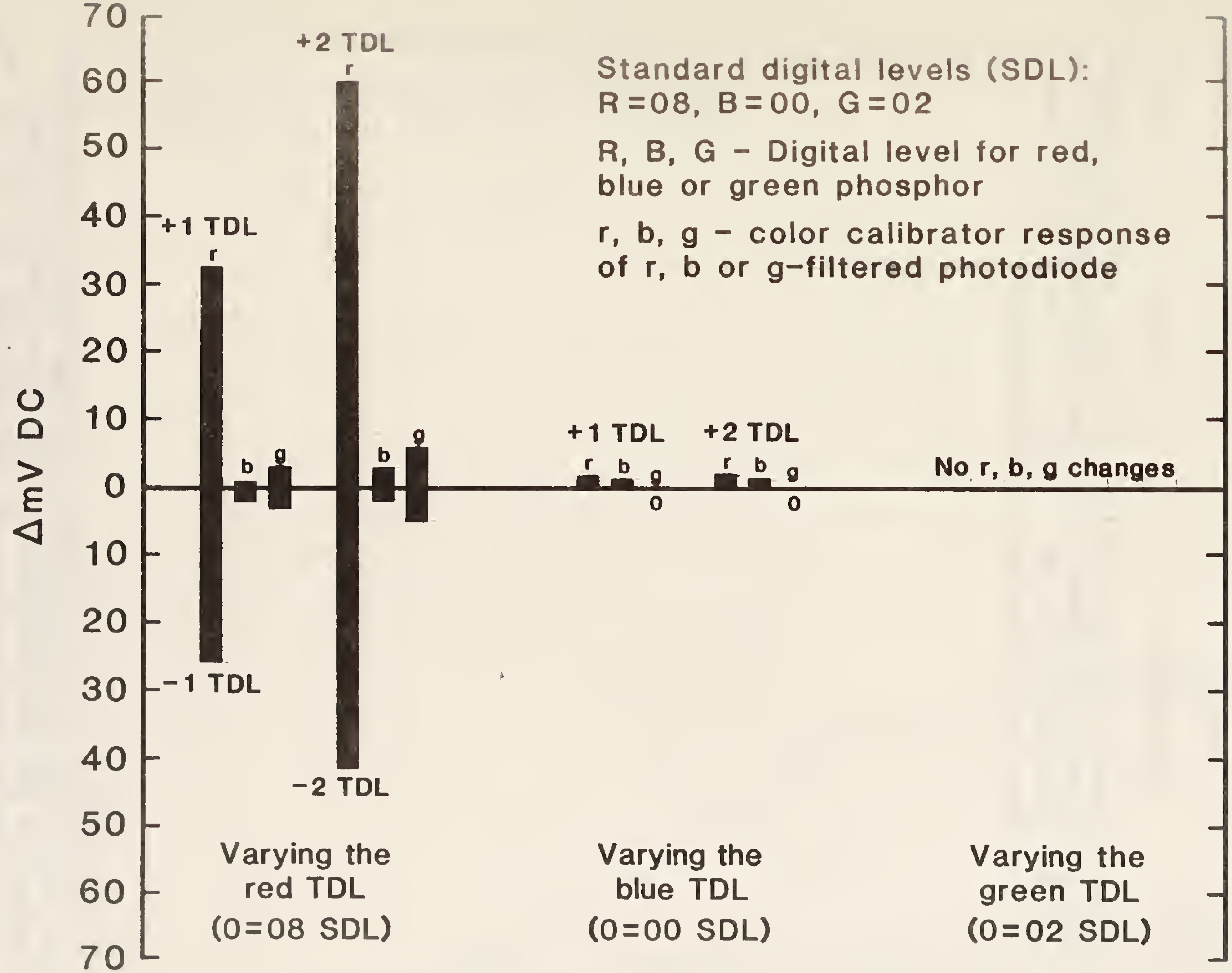

Figure 31. Color calibrator difference voltages for each RBG color in WIL #6 using medium-band Wratten filters

Figures 4A-C. Silicon Photodiodes With Wide-Band Wratten Filters

Single Color Tests [1]	Figure No.
Red (R)	4A
Blue (B)	4B
Green (G)	4C

Description -- Color calibrator voltage readings (mVDC) for each test digital level (TDL) setting for the R gun (figure 4A), B gun (figure 4B), and G gun (figure 4C), starting from TDL = 00 to TDL = 15 (i.e., 16 steps), for each of the three RGB photodetectors in the color calibration hed.

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[1] These single color tests were conducted using Power Supply #2. To obtain the same subjective dim grey background as for Power Supply #1, the Brightness and Contrast controls were set at B = 150 VDC and C = +1.5 VDC. Due to the increased transmittance of the wide-band Wratten filters, there is a corresponding increase in the scale factor.

