THE NRAO IMAGE RECORDING SYSTEM

by

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COVER

The cover photograph, produced by the NRAO Image Recording System, shows the distribution of neutral hydrogen in the spiral galaxy M81. The observations were made with the Westerbork Synthesis Radio Telescope at a resolution of 23'.9 X 25'.6 by A. H. Rots and W. W. Shane. The celestial coordinates (1950.0), the synthesized beam, the linear scales in the plane of the galaxy, and the scale of neutral hydrogen column density (in 10**20 atoms / cm**2) are shown in the photograph. (See Rots, A. H. and Shane, W. W. 1975, Astr. and Ap., 45,25.)

The authors would like to thank A. H. Rots for providing the data and plotting instructions in advance of publication and for making many helpful suggestions on this manuscript.

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I. Introduction

The NRAO Image Recording System is an attempt to solve the perennial problem of displaying observed and processed data. In the early days of radio astronomy small amounts of data were collected. Chart recordings and simple line drawings were sufficient to display these data. With the advent of multi-antenna arrays, low noise amplifiers, and multi-channel receivers, the volume of data collected has increased enormously. Today, many observers obtain on the order of 1 x 10**5 data points, while some observers obtain in excess of 1 x 10**7 points. Using large computers, interactive graphics terminals, and computer-controlled plotters, this volume of data may be reduced and displayed. However, the resulting displays often either contain only a small portion of the data per display or are too complicated to be readily used. This report describes a system which can convert up to 1.6 x 10**7 data points having a dynamic range greater than 100 to 1 into a photographic picture. The system is believed to solve many of the current and future problems involving the presentation of large quantities of data.

The NRAO Image Recording System is a hardware-software system designed to convert digital data, in particular radio astronomical maps, into optical photographs. This system consists of three major parts: (1) the Dicomed Image Recorder ("Dicomed"), (2) the Dicomed Control Program ("DCP"), and (3) the various data preparation programs. The Dicomed is a digitally-controlled device which converts digital data to specified exposures at specified positions on photographic film. This device is controlled by the DCP which runs in a minicomputer attached to the Dicomed. The command

language of the DCP allows the user to exercise control over all aspects of picture generation. The user may enter commands from a terminal or have them read from cards or magnetic tape. Normally these tapes are generated on NRAO's IBM 360/65 computer.

There are three types of pictures commonly made by the Image Recording System. The first is a black and white picture, analogous to an optical photograph, in which the intensity on the film is proportional to the data values. The second is a contour map with each level being photographed in a different color. Such pictures are believed to be useful for presentation to the public and at scientific meetings and colloquia. The third is a four-dimensional map in which color is used as the fourth dimension. This type of picture has proven particularly useful in displaying spectral-line maps of external galaxies.

The three major parts of the NRAO Image Recording System are the subjects of Sections II-V of this report. Section VI is devoted to a discussion of the photographic process and its use in the display of radio astronomy data. The command language of the DCP is described at length in Appendix A, while Appendix B is devoted to a description of the program INTERFACE designed to produce tapes to be read by the DCP. References, including references to the standard data-reduction programs which have picture making options, are given in Appendix C.

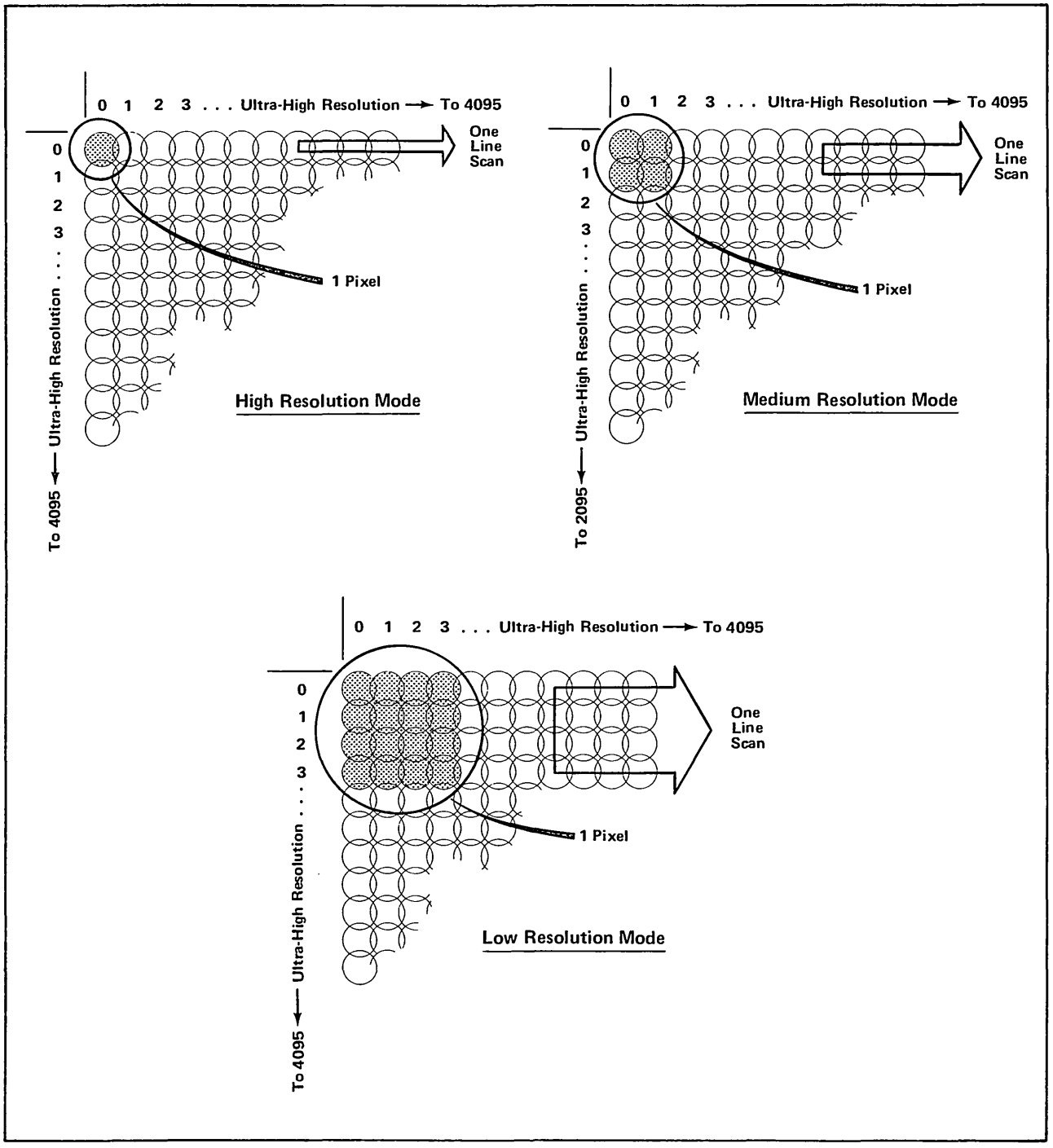
II. The Image Recorder

The Dicomed D47 Image Recorder, shown in Figure 1 together with the Modcomp computer and its tape units, terminal and card reader, is a high-precision variable-intensity point plotter. At the heart of this unit is a digitally-controlled cathode ray tube (CRT). The CRT beam may be positioned to specified horizontal and vertical coordinates with high accuracy. Each data element received during the recording process consists of a digital value, between 0 and 255, determined by the desired exposure. Once the CRT beam has been positioned to the specified location, it is energized at a constant intensity for a length of time linearly or exponentially proportional to the input value. The image area of the CRT is projected through a lens and one of a set of selectable filters and is focused on the film plane. The set of filters consists of a neutral filter used in generating black and white photographs and red, green, and blue filters used in generating color photographs. The Image Recorder also contains an upper case character generator.