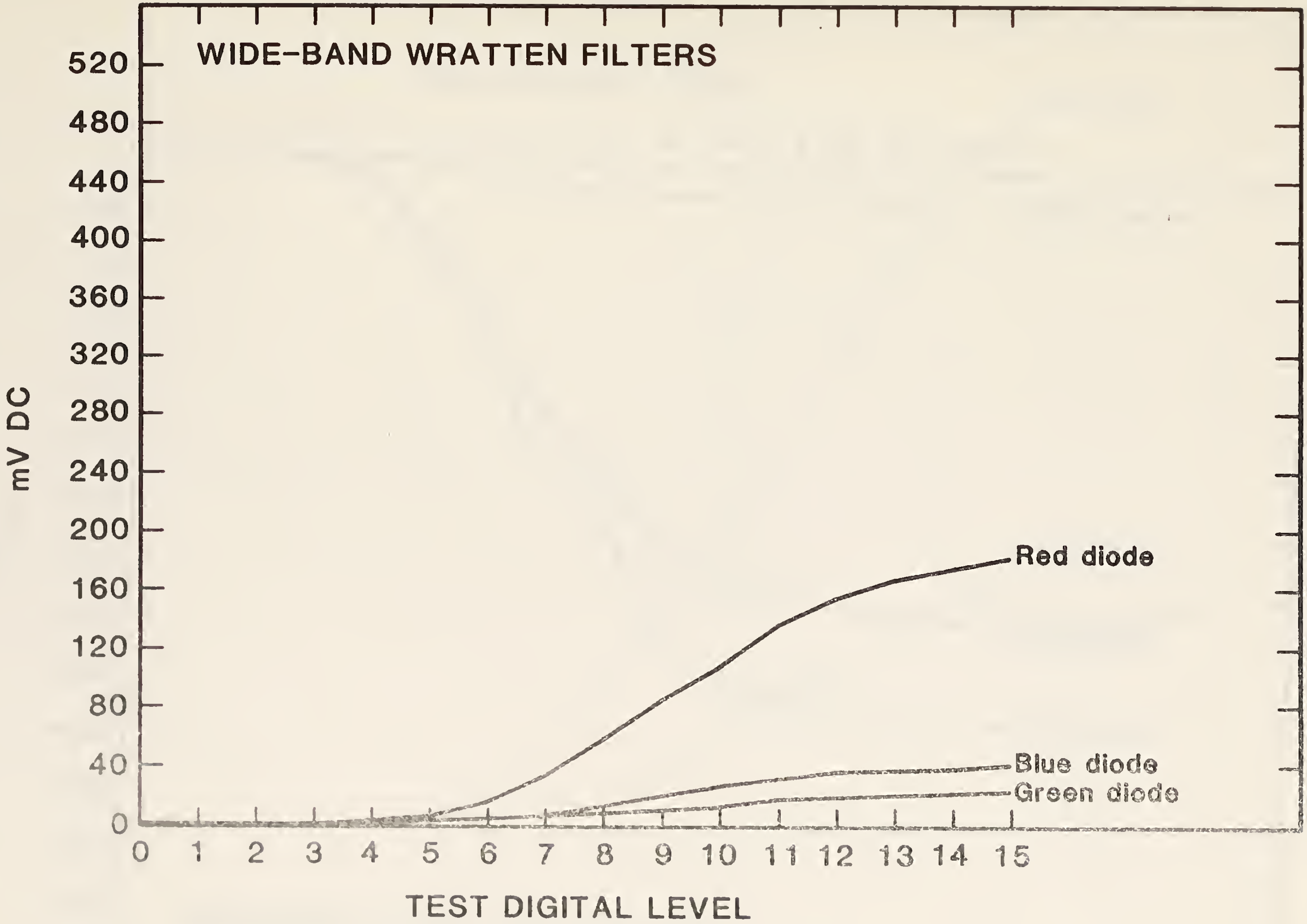

Figure 4A. Color calibrator voltage vs test digital level for CRT's red gun

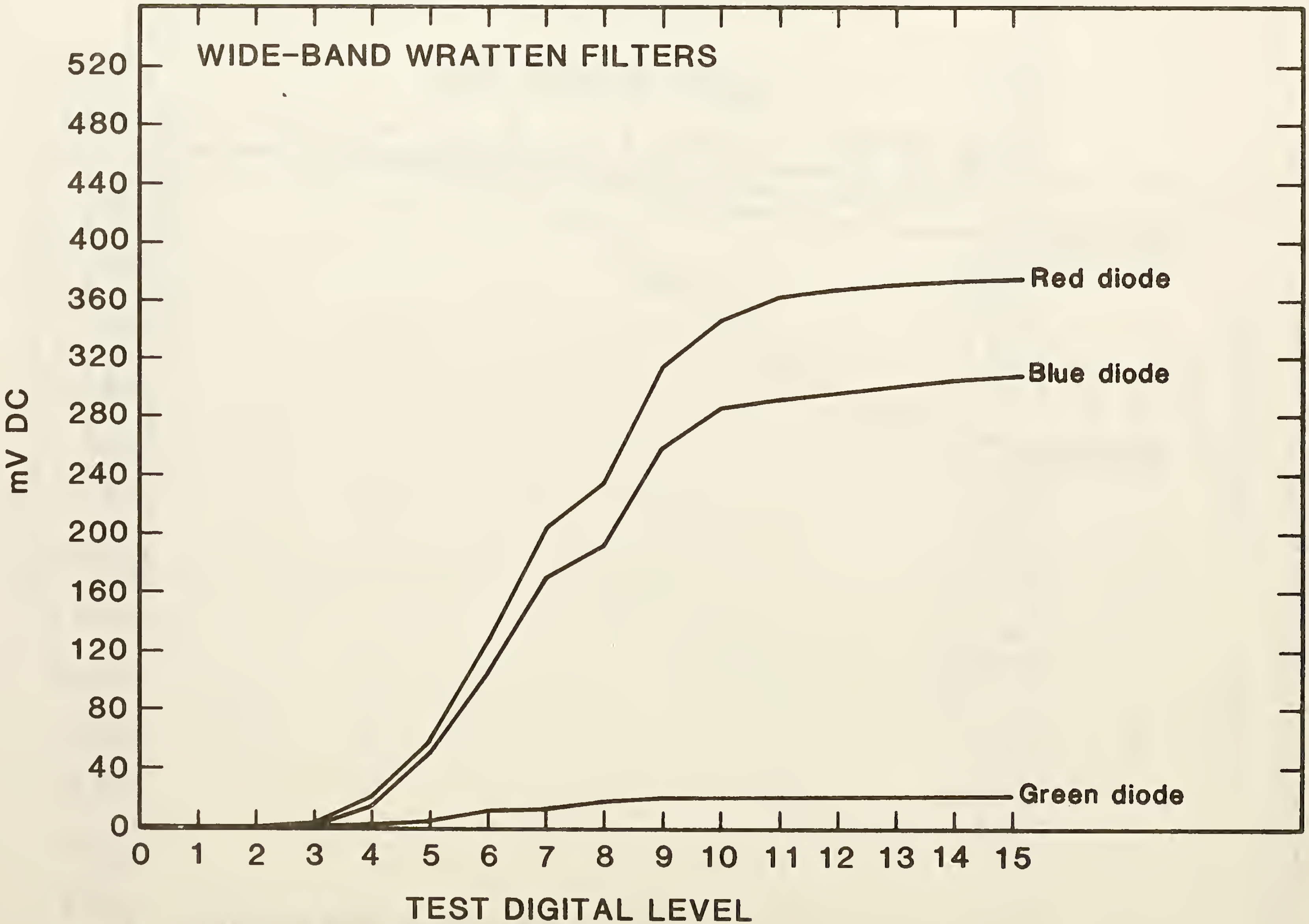

Figure 4B. Color calibrator voltage vs test digital level for CRT's blue gun

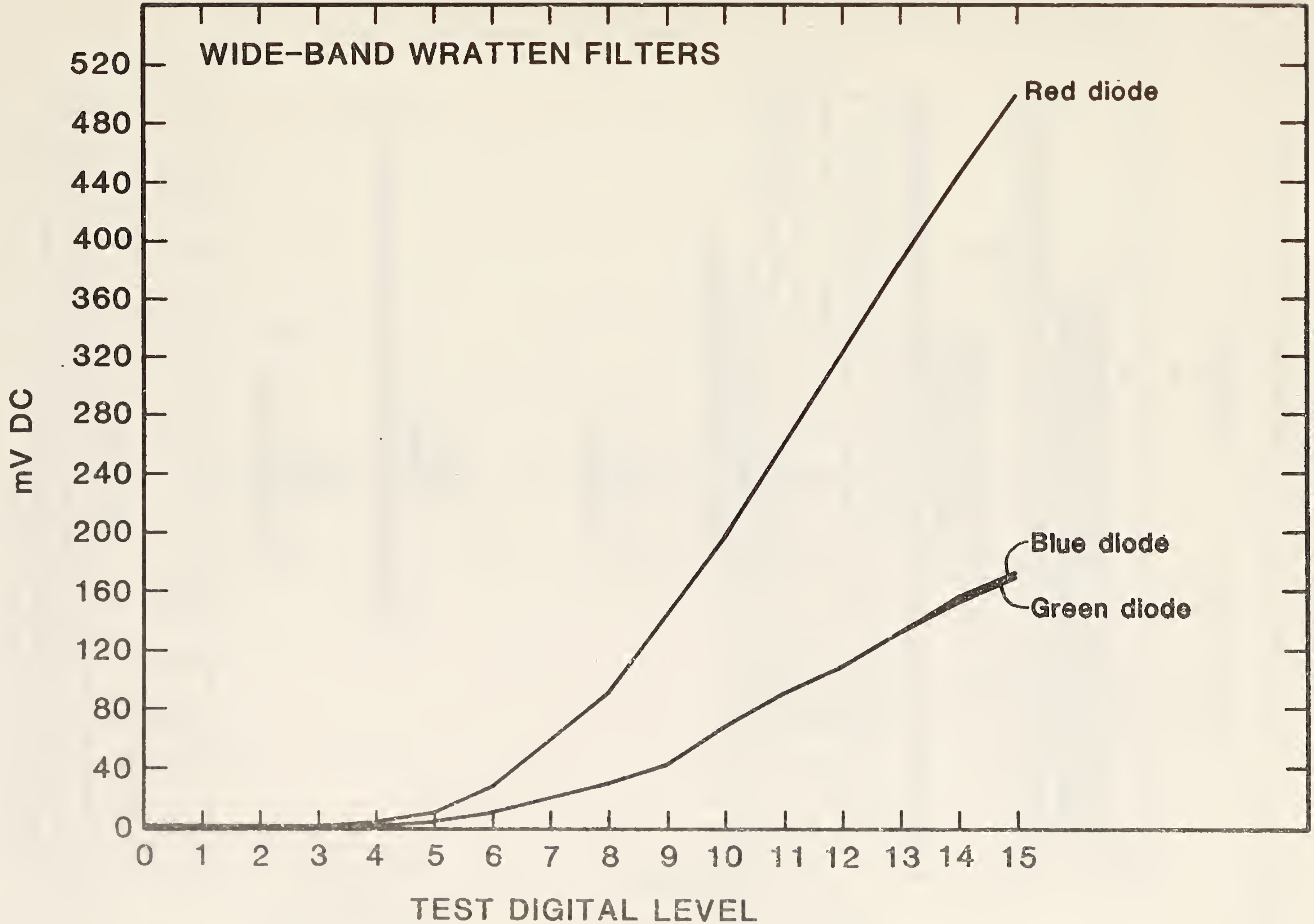

Figure 4C. Color calibrator voltage vs test digital level for CRT's green gun

Figures 4D-I. Silicon Photodiodes With Wide-Band Wratten Filters

WIL Color Tests	Figure No.
WIL #1	4D
WIL #2	4E
WIL #3	4F [1]
WIL #4	4G
WIL #5	4H
WIL #6	4I

Description -- Differential voltages (mVDC) between color calibrator RBG voltages: a) when TDLs for all RBG guns are set to manufacturer's color specifications for the WIL number, and b) when unit incremental or decremental TDL setting changes are made for each gun, one gun at a time. The RBG abcissa represents condition (a) above and the RBG vertical bars represent condition (b). The vertical bars are read left to right in the order RBG. B is actually used only in WILs #1 and #2.

1/ Figure 4F(a) demonstrates the effect of a 1 inch diameter, 1 inch focal length Fresnel lens (plus light tube) on the color calibrator's response when the photodiodes are located sufficiently behind the focal length to equally illuminate all three photodiodes.

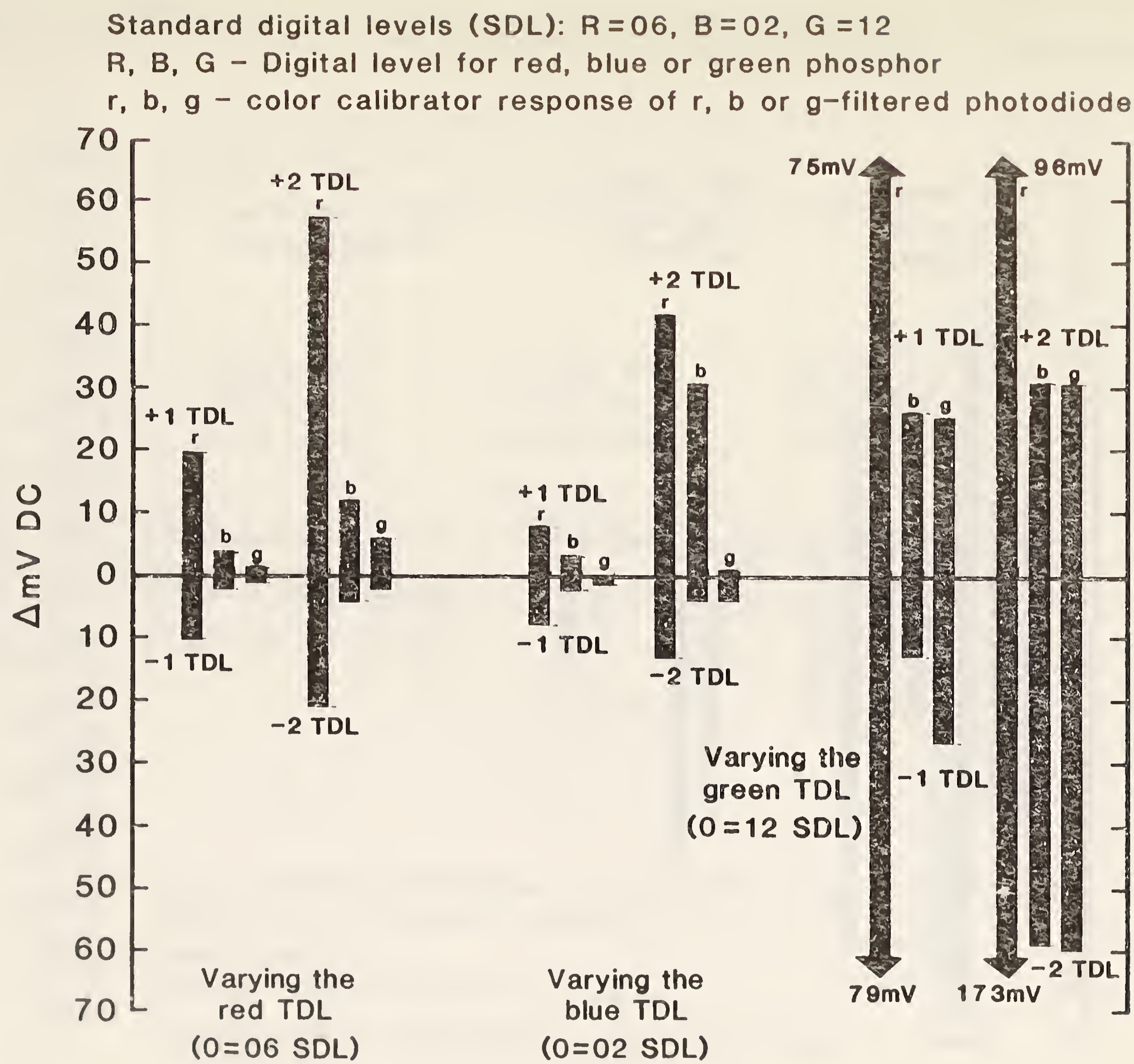

Figure 4D. Color calibrator difference voltages for each RBG color in WIL #1 using broad-band Wratten filters