On the Dicomed, images are represented by a number of small unit areas, called picture elements or "pixels", of constant intensity. The pixels are arranged in a square matrix 98 mm on a side. This recording area is divided into 4096 by 4096 addressable "points" (0 through 4095). Each point may be assigned an intensity value in the range 0 through 255. The Dicomed provides three resolution modes as illustrated in Figure 2. In the high resolution mode each pixel consists of one point. In medium resolution each pixel consists of a 2 by 2 matrix of points, and in low resolution each pixel consists of a 4 by 4 matrix of points. Each point within a pixel receives equal

Figure 1. The Modcomp computer, the Dicomed, and peripherals

Figure 2. The Image Recorder resolution modes.



exposure. Images are normally constructed on film in raster fashion with exposure values being transmitted to the recorder pixel by pixel for each line. The raster procedes from left to right and from top to bottom. Images may also be generated in a random plotting fashion using a mixture of position commands and data. This method is seldom used, since it requires around forty times as much time to generate the same picture.

The Image Recorder is controlled by commands and data from a computer. The commands control the positioning of the CRT beam and the starting and stopping of image generation, and they also select options including filters, resolution, transfer functions, and data precision. The commands will not be described here since, in the NRAO Image Recording System, the commands are generated by the Dicomed Control Program described in Section IV. The Dicomed can also be controlled with the Operator Control Panel shown in Figure 3. The user may select all options and terminate picture generation using this control panel. However, the hardware is designed so that the control computer cannot determine which options have been manually selected. Thus, the user should employ the control program, rather than the control panel, to select options. The POWER key should be left in the "LOCK ON" position to prevent accidental use of the Control Panel buttons.

The actual exposure of the film is an analogue process which is subject to drifts in calibration. There are two controls to adjust the exposure values. A ten-turn lockable potentiometer located on the control panel and labeled "EXPOSURE" allows the user to adjust the exposure for different types of film. A second potentiometer located on the Test and Calibration Panel (shown in Figure 4) and labeled

Figure 3. The Operator Control Panel

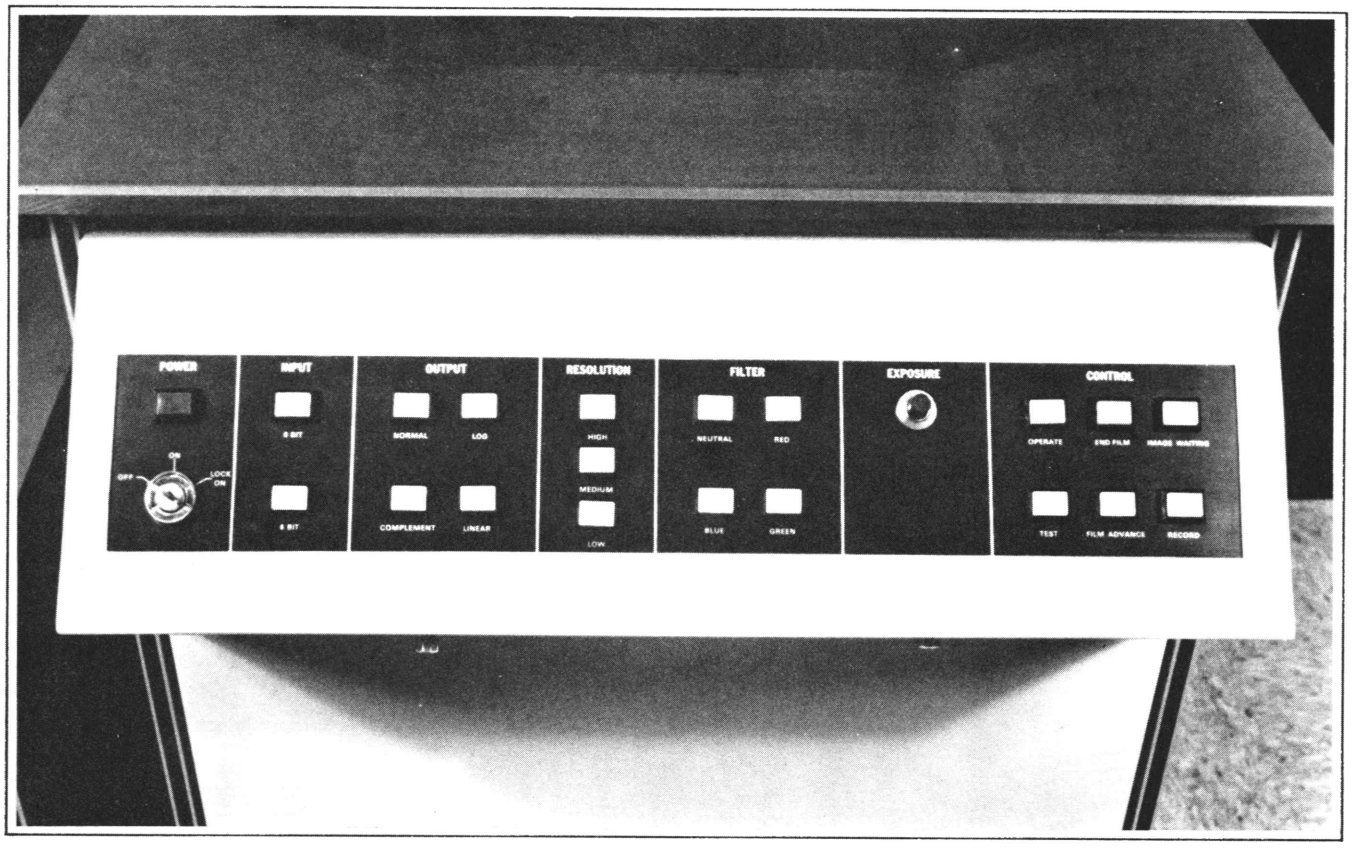
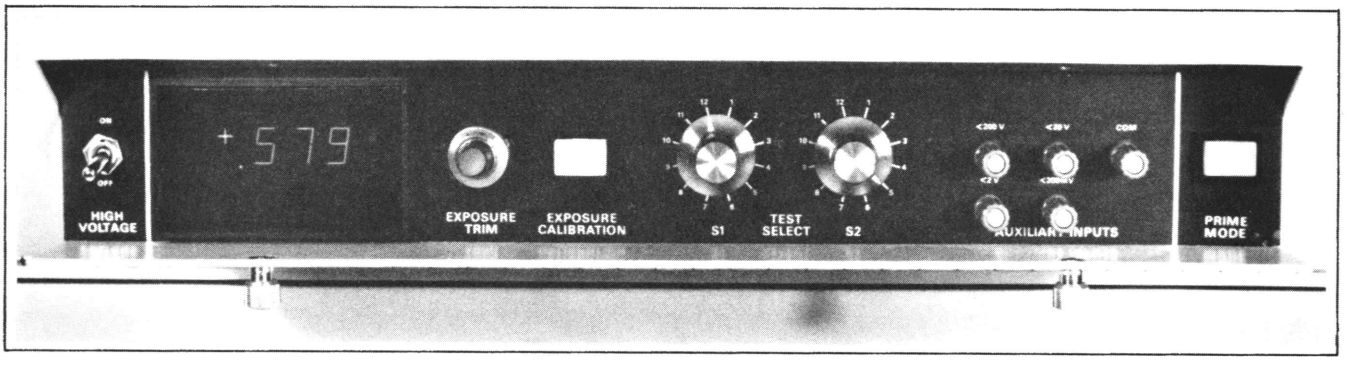