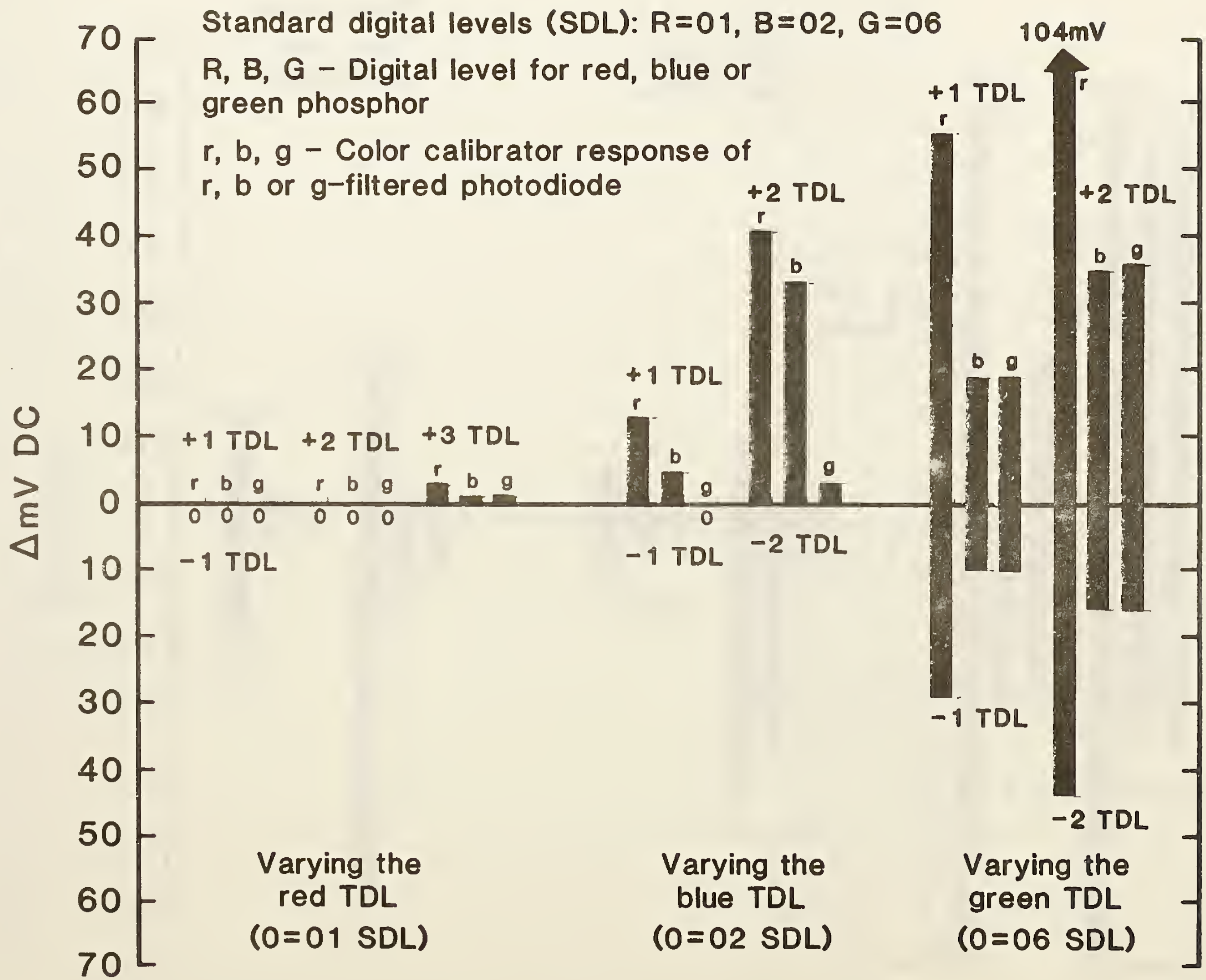

Figure 4E. Color calibrator difference voltages for each RBG color in WIL #2 using broad-band Wratten filters

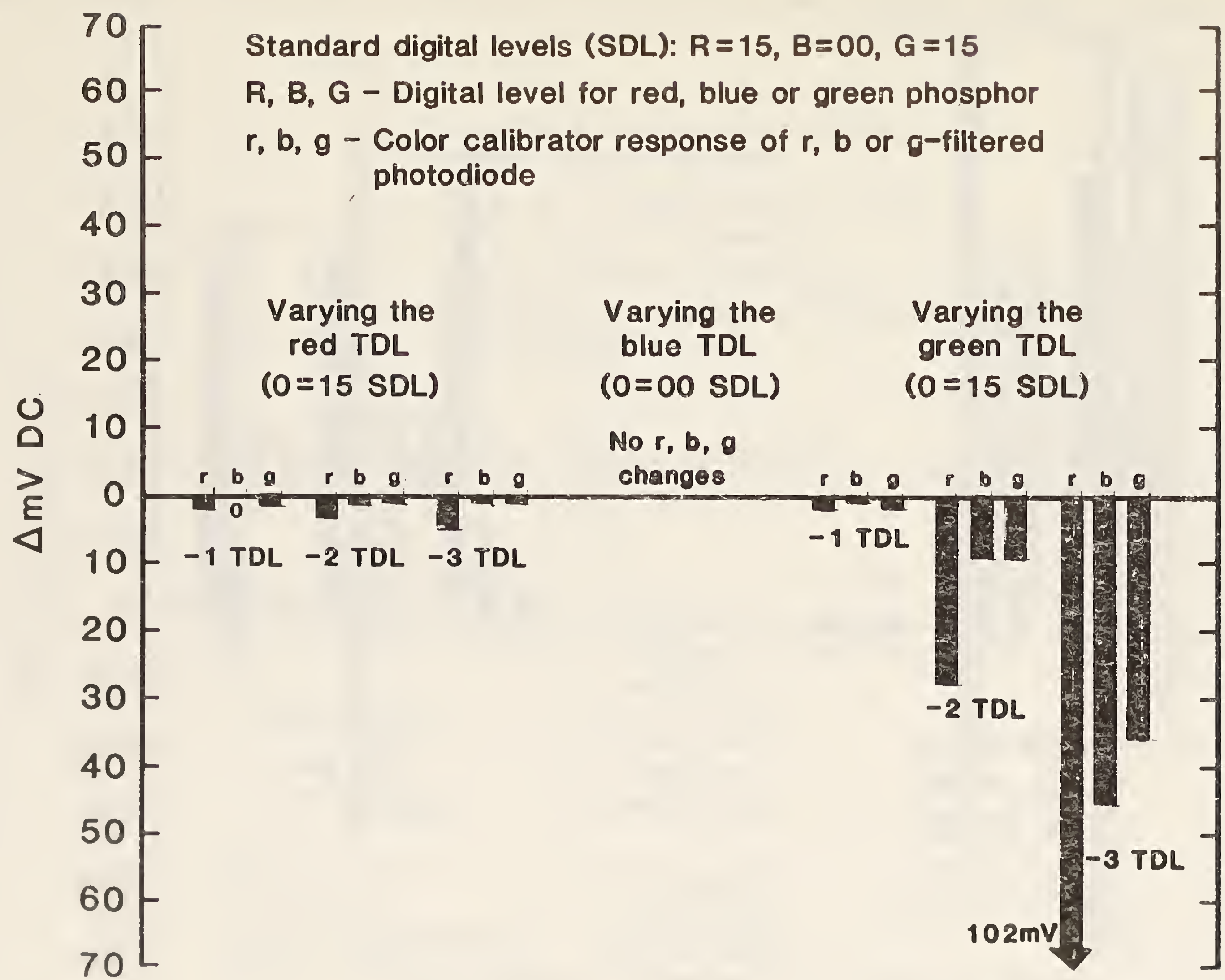

Figure 4F. Color calibrator difference voltages for each RBG color in WIL #3 using broad-band Wratten filters

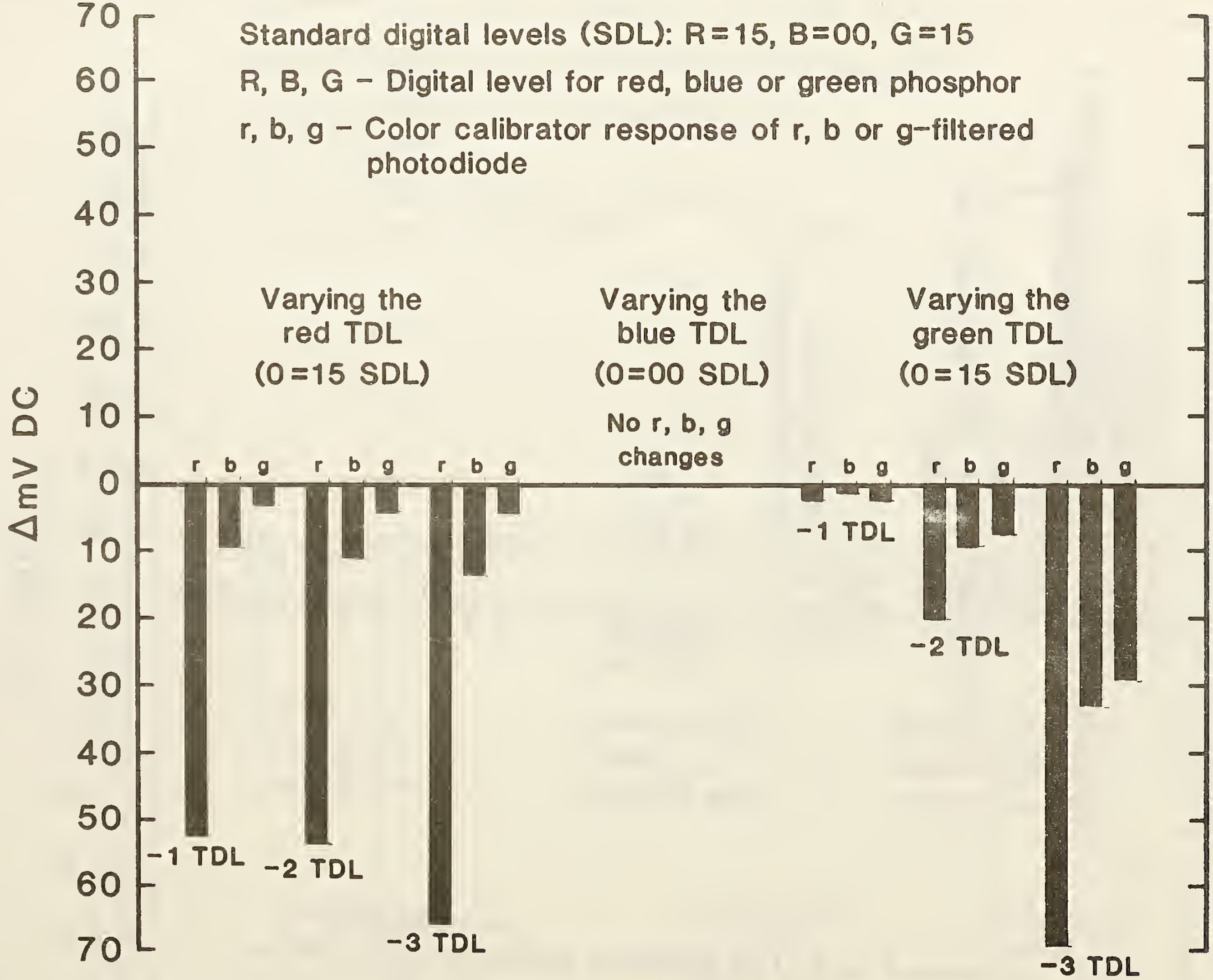

Figure 4F(a). Color calibrator difference voltages for each RBG color in WIL #3 using broad-band Wratten filters and a Fresnel lens