Figure 4. The Test and Calibration Panel



"EXPOSURE TRIM" allows the user to adjust the normal operating levels. These adjustments are described in Section III. The CRT may retain a residual image of previously recorded photographs. This retention is due to an increased sensitivity of the recording phosphor, particularly in areas of high contrast. To prevent image retention, the recording area should be "primed" periodically. The prime operation requires the recording of a constant-intensity image over the full recording area at the color-film exposure setting. This operation requires approximately 13 minutes and may be initiated using the "PRIME MODE" button on the Test and Calibration Panel (see Section III) or using the 'PR' command of the Dicomed Control Program (see Appendix A).

The specifications for NRAO's D47 Image Recorder are given in the table on the following page.

D47 IMAGE RECORDER SPECIFICATIONS

GEOMETRICS:

a. Orthogonality of the horizontal and vertical axes is better than ±0.25% of the matrix diagonal.

b. Linearity is better than ±0.35% of the major axes.

c. Pin cushion distortion is less than ±0.15% of the major axis.

d. Trapezoiding is better than ±0.30% of the major axis.

e. Rectangularity is better than ±0.30% of the major axis.

f. Spatial repeatability is better than ±0.05% of each major axis for successive images repeated during a 20-minute interval, after the unit has been warmed up.

PHOTOMETRICS:

a. A range of two decades in exposure is provided, with the contrast range for Super XX Pan 4142 being about 1.8D (diffuse density units).

b. Uniformity is better than ±0.035D.

c. Resolution is 1500 line pairs over the total picture area.

TIMING:

a. Positioning time is less than 8 microseconds.

b. Point exposure time varies between 1 and 30 microseconds.

c. Normal image generation time for the full recording area is about 8 minutes.

FILTERS:

a. Red: Wratten # 25

b. Green: Wratten # 58

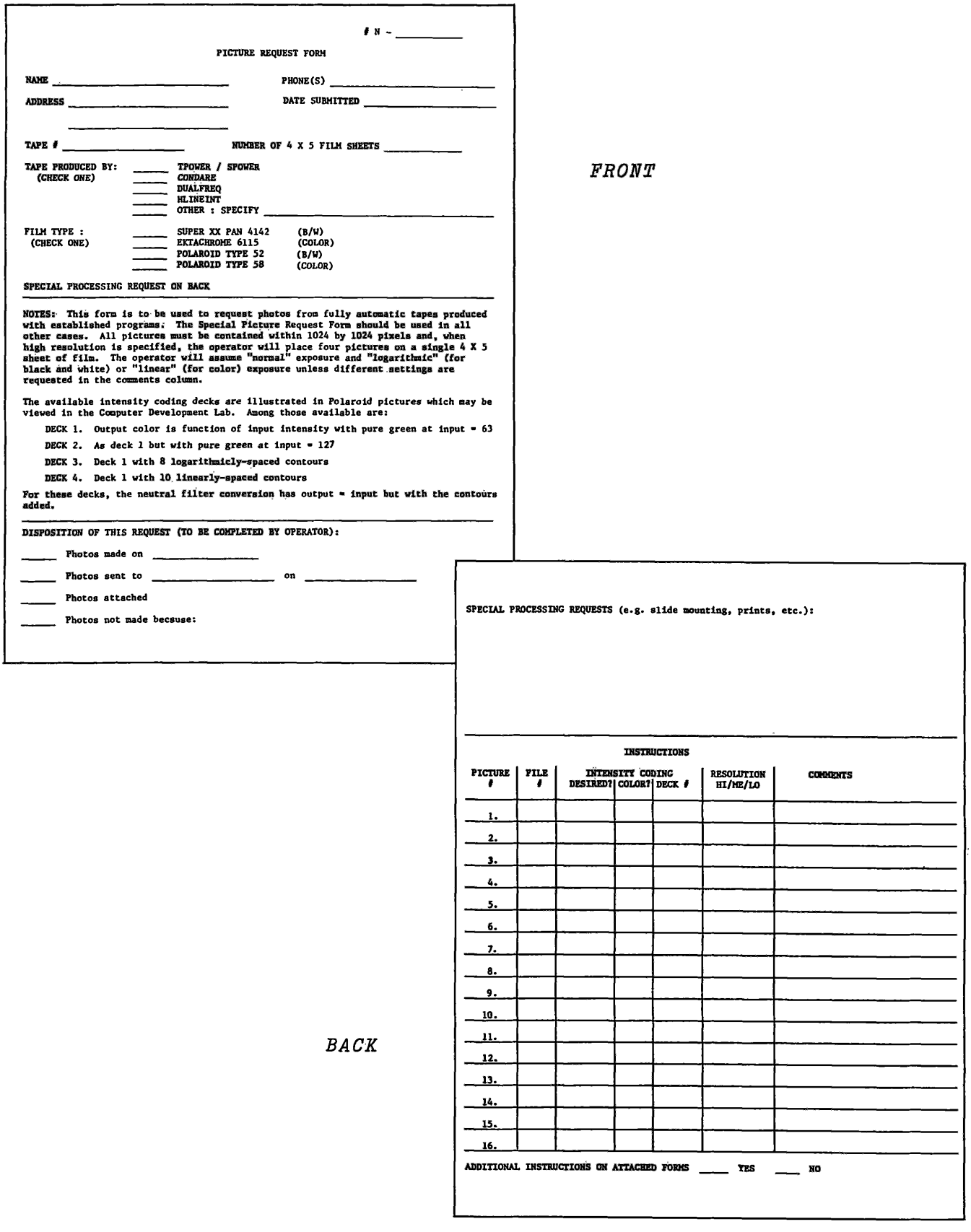
c. Blue: Wratten # 47B

III. Operating Procedures

The NRAO Image Recording System is to be used in one of two fashions. To make "permanent" pictures using high-quality films, the user must prepare a tape for the DCP, complete a "Picture Request Form", and place both in the appropriate input stacks (located in the Computer Development Lab). To make "temporary" pictures and to debug automatic-mode tapes using Polaroid films, the user may either follow the procedure for high-quality pictures or he may operate the Dicomed and the DCP himself.