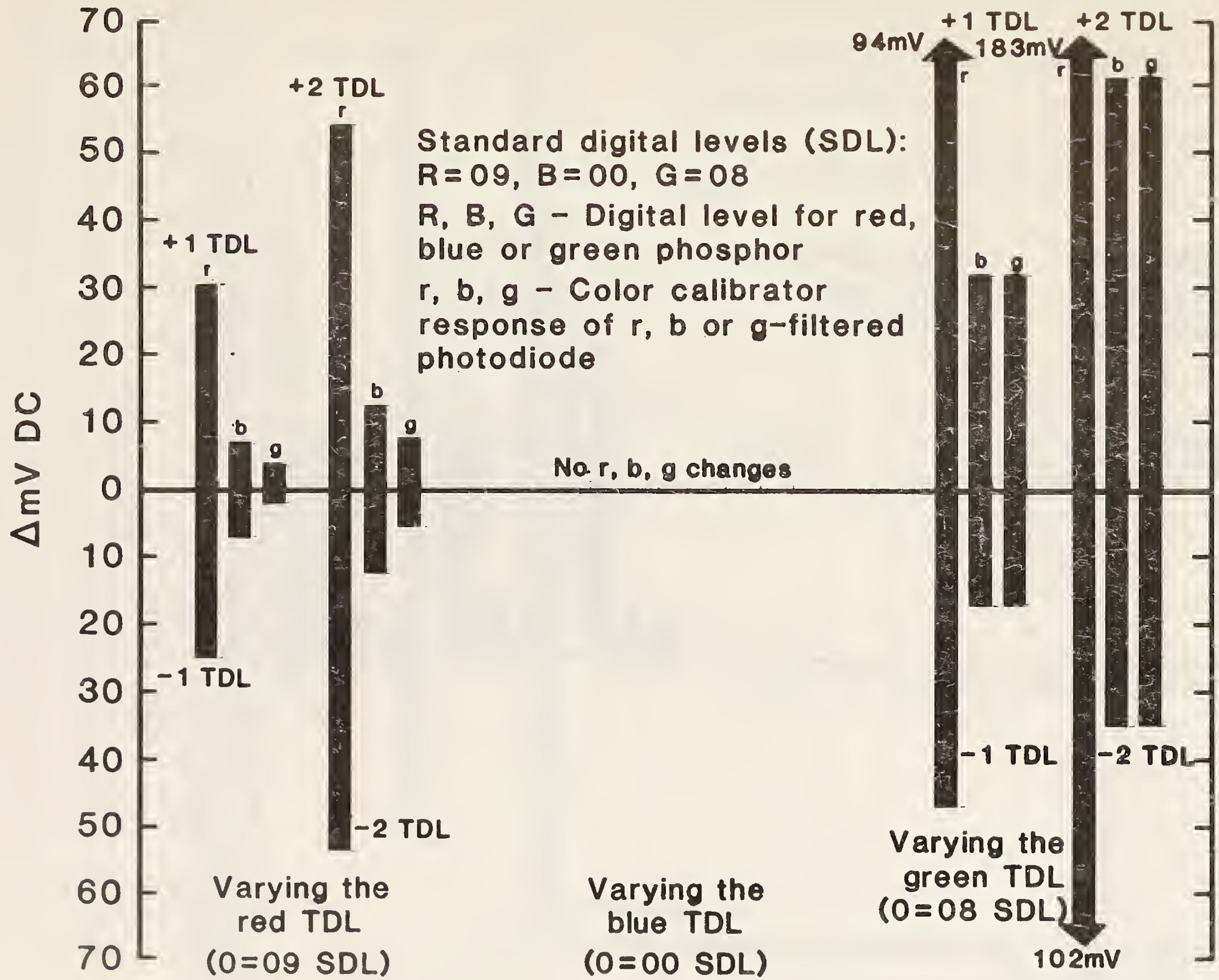

Figure 4G. Color calibrator difference voltages for each RBG color in WIL #4 using broad-band Wratten filters

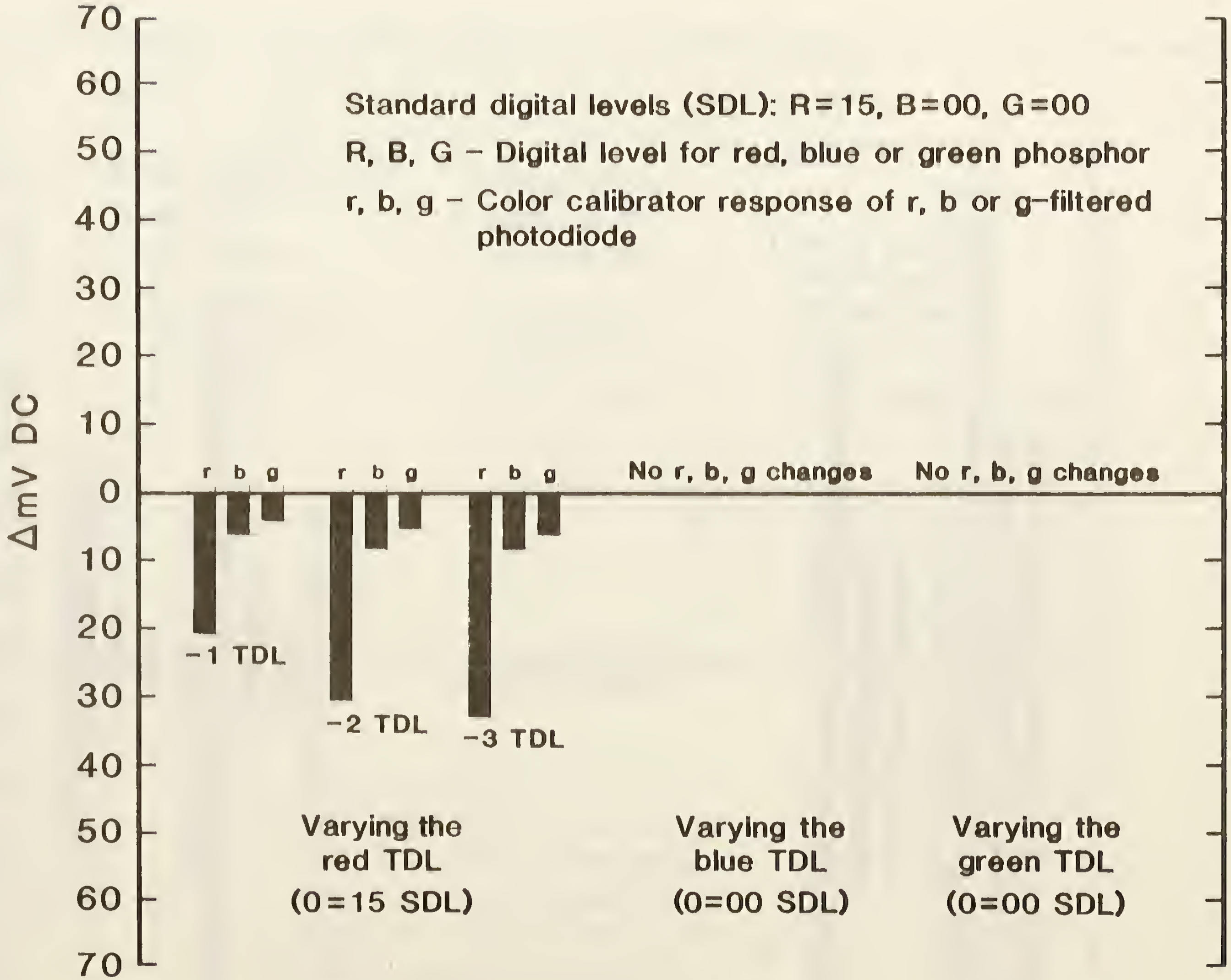

Figure 4H. Color calibrator difference voltages for each RBG color in WIL #5 using broad-band Wratten filters