For permanent pictures, the user must complete one of the picture request forms illustrated (photo-reduced) in Figure 5. The regular Request Form (Figure 5a) is to be used only with completely automatic tapes. The user then needs to supply only the desired resolutions, the intensity coding (if any), and any abnormal exposure types (e.g., complement exposure). The file number given must be the number of the command file immediately preceding the map array to be photographed. If the file number is not given, the operator will assume file 2*N-1 for picture N. If the tape is not fully automatic, the user must employ the Special Picture Request Form of Figure 5b instead. On this form, the user must list all commands which need to be given to the DCP in the manual mode,and the user must indicate when the film is to be changed. The user should also provide some comments so that the operator may judge the progress of the recording process. If the manual mode commands are complicated or extensive, the user is requested to prepare them on cards and to submit the card deck with the Special Picture Request Form. The user must submit separate request forms for each tape and film type. Picture requests submitted

Figure 5a. Picture Request Form



N - _____

PICTURE REQUEST FORM

NAME _____ PHONE(S) _____

ADDRESS _____ DATE SUBMITTED _____

_____

TAPE # _____ NUMBER OF 4 X 5 FILM SHEETS _____

TAPE PRODUCED BY: (CHECK ONE)
_____ TPOWER / SPOWER
_____ CONDARE
_____ DUALFREQ
_____ HLINEINT
_____ OTHER : SPECIFY _____

FILM TYPE : (CHECK ONE)
_____ SUPER XX PAN 4142 (B/W)
_____ EKTACHROME 6115 (COLOR)
_____ POLAROID TYPE 52 (B/W)
_____ POLAROID TYPE 58 (COLOR)

SPECIAL PROCESSING REQUEST ON BACK

NOTES: This form is to be used to request photos from fully automatic tapes produced with established programs. The Special Picture Request Form should be used in all other cases. All pictures must be contained within 1024 by 1024 pixels and, when high resolution is specified, the operator will place four pictures on a single 4 X 5 sheet of film. The operator will assume "normal" exposure and "logarithmic" (for black and white) or "linear" (for color) exposure unless different settings are requested in the comments column.

The available intensity coding decks are illustrated in Polaroid pictures which may be viewed in the Computer Development Lab. Among those available are:

DECK 1. Output color is function of input intensity with pure green at input = 63

DECK 2. As deck 1 but with pure green at input = 127

DECK 3. Deck 1 with 8 logarithmicly-spaced contours

DECK 4. Deck 1 with 10 linearly-spaced contours

For these decks, the neutral filter conversion has output = input but with the contours added.

DISPOSITION OF THIS REQUEST (TO BE COMPLETED BY OPERATOR):

_____ Photos made on _____

_____ Photos sent to _____ on _____

_____ Photos attached

_____ Photos not made becsuse:

FRONT

SPECIAL PROCESSING REQUESTS (e.g. slide mounting, prints, etc.):

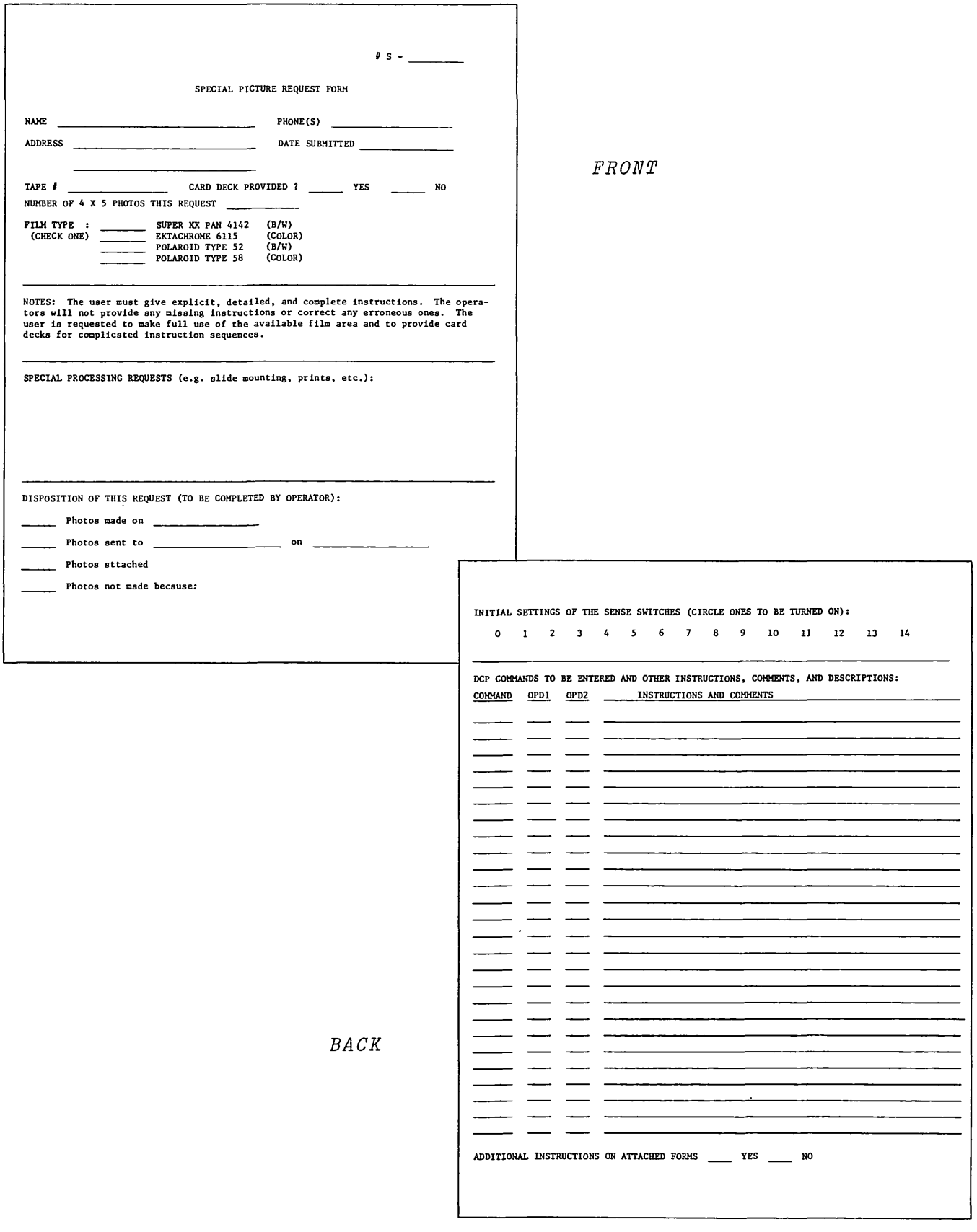
INSTRUCTIONS

PICTURE #	FILE #	INTENSITY CODING DESIRED?	COLOR?	DECK #	RESOLUTION HI/ME/LO	COMMENTS
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						
11.						
12.						
13.						
14.						
15.						
16.						

ADDITIONAL INSTRUCTIONS ON ATTACHED FORMS ____ YES ____ NO

BACK

Figure 5b. Special Picture Request Form



S - _____

SPECIAL PICTURE REQUEST FORM

NAME _____ PHONE(S) _____

ADDRESS _____ DATE SUBMITTED _____

_____

TAPE # _____ CARD DECK PROVIDED ? _____ YES _____ NO

NUMBER OF 4 X 5 PHOTOS THIS REQUEST _____

FILM TYPE : _____ SUPER XX PAN 4142 (B/W)
(CHECK ONE) _____ EKTACHROME 6115 (COLOR)
_____ POLAROID TYPE 52 (B/W)
_____ POLAROID TYPE 58 (COLOR)

NOTES: The user must give explicit, detailed, and complete instructions. The operators will not provide any missing instructions or correct any erroneous ones. The user is requested to make full use of the available film area and to provide card decks for complicated instruction sequences.