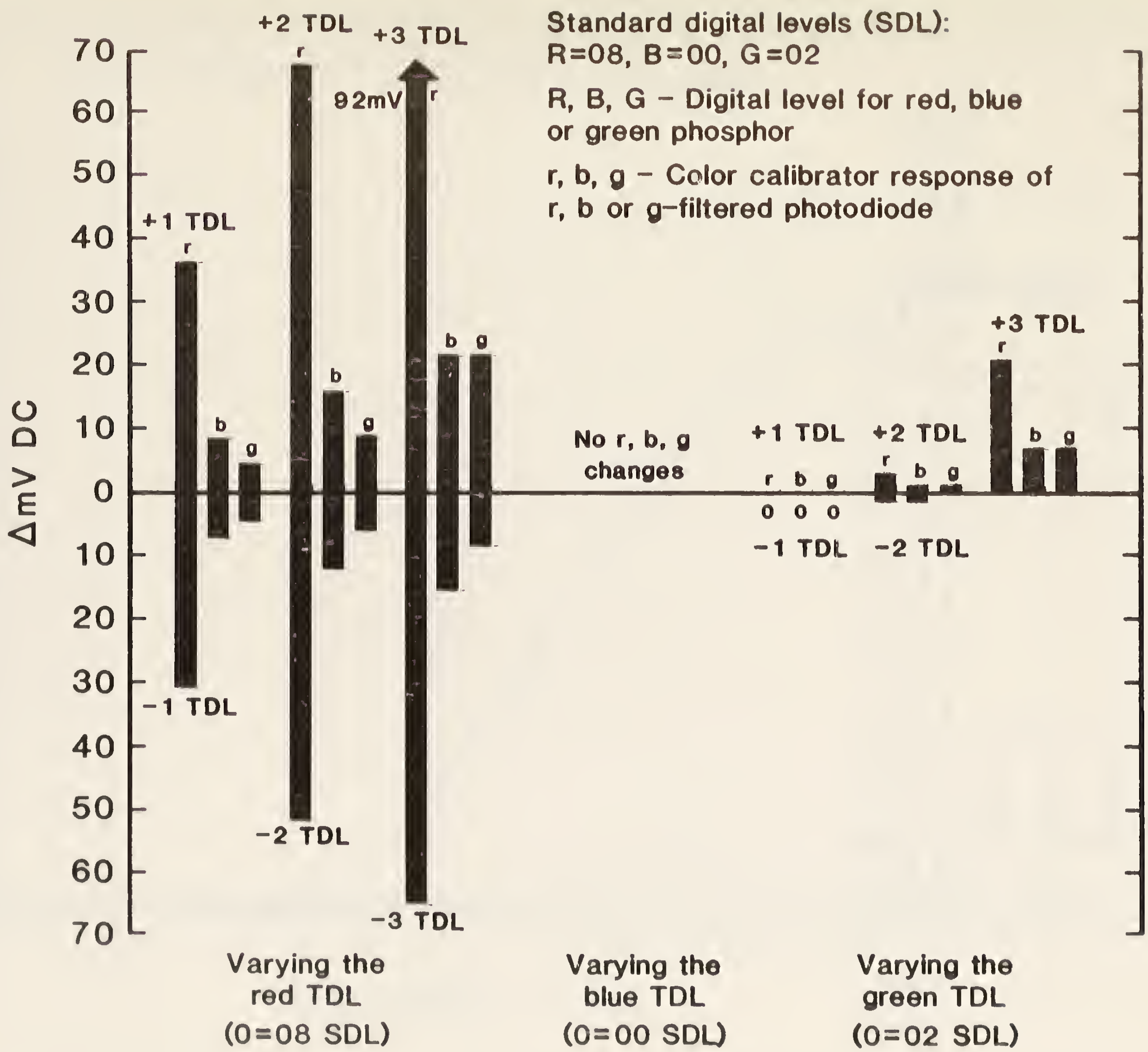

Figure 4I. Color calibrator difference voltages for each RBG color in WIL #6 using broad-band Wratten filters

Figures 5A-C. GaAsP Photodiodes With Dichroic Filters

Single Color Tests	Figure No.
Red (R)	5A
Blue (B)	5B
Green (G)	5C

Description -- Color calibrator voltage readings (mVDC) for each test digital level (TDL) setting for the R gun (figure 5A), B gun (figure 5B), and G Gun (figure 5C), starting from TDL = 00 to TDL = 15 (i.e., 16 steps), for each gun of the RBG photodetectors in the color calibrator head.