SPECIAL PROCESSING REQUESTS (e.g. slide mounting, prints, etc.):

DISPOSITION OF THIS REQUEST (TO BE COMPLETED BY OPERATOR):

_____ Photos made on _____

_____ Photos sent to _____ on _____

_____ Photos attached

_____ Photos not made because:

FRONT

INITIAL SETTINGS OF THE SENSE SWITCHES (CIRCLE ONES TO BE TURNED ON):

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

DCP COMMANDS TO BE ENTERED AND OTHER INSTRUCTIONS, COMMENTS, AND DESCRIPTIONS:

COMMAND	OPD1	OPD2	INSTRUCTIONS AND COMMENTS

ADDITIONAL INSTRUCTIONS ON ATTACHED FORMS ____ YES ____ NO

BACK

in this manner will be processed as quickly as is reasonable. Polaroid pictures should be ready within one business day, while other film types should be ready within two weeks (depending on outside film laboratories).

Users wishing to make "quick-look" Polaroid pictures may follow the instructions given below. These instructions include: how to turn on the equipment, how to prepare the Dicomed and the DCP for use, how to use the Tektronix CRT terminal, how to load and process Polaroid film, and how to turn off the equipment.

TO TURN ON THE COMPUTER:

(1) Turn on power switches (located under hinged covers at tops of racks)

   (a) One switch on the CPU (left) rack

   (b) Two switches on the disk (right) rack

   (c) Two switches on the first (left) tape rack

   (d) One switch on the second (right) tape rack - only if two tape drives are required

   (e) Power buttons on the two tape racks

(2) Turn on disks

   (a) The disk switch, a white sideways-mounted switch on the upper disk unit, must be turned to RUN.

   (b) A red light on the lower disk unit and a red and a yellow light on the upper disk unit should be on.

(3) Turn on the control terminal (TEK 4023) and, if needed, the graphics terminal (TEK 4012) and the card reader

   (a) The power switch for the TEK 4023 control terminal is located along the base on the right hand side.

   (b) The power switch for the TEK 4012 graphics terminal is located under the keyboard on the right hand side.

(c) After 10 to 15 seconds the TEK 4012 screen should become bright. Press the RESET PAGE key on the 4012 keyboard several times in order to fully erase the screen.

(d) The card reader power switch is located on the back of the unit on the right hand side.

(e) If the card stack has been exhausted, insert cards in the stacker, replace the weight, and press the green reset button.

TO TURN ON AND READY THE FILM RECORDER:

(1) The film recorder should be on at all times. If it has been turned off or set to the LOCK ON position, reset the key switch (located on the left side of the Operator's Control Panel) to the ON position.

(2) Open (let down) the Test and Calibration Panel by unscrewing the thumb screws below the Operator's Control Panel.

(3) Press the following Operator's Control Panel buttons:

(a) INPUT - 8 BIT

(b) OUTPUT - NORMAL

(c) OUTPUT - LOG

(d) RESOLUTION - HIGH

(e) FILTER - NEUTRAL

(f) CONTROL - OPERATE

(4) Prime the recorder (fairly often) using the sequence

(a) Turn on the HIGH VOLTAGE switch at the left hand edge of the Test and Calibration Panel.

(b) Set the EXPOSURE potentiometer located on the Operator's Control Panel to 5.5.

(c) Press the PRIME MODE button located on the Test and Calibration Panel.

(d) Press the TEST button located on the Operator's Control Panel.

(e) Go for a leisurely coffee break (about 13 minutes).

(f) When the RECORD light stops blinking, press the PRIME MODE button to restore normal operation.

(g) The recorder should be primed at least once per day. It must be primed whenever black and white film is to be exposed after color film has been exposed.

(5) Calibrate the recorder carefully following the sequence

(a) Turn off the HIGH VOLTAGE switch located on the Test and Calibration Panel. ***** IF THIS STEP IS OMITTED, THE DICOMED CRT COULD BE BURNED OUT. *****

(b) Set the EXPOSURE potentiometer located on the Operators Control Panel to 1.0 (8.88 for color).

(c) Press the EXPOSURE CALIBRATION button on the Test and Calibration Panel. The light should turn on after a brief pause.

(d) Adjust the EXPOSURE TRIM potentiometer located on the Test and Calibration Panel until the digital readout is +.130 (+1.250 for color).

(e) Press the EXPOSURE CALIBRATION button to turn off the light and the calibration mode.

(f) Turn the HIGH VOLTAGE switch on.

(g) Turn the Dicomed POWER key to LOCK ON.

(h) The calibration will remain stable only if the Dicomed has warmed up for at least 20 minutes.

TO READY THE DICOMED CONTROL PROGRAM:

(1) Restart the Modcomp operating system using the sequence

(a) Set all rocker switches on the CPU rack to the off position (upper half depressed).

(b) Set Sense Switch 15 on - the Sense Switches are the upper row of numbered rocker switches on the CPU rack.

(c) Press: MASTER CLEAR

(d) Press: FILL

(e) Press: RUN

(f) The message "SAL @ 7872 CSW=BIAS" should appear on the terminal.

(g) Type on the terminal: M02 and press RETURN. The message "SATISFIED" should appear.

(h) Type on the terminal: GO and press RETURN. The message ":MAX-II-REVI-DICOMED-7-6-75
II/B /" should appear.

(i) Within 10 seconds type: /R and press RETURN. The computer should respond by changing the / to an X.

(2) Start the DCP using

(a) Type: $JOB

(b) Type: $DO DCP

(c) The message "DCP ACTIVE" should appear on the screen.

(d) If tape unit MT2 is to be used instead of the default unit MT1, replace step (b) with type: $DO DCP,MT2

(3) Mount the command and data tape on the tape unit labeled MT1 (or on MT2 if it was specified above).

(a) Follow the tape mounting diagram found at the lower left corner of the tape unit.

(b) Turn the take-up reel clockwise a few turns to make sure that the tape is securely mounted.

(c) Press the LOAD switch on the right hand side of the tape unit. The tape should advance to the load point, and the LOAD and ON LINE buttons should light up.

TO USE THE TERMINAL:

(1) Commands are prepared in the terminal input buffer by typing on the keyboard. A blinking cursor shows the current position in the buffer. The characters that have been typed are shown on the screen. Commands can be no longer than one line (72 characters).

(2) The contents of the buffer are sent to the computer by pressing the RETURN key. After the buffer has been transmitted, the buffer is cleared, and the cursor is reset to column one of the next line.

(3) To clear the buffer and do the carriage-return/line-feed without transmitting the buffer contents to the computer, press the RUB OUT key. This key allows bad typing errors to be kept from the computer.

(4) To correct minor typing errors, press the BACK SPACE key as many times as is needed. The cursor will move to the left to show the curent position in the buffer. Although the previously-typed characters will remain on the screen, all

characters to the right of the cursor will have been eliminated from the buffer.

(5) The user is reminded that the system commands listed above and the DCP commands described in Section IV have fixed formats. They must be typed beginning in the left-most column on the screen (column 1).