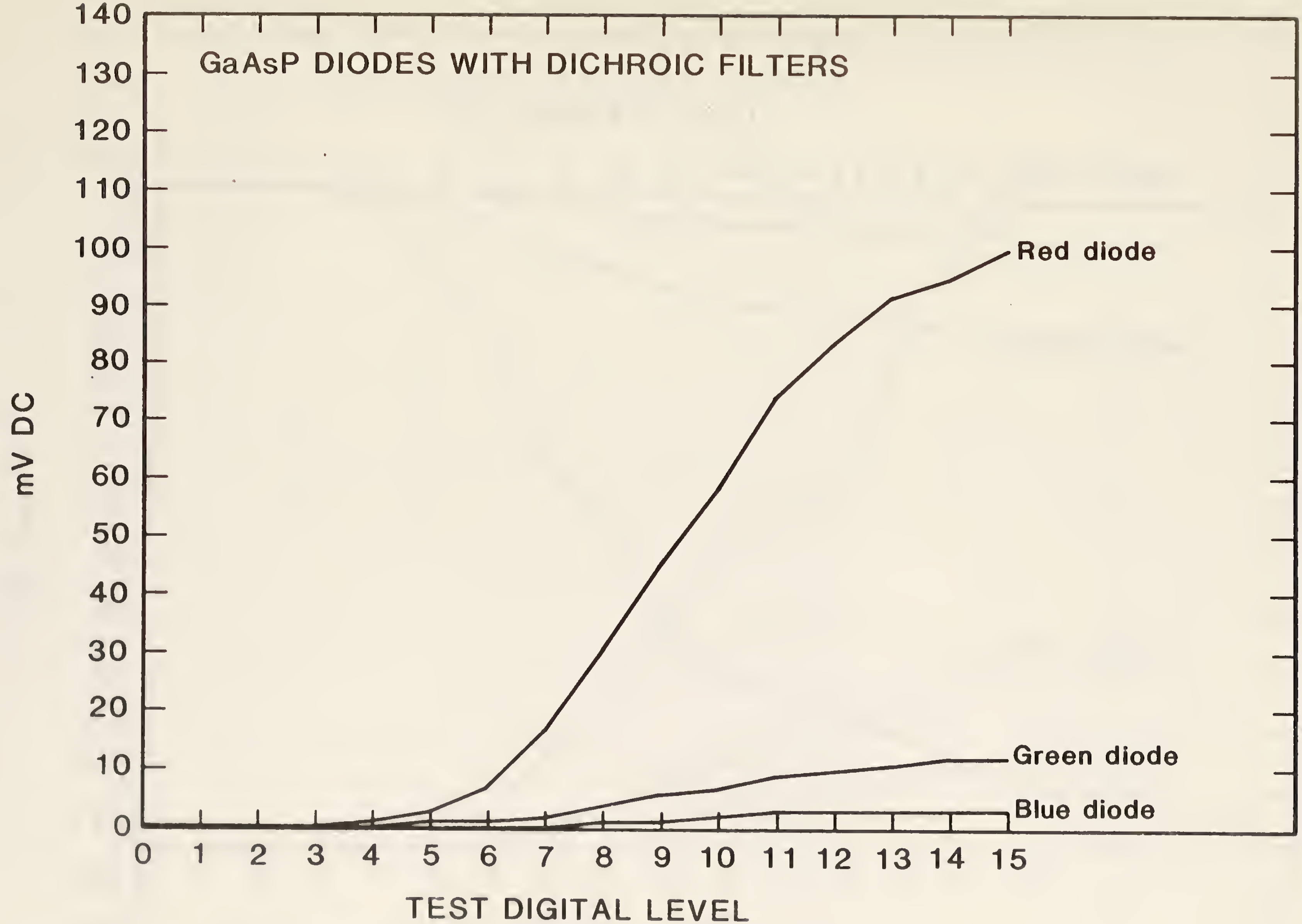

Figure 5A. Color calibrator voltage vs test digital level for CRT's red gun

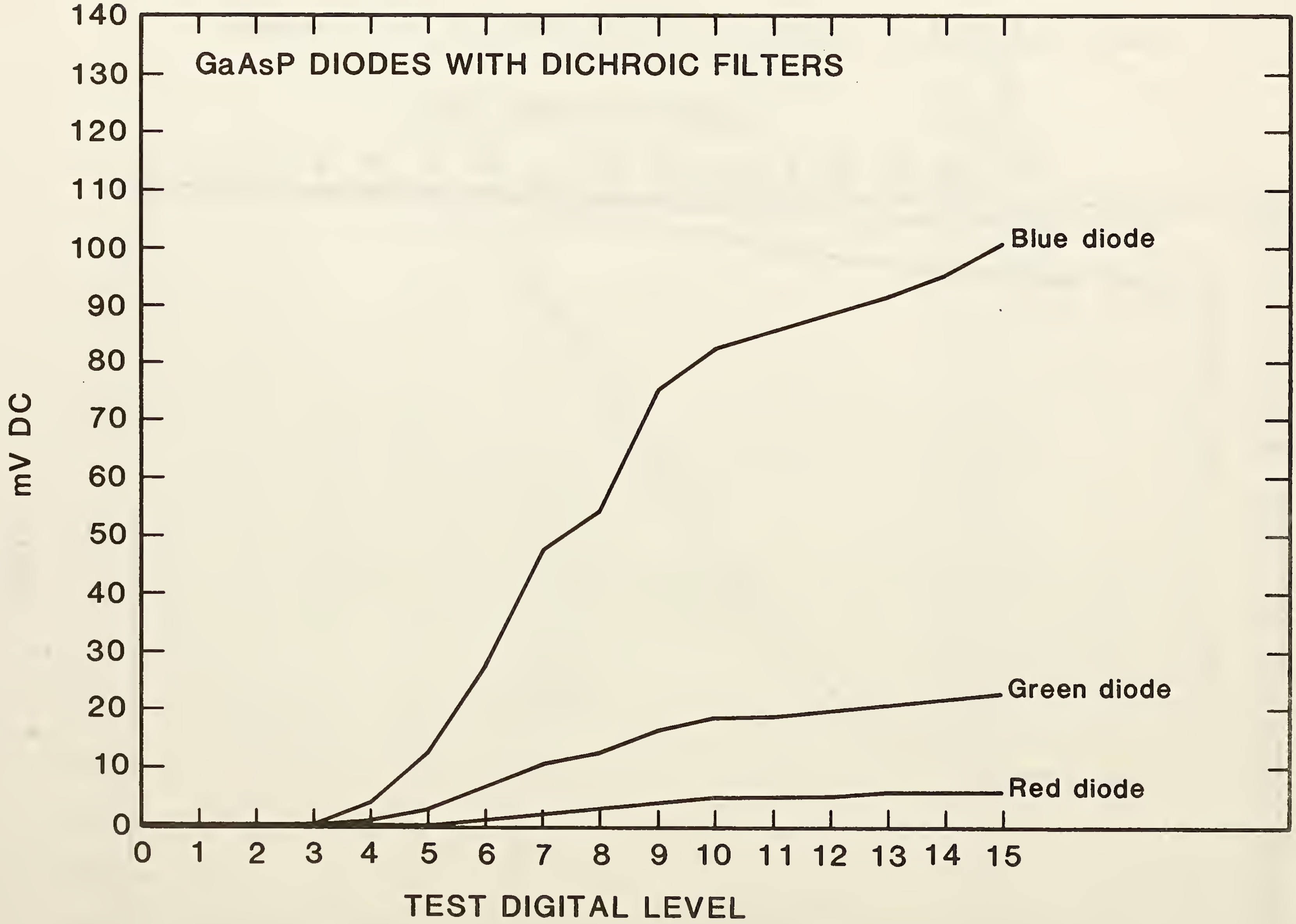

Figure 5B. Color calibrator voltage vs test digital level for CRT's blue gun

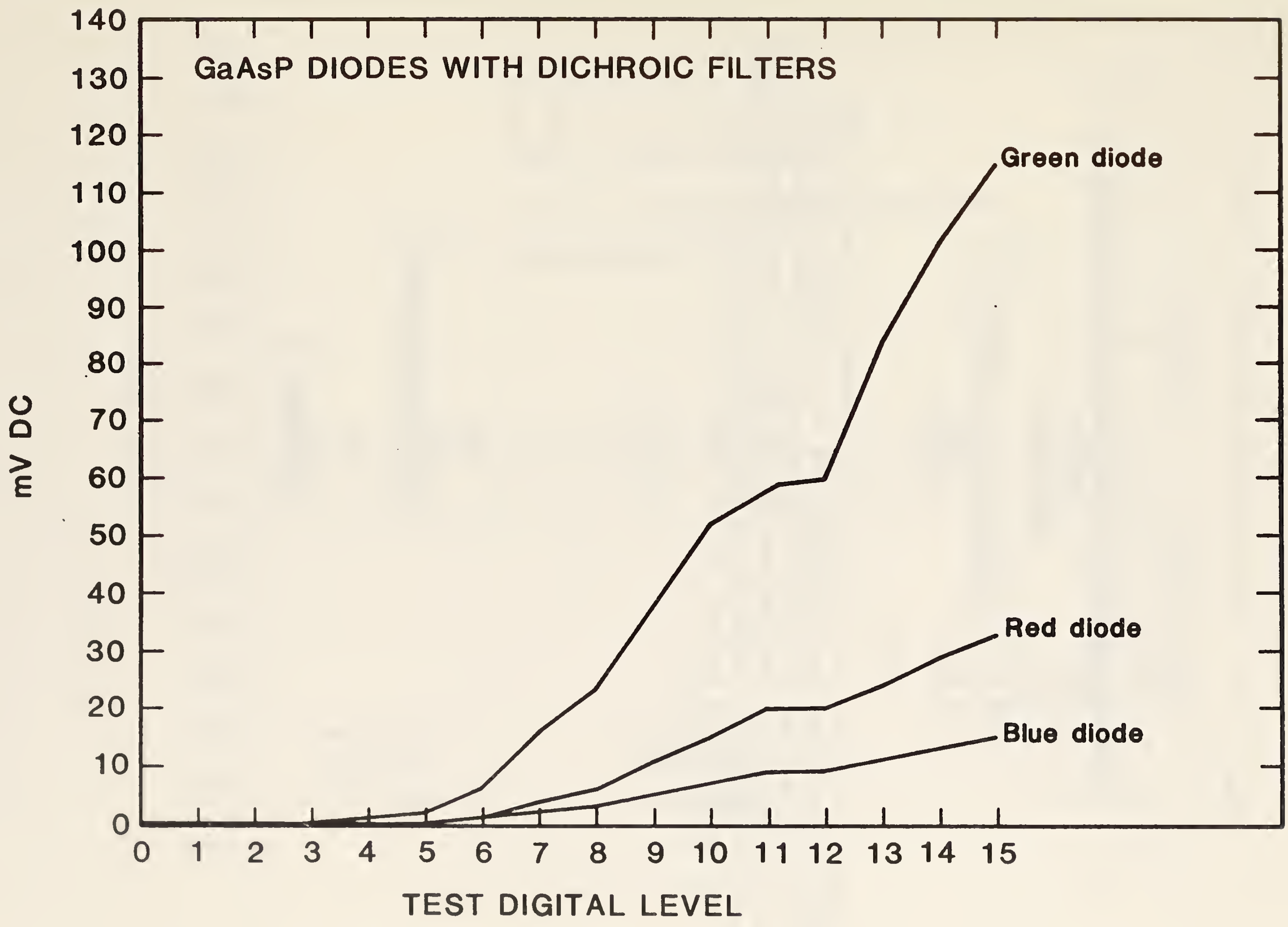

Figure 5C. Color calibrator voltage vs test digital level for CRT's green gun

Figures 5D-I. GaAsP Photodiodes With Dichroic Filters

WIL Color Tests	Figure No.
WIL #1	5D
WIL #2	5E
WIL #3	5F
WIL #4	5G
WIL #5	5H
WIL #6	5I

Description -- Differential voltages (mVDC) between color calibrator RBG voltages: a) when TDLs for all RBG guns are set to manufacturer's color specifications for the WIL number, and b) when unit incremental or decremental TDL setting changes are made for each gun, one gun at a time. The RBG abcissa represents condition (a) above and the RBG vertical bars represent condition (b). The vertical bars are read left to right in the order RBG. B is actually used only in WILs #1 and #2.

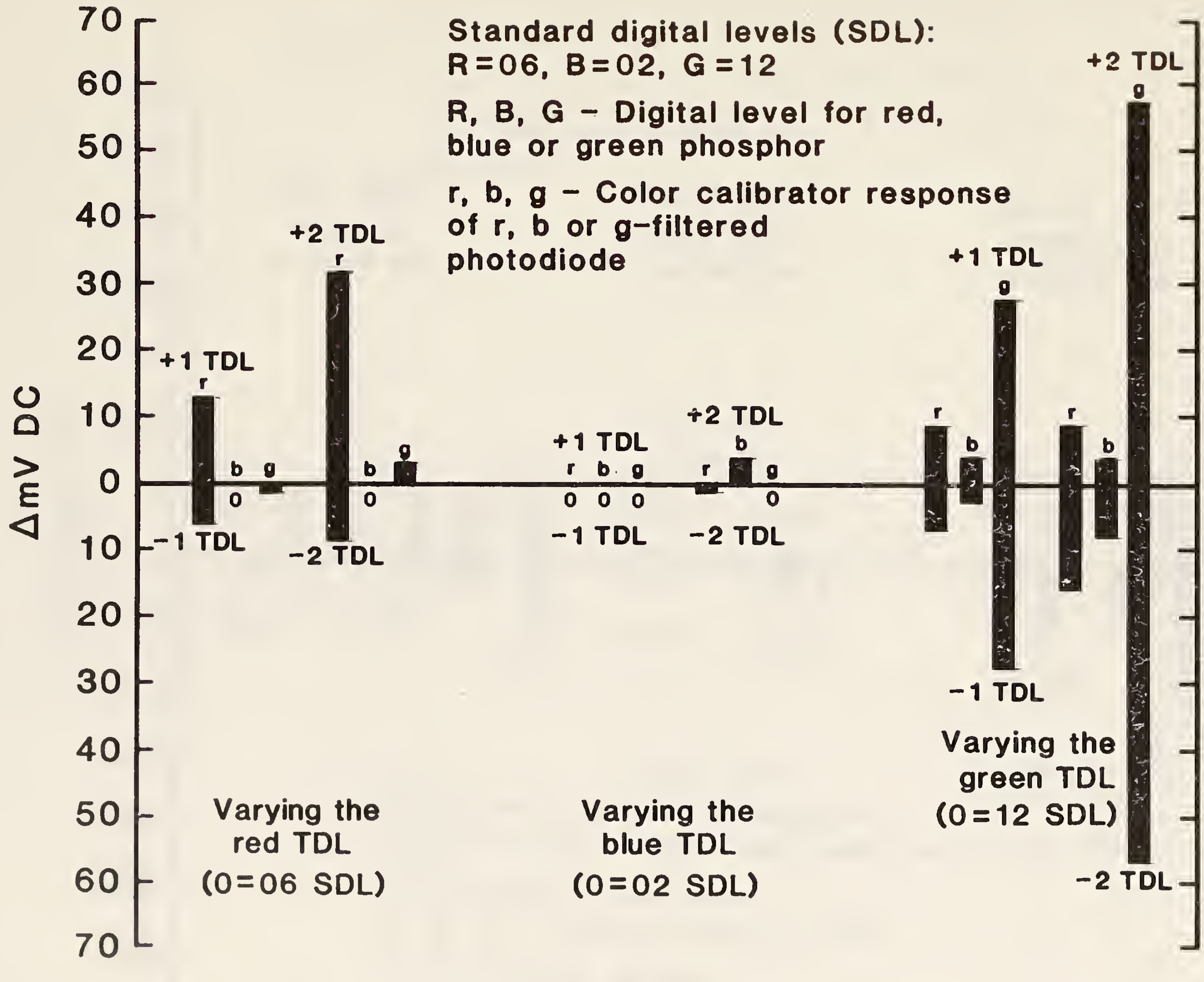

Figure 5D. Color calibrator difference voltages for each RBG color in WIL #1 using dichroic filters

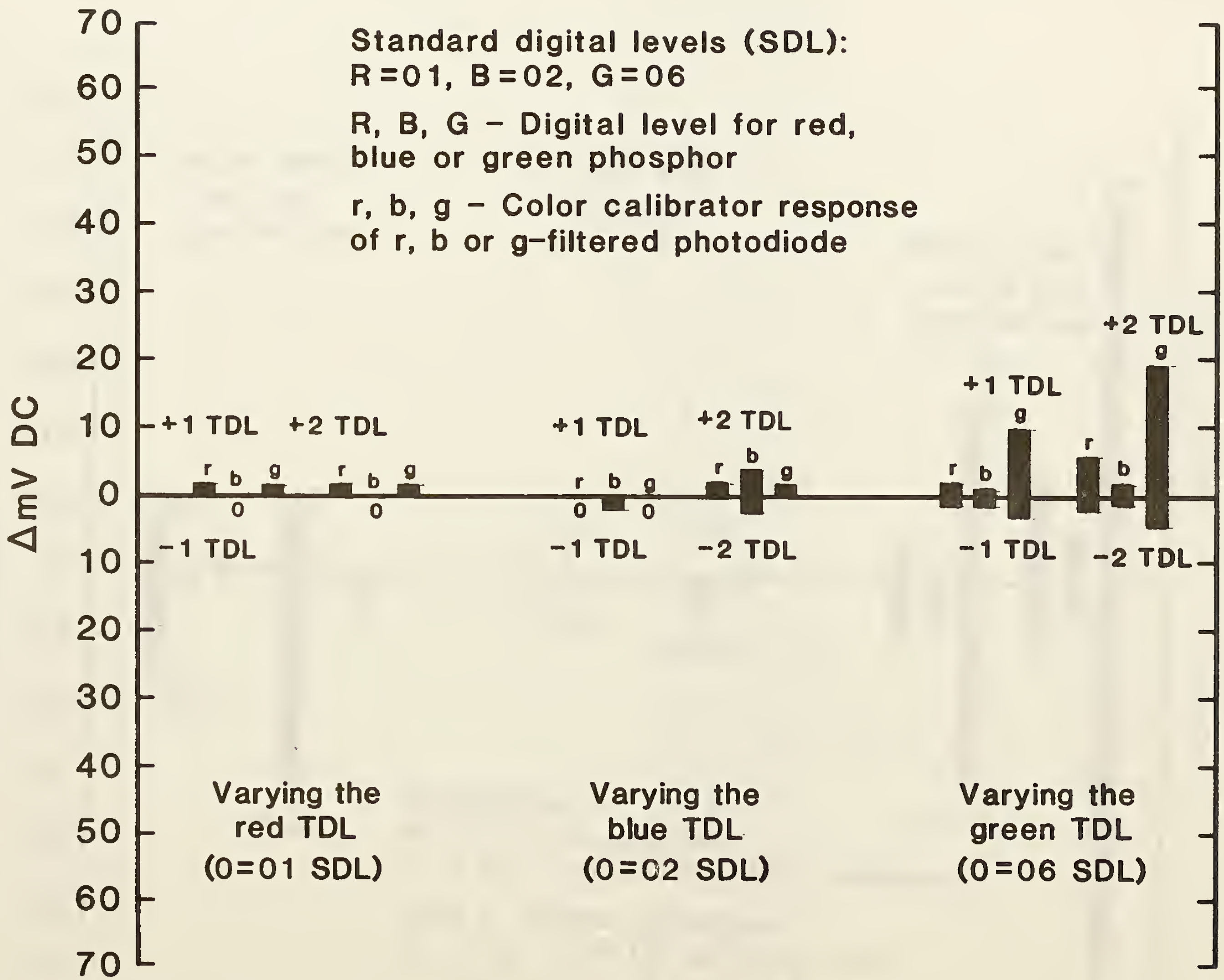

Figure 5E. Color calibrator difference voltages for each RBG color in WIL #2 using dichroic filters

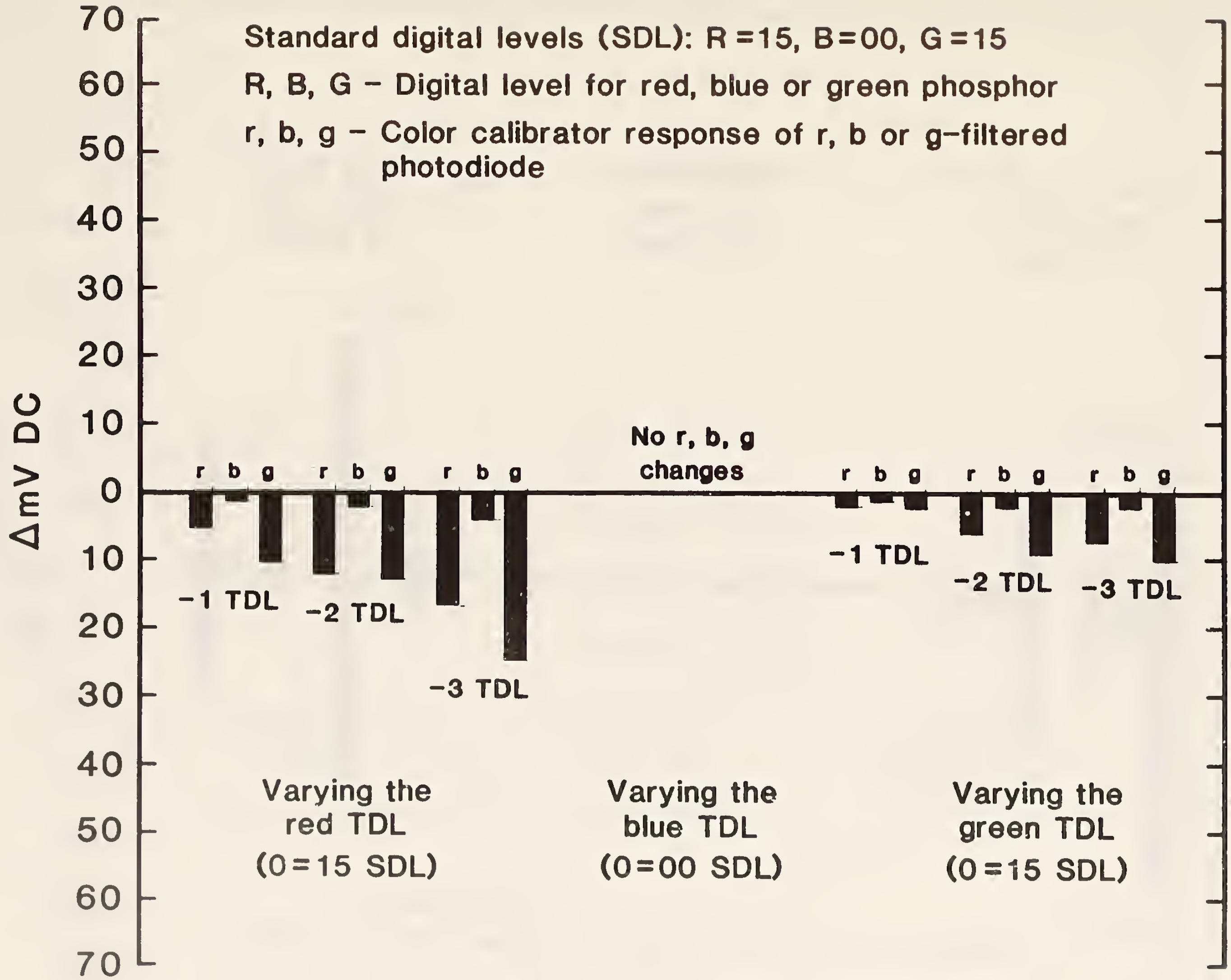

Figure 5F. Color calibrator difference voltages for each RBG color in WIL #3 using dichroic filters

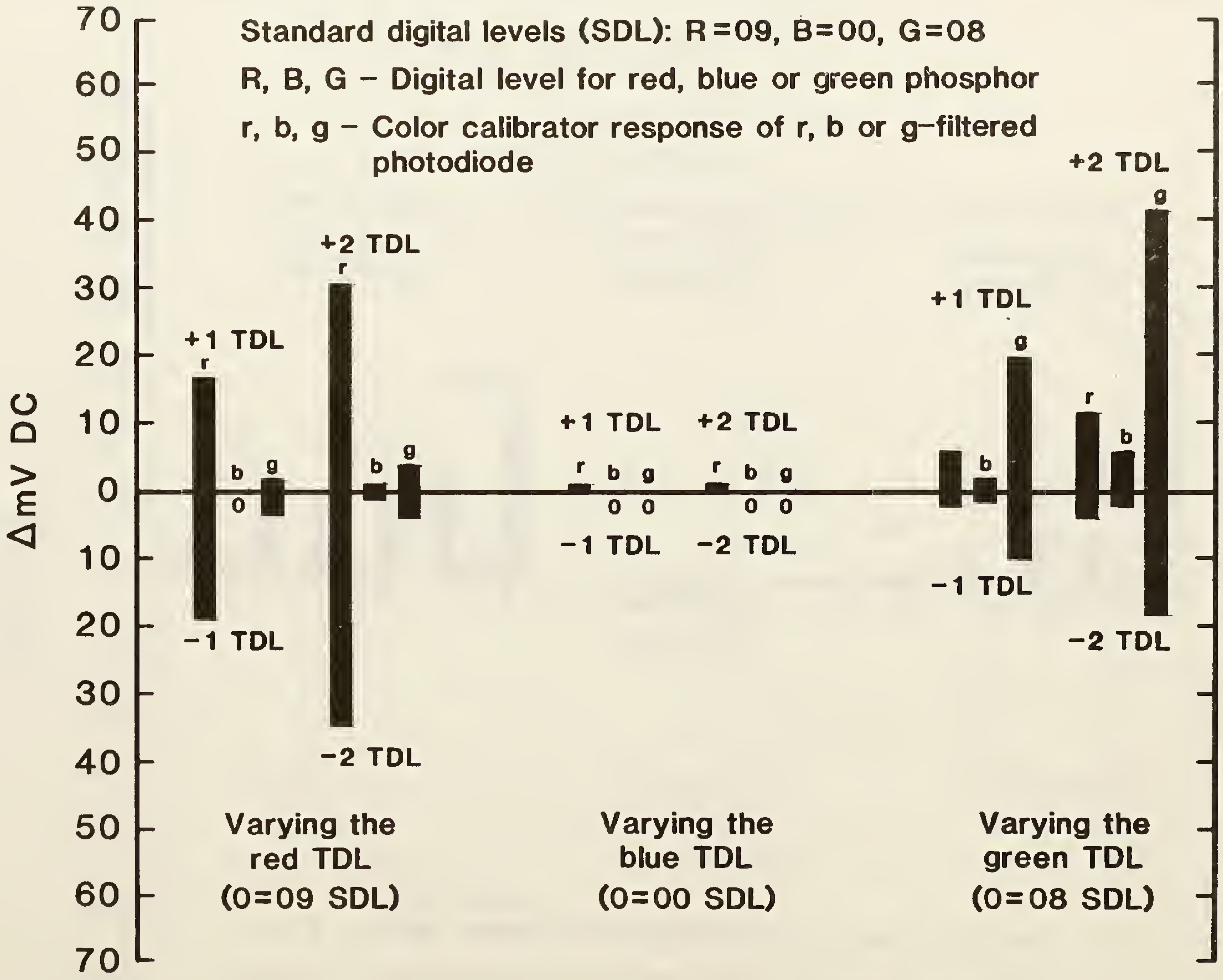

Figure 5G. Color calibrator difference voltages for each RBG color in WIL #4 using dichroic filters