(6) To erase the screen of the graphics terminal (TEK 4012), press the RESET PAGE button. When leaving the terminal for any length of time, please press this button several times to fully erase, and thus prevent further damage to, the TEK 4012.

(7) When the screen on the command terminal is full, new lines will appear at the bottom of the screen pushing older lines off the screen at the top. If the PAGE-FULL control switch (located on the keyboard above the normal keys) is enabled, processing will cease when the screen is full until the PAGE ERASE INPUT button is pressed.

(8) To release a pause condition, such as those generated by the DCP, the user must depress the console interrupt switch and then promptly type /R . This switch is located on the keyboard above the normal keys. An alternate console interrupt switch may be found on the CPU unit. The console interrupt switch will generate the message "II/B /", and the computer will respond to the /R command by changing the / to an X.

TO LOAD AND RELOAD POLAROID FILM:

(1) The Polaroid film holder (shown in Figure 6) will usually be mounted on the Dicomed. If it is not, insert the holder by

   (a) Lifting the right hand (as one faces the recorder) edge of the ground glass assembly (located at the top of the recorder) and

   (b) Sliding the film holder in as far as it will go.

   (c) The film holder goes beneath the ground glass screen with the control arm and printed directions facing up.

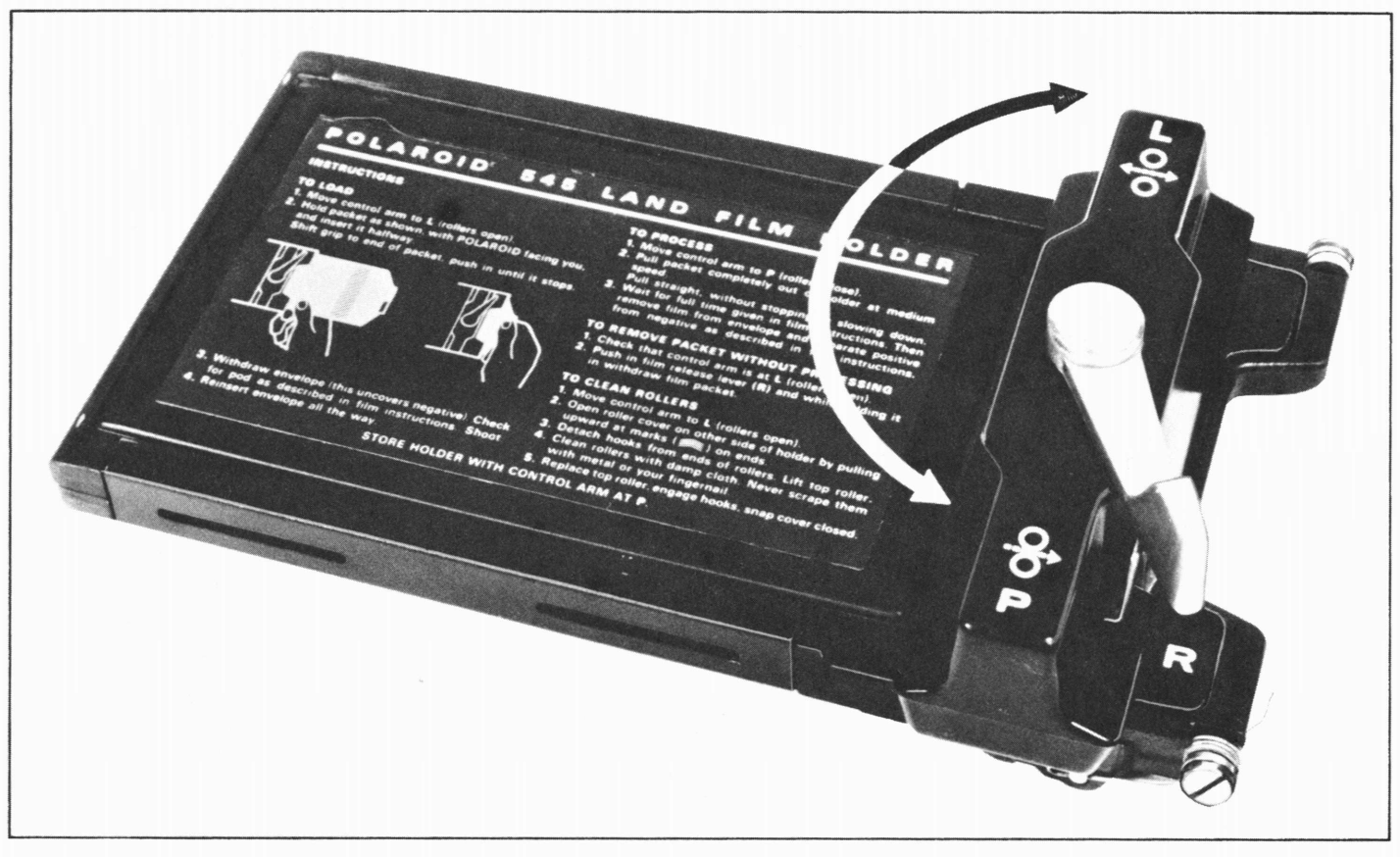
   (d) Slide the side locks to the right to firmly hold the film holder and to prevent light leaks.

(2) To load film

   (a) Move the film holder control arm to the load (L) position.

   (b) Insert one film packet in the holder slot with the indicated side up. Do not press on the developer pad or bend the film packet. Insertion is complete when the metal edge at the inserted end of the film clicks into place.

Figure 6. Polaroid film holder



(c) Pull out the paper envelope by the tabs until it comes to a firm stop. The film is now uncovered.

(d) Set the EXPOSURE potentiometer on the Operator's Control Panel to the desired value.

(e) Expose the film, as desired, using the DCP.

(3) After exposing the film

(a) Push paper envelope all the way back in.

(b) Move the control arm on the holder to the process (P) position.

(c) Pull the film packet from the holder using a smooth, moderately rapid motion.

(d) Open the packet after allowing the film to develop for the times given below. Do not allow the film to develop for too little or too much time.

(e) Move the control arm on the holder to the load (L) position.

(4) The available types of Polaroid film are

(a) Type 52: black and white positive film in green colored boxes and film packets. Develop for 15 seconds, and use the fixer wipe. Nominal exposure setting is 0.85.

(b) Type 58: color positive film in red colored boxes and film packets. Develop for 65 seconds, and do not use fixer. Nominal exposure setting is 8.88.

TO TURN OFF THE IMAGE PROCESSING SYSTEM:

(1) Press the RESET PAGE key on the TEK 4012 several times.

(2) Turn off the HIGH VOLTAGE switch on the Test and Calibration Panel, but leave the rest of the film recorder turned on. The recorder POWER key should be left in the LOCK ON position.

(3) Turn off the card reader.

(4) Turn off the TEK 4023 and TEK 4012 terminals.

(5) Turn off the computer power switches:
(a) One on left-most tape unit
(b) Two on right-hand tape unit
(c) Two on disk rack
(d) One on CPU rack.