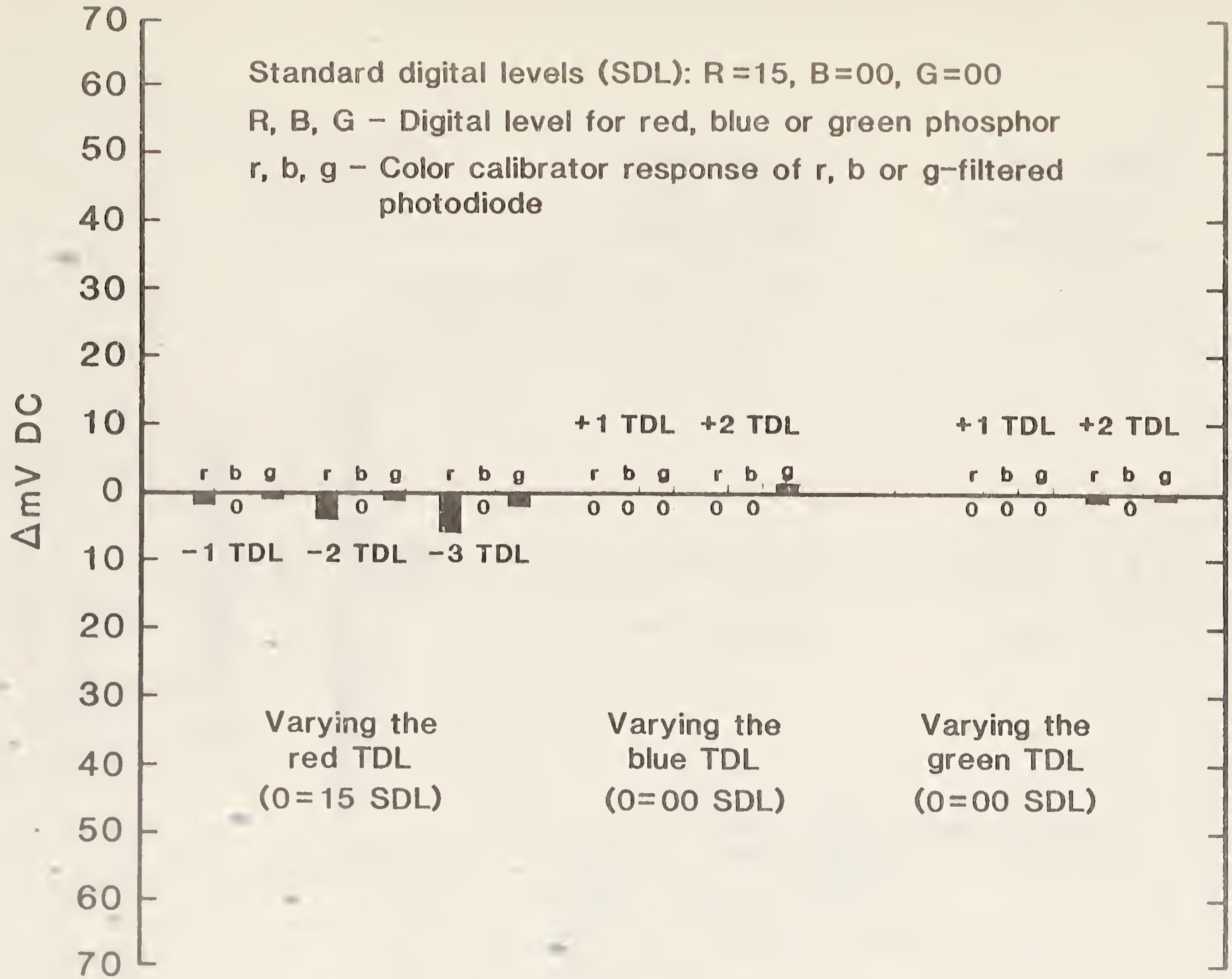

Figure 5H. Color calibrator difference voltages for each RBG color in WIL #5 using dichroic filters

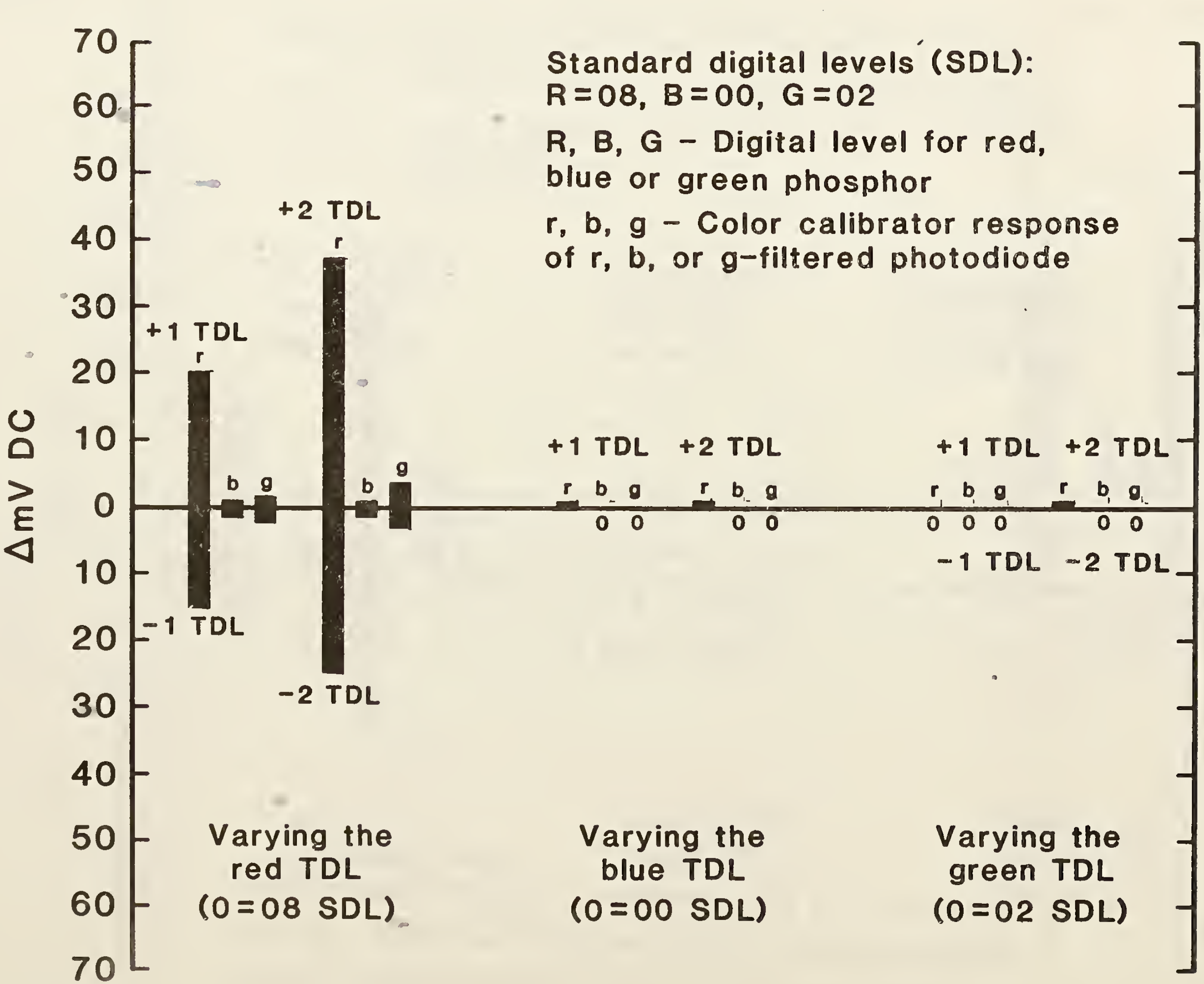

Figure 5I. Color calibrator difference voltages for each RBG color in WIL #6 using dichroic filters

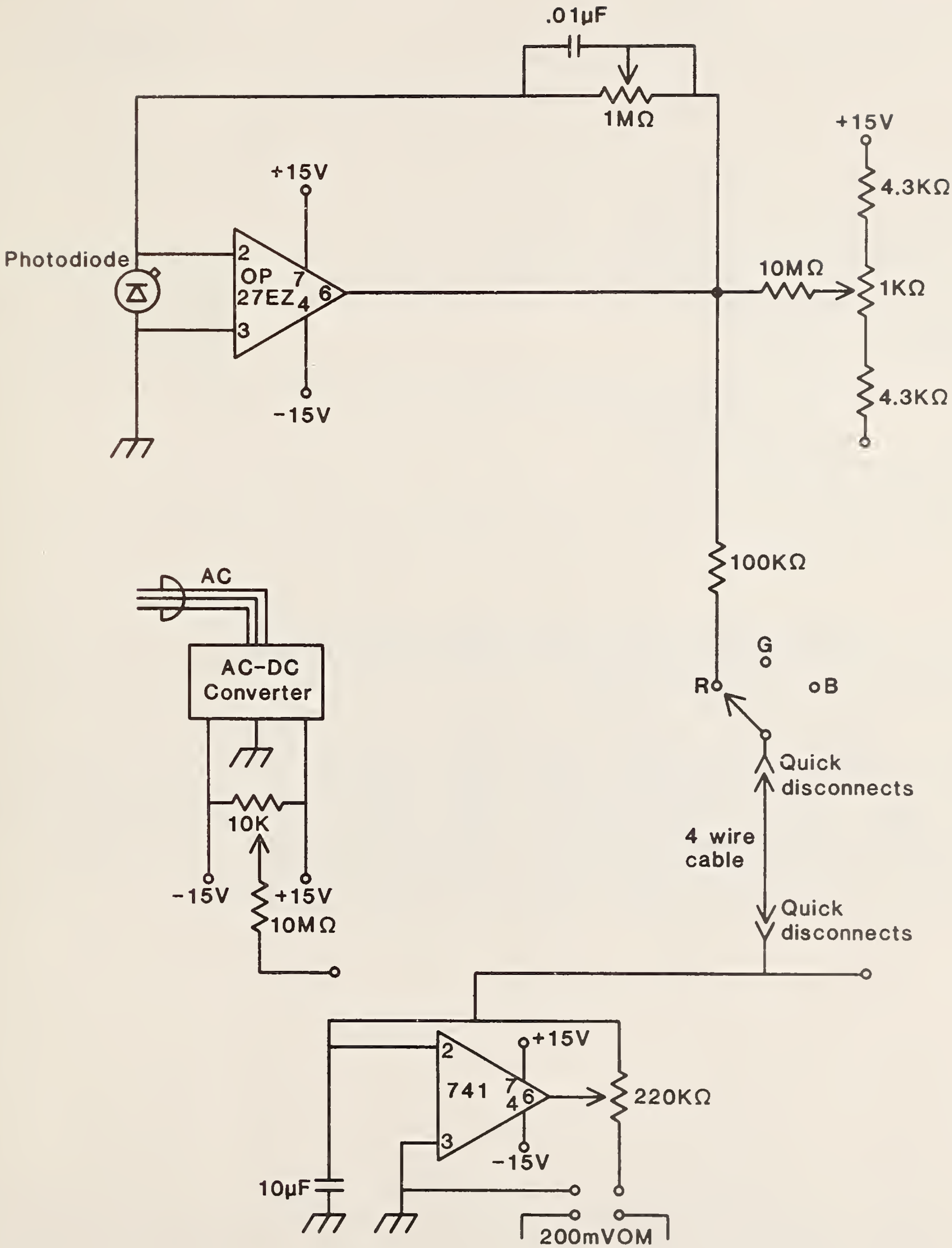

Figure 6. Schematic circuit diagram for engineering model color calibrator

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 84-2924	2. Performing Organ. Report No.	3. Publication Date August 1984

4. TITLE AND SUBTITLE

Color Calibrator for RRWDS Remote Radar Weather Display System

5. AUTHOR(S)

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6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.
DTF01-83-Y-20592
Mod. No. 1

8. Type of Report & Period Covered
NBISR 7/84-6/84

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

Federal Aviation Administration
800 Independence Ave., SW
Washington, DC 20591

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A color calibrator was designed, fabricated, and evaluated with a remote radar weather display system (RRWDS). This report describes the feasibility of an inexpensive color calibrator based on three photodiodes encapsulated with special red, green, and blue color filters to detect light from the phosphor colors used in the weather intensity levels. Further development of the color calibrator is recommended to produce a "true" colorimeter, which could measure chromaticity directly in terms of the C.I.E. coordinate system.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Calibrator; chromaticity; color calibrator colorimeter; CRT display; display luminance; radar; RRWDS; weather radar; weather display.

13. AVAILABILITY

☐ Unlimited
☒ For Official Distribution. Do Not Release to NTIS
☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
☐ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES
80

15. Price

USCOMM-DC 6043-P80