IV. The Control Program

The Dicomed Color Image Recorder is operated with a computer program, called the Dicomed Control Program ("DCP"), which runs in a Modcomp IV/MAX III minicomputer connected to the Dicomed. The DCP was written by the authors, Stephen J. Hirsch, and David Ehnebuske. The command language of the DCP allows the user to operate all controls on the Dicomed Operator's Control Panel, to arrange the positioning of the input data tape, to place lines and textual material on the photograph, and to place images of map arrays on the photograph either directly or with alterations determined by the "intensity coding tables". The DCP accepts commands from a terminal or a card reader ("manual mode") or from a magnetic tape ("automatic mode"). The map arrays to be photographed are always read from the tape. A number of control options may be entered during execution of the DCP using the 16 Sense Switches located on the control panel of the Modcomp. The command vocabulary and the control options are described briefly below and in considerable detail in Appendix A.

DCP commands consist of a 51-character record containing four fields and having format:

column	format	parameter
1-2	A2	command mnemonic
4-7	I4	first numeric operand ("OPD1")
8-11	I4	second numeric operand ("QPD2")
12-51	20A2	alphameric operand ("QPD3")

All commands are composed of two alphabetic characters. The numeric operands must be right justified in their respective fields, and the alphameric operand must be left justified in its field. The only exceptions to this format are the 'PT' and 'TI' parameter commands described in Appendix A. For operation in the automatic mode, command records for a particular map appear in a separate tape file which

immediately precedes the associated data file. The map data occupy one file per map on the tape. The map values are unsigned integers having values from 0 through 255 and occupy one byte each. The map values appear in the order in which column number increases more rapidly. Each map row is a separate record on the tape.

The list of commands together with the significant operands is given in the table on pages 24 and 25. When OPD3 is not a significant operand, it may be used to display comments on the terminal. Some of the commands correspond directly to the manual operating controls on the Dicomed console. However, since the DCP will function properly only if it "knows" what control options are in effect, the user manipulates the manual controls at his own risk. The DCP commands are explained in considerable detail in Appendix A. The DCP executes a 'CL' command when it begins execution.

The Dicomed recorder area is arranged in an X-Y coordinate system, where $0 \leq X,Y \leq 4095$ points,and where X increases to the right,and Y increases down the recorder area. The user may specify any point on the recorder area as a coordinate origin using the 'OR' command. All positioning commands ('PO', 'PP', 'VE') will then be relative to the specified coordinate origin.

All input numbers (OPD1 and OPD2) are in units of pixels rather than points. This property allows a single set of commands to be photographed in all resolutions,if the commands respect the low resolution limits on the number of pixels. All commands except 'FC' and 'PI' and, when necessary, 'TE' and 'VT' are executed in high resolution. Input operands are scaled to the currently specified

resolution. All commands leave the current recorder position in points unchanged, except for those commands ('OR', 'PO', 'PP', 'VE') directly designed to alter that position. Thus, the resolution commands ('HI', 'ME', 'LO') alter the coordinate origin and the current recorder position as measured in pixels.

The only commands to alter which filter is in the light path are those ('NF', 'RF', 'GF', 'BF') directly designed to do so. During execution of the 'FC' and 'FS' commands the filter is changed, but the original filter is restored before the next command is read. The 'FC' and 'FS' commands are executed using linear exposure with the specified exposure (logarithmic or linear) restored before the next command is read. Inverse (complement) exposure, when specified, is used only during execution of the 'FC', 'PI', 'FS', and 'SC' commands.

The user may chose to alter the input intensity levels with the DCP before they are photographed. The alteration is carried out with "intensity coding tables" for such purposes as representing intensity with color and showing contour lines. The tables are used as follows: if the input map or scale intensity is I(X,Y) and the current filter is F, the output (photographed) intensity is

$$P(X,Y) = T(I(X,Y) , F)$$

where T(intensity, filter) is the intensity coding table. The 'FC' and 'FS' commands cause a single map or intensity scale to be photographed in three colors (blue, green, red) using the appropriate parts of the coding tables. The 'PI' and 'SC' commands cause a single map or intensity scale to be photographed using the current filter. When the intensity coding flag is unequal to zero, the input intensities

DCP COMMANDS

COMMAND	OPD1	OPD2	OPD3	FUNCTION
AD				ADvance film
AU				enter AUtomatic mode
BF				insert Blue Filter
BR				draw lines around map area (BordeR)
CC	aaaa			set intensity Coding flag
CL				initialize (CLear)
CM	aaaa			enter CoMmand
CO	aaaa	cccc	eee...	display COmment
CR	aaaa	cccc		add CcntouRs to coding tables
CT	aaaa	cccc		Change coding Table (sequence command)
CT	aaaa	cccc		Change coding Table (parameter command)
EX				stop DCP execution (EXit).
FC	aaaa			photograph map in False Colors
FS	aaaa	cccc		photograph intensity Scale in False colcrs
GF				insert Green Filter
GR				GRaph coding table on graphics terminal
HI				scale operands to HIgh resolution
HL	aaaa			draw Horizontal Line
HS	aaaa	cccc		plot HiStogram of map values
IN				use INverse (complement) exposure
IV	aaaa	cccc		set point-plot size and Intensity Values
LG				switch to LoGarithmic exposure
LI				switch to LInear exposure
LO				scale operands to LOw resolution
MA	aaaa			enter MAnual mode
ME				scale operands to MEdium resolution

COMMAND	OPD1	OPD2	OPD3	FUNCTION
NF				insert Neutral Filter
NO				use NOrmal exposure
OR	aaaa	cccc		set coordinate ORigin
PA				PAuse
PI	aaaa			photograph map in single color (PIx)
PO	aaaa	cccc		move recorder POsition
PP	aaaa	cccc		Photograph Point at specified position
PR				PRime the recorder
PT	aaaa	cccc		Polyncmial Table (sequence command)
PT	xxxxyyyyaaaaaaaabbbbbbbbccccccccddddddddeeeeeeee			Polyncmial Table (parameter command)
RC				Read Cards having intensity coding tables
RF				insert Red Filter
RW	aaaa			ReWind tape
SC	aaaa	cccc		photograph intensity SCale in one color
SI	aaaa	cccc		set map SIze
SK	aaaa			forward SKip tape
ST				print STatus
TE	aaaa	cccc	eee...	photograph TExt
TI				photograph TIck marks and axis labels (sequence command)
TI	aaaa bbbb ccc dddd eeeffffffffffffgggggggggggg			TIck mark parameter command
VE	aaaa	cccc		photograph bright VEctor
VL	aaaa			photograph Vertical Line
VT	aaaa	cccc	eee...	photograph Vertical Text
ZR	aaaa			photograph ZeRo input intensities ?

SENSE SWITCH COMMANDS

SWITCH	IF ON THEN
0	Enter the manual mode when the current command is completed or when the current pause is released
1	Pause before executing each command
2	Suppress normal output to the terminal
3	Remain in automatic mode when error conditions not connected with 'PI' or 'FC' commands are detected
4	Pause before executing 'PI' and 'FC' commands
5	Pause after executing 'PI' and 'FC' commands in the automatic mode
6	Execute an 'FC' command on an input 'PI' command and execute an 'FS' command on an input 'SC' command
7	Execute automatic film advance on an input 'AD' command
8	Execute an 'HS' command before 'PI' and 'FC' comands
9	Ignore 'SC' and 'FS' commands
10	Ignore 'TI' and 'BR' commands
11	Ignore 'TE' and 'VT' commands
12	Reserved
13	Unused
14	Unused
15	Reserved

are converted using the appropriate part of the intensity coding tables before being photographed. To enter the code tables in the DCP, a deck of 64 cards (16 for each color) may be used in the format (16I4). The command 'RC' causes the DCP to read the card deck in the color order red, blue, green, and neutral. The coding tables may also be entered in the form of a set of linear functions using the 'CT' command, or as a set of polynomials using the 'PT' command. "Contour lines" may be added using the 'CR' command.

The Sense Switches on the control panel of the Modcomp may be used to input additional control information to the DCP. The toggle switches are "on" when the lower half is depressed. The controls represented by the Sense Switches are listed in the table on page 26. If switch 7 is off, an 'AD' command will cause the DCP to enter the manual mode. To resume execution after a pause, press the console interrupt switch on the terminal and type /R.

The Sense Switches are designed to make the use of tapes containing automatic command files more flexible. For example, if commands are to be inserted in a command sequence, the user may execute the commands in the file one at a time with switch 1 on. When the desired insertion point is reached, the user turns switch 0 on and switch 1 off before releasing the pause. The DCP will then enter the manual mode, allowing the user to insert the desired commands. The DCP normally writes a copy of each input command on the terminal screen. Sense Switch 2 suppresses this "normal" output (which often fills the screen many times over), but allows the writing of comment commands, error messages, and other "abnormal" messages. Sense Switch 3 allows the user to bypass commands containing errors. Sense Switch 4 causes

the DCP to pause before photographing a map to allow the user to enter the intensity coding tables and flag. Sense Switch 5 causes the DCP to pause after photographing a map to allow the user to change film before proceding. Sense Switch 7, together with the use of the 'AD' command at the start of command files, performs a similar function, but allows for completely automatic processing when an automatic roll film device is installed and allows for the automatic use of several 'PI' or 'FC' commands per photograph. Sense Switch 6 allows for the production of three-color photographs from automatic tapes normally used with 'PI' and 'SC' commands to produce gray-scale photographs. Sense Switch 8 allows the user to obtain histograms of the map data on automatic tapes containing 'PI' and 'FC' commands. Sense Switches 9, 10, and 11 may be used to suppress most of the "extraneous" writing surrounding the photograph of a map.

V. Preparing Data Tapes

Most of the standard data-reduction program packages of the NRAO have the capability of producing tapes for the Dicomed. This section will be of interest mostly to those programmers wishing to develop their own tape-producing programs. There are a few essentially fixed requirements for the tapes to be read by the DCP. These are:

(1) The tapes must <u>not</u> be labeled.

(2) The tapes are nine-track, 800 bits per inch.

(3) All command records are 51 bytes in length and are coded in no-parity ASCII code.

(4) The file containing command records for a particular map must immediately precede the file containing the map.

(5) Two command files may be consecutive, but the last command of the first of the two must be an 'SK' command in order to enter the second file.

(6) Each record of the data file represents a single row of the data array.

(7) Each data value is an unsigned integer between 0 and 255 and occupies <u>one</u> byte.

Thus, the tape will, normally, consist of alternating command and data files beginning with a command file.

The production of tapes for the Dicomed requires considerable amounts of CPU time. Thus, the tapes should contain as flexible a set of commands as possible. There are a number of programming practices which the authors have found to be very useful. These practices are intended to allow the data tapes to be processed on the Dicomed in a completely automatic fashion without intervention by the user, but to provide the user, should he so desire, as much flexibility as possible in processing the tapes. Included in the recommended set of practices are:

(1) The tape-writing program should assume that the tape will be run at low resolution, and hence keep all operand values and the arrays within the low resolution limits ($0 \leq X,Y \leq 1023$ pixels). In this fashion, the tape may be used in low or medium resolution with Polaroid film and in high resolution with 35-mm film.

(2) Start the first command file with the commands 'CL' and 'MA'. The clear command resets many parameters (particularly the origin, resolution, and false color flag) to their default values. The DCP does a 'CL' command when it begins execution. However, the programmer should not depend on this action since the tape may not be the first tape used after the DCP begins execution. The 'MA' command returns the DCP to the manual mode to allow the user to change the types of exposure, the resolution, the coordinate origin, the false color coding flag, and the filter from the default values. The cessation of automatic functions is a good reminder to load the film as well.

(3) Start remaining command files with an 'AD' command. In completely automatic operation with Sense Switch 7 on and the roll film device mounted, this command will cause the film to advance and thus will allow the automatic processing to continue. In more closely controlled operation with sense switch 7 off, this command is equivalent to an 'MA' command to remind the user to change film and to allow him to alter his choice of parameters.

(4) The programmer should employ the 'BR', 'TI', 'TE', 'VT', 'SC', and 'FS' commands wherever such actions are desired, rather than using some combination of 'PO', 'HL', and 'VL' commands to generate tick marks and 'PI' and 'FC' commands to generate the intensity scales. In this way the user may employ the Sense Switches to suppress all or part of the labeling of his array data.

(5) The programmer should never place an 'OR' command on the tapes. An origin given before the user specifies the desired resolution may not be appropriate to the desired resolution. An origin set after the user returns the processing to the automatic mode will not allow the user to offset the positioning of the photograph.

(6) Similarly the programmer should not use the resolution commands. Of course, if the size of the data array(s) to be photographed is such that only high resolution will work properly, then the programmer should use an 'HI' command immediately after the 'MA' and 'AD' commands.

(7) The programmer should use the 'PI' and 'SC' commands, rather than the 'FC' and 'FS' commands. The user may easily switch 'PI' to 'FC' and 'SC' to 'FS' with Sense Switch 6. The use of the 'CC' command is also not recommended.

(8) In planning the arrangement of the textual material, the map array(s), and the axis labeling, the programmer should leave some blank space (e.g., 32 pixels) around the whole picture area. The blank space gives a pleasing appearance to the photographs and, in the case of Polaroid film, is necessary since the film is smaller in the Y-direction than the Dicomed recording area.

(9) The programmer should avoid the photographing of zero intensities or blank characters as much as is reasonable. A zero intensity causes the film to be exposed to near or just beyond its threshold. Thus, a "zero"-intensity exposure may just be visible on the film, while two such exposures of the same area of the film will certainly be visible. This characteristic may now be altered using the 'ZR' command.

To write a tape for the Dicomed requires programming which is both efficient and foreign to the standard IBM practices. Problems occur in trying to write multi-file unformatted tapes containing both binary and ASCII records. For the PLI and FORTRAN programmers wishing to write their own programs, we have provided subroutines which overcome these problems. For the typical user, we have provided a general purpose program which writes tapes for the Dicomed. The program is called "INTERFACE" and is described in Appendix B. The special purpose subroutines are described below.

FOR PLI USERS:

Declarations statements required

```
DCL TEXT CHAR (51) ;
DCL DATA CHAR (1024) VARYING ;
DCL (ARRAY(1024)) BIN FIXED (31) VARYING;
DCL IVALUE BIN FIXED(15), HALFWORD CHAR(2) DEF IVALUE ;
DCL (NBYTES, NPOINTS) BIN FIXED (15). ;
```

Subroutines

The following routines are provided to write multi-file tapes containing both binary and character records:

routine	arguments	description
TOPEN	none	opens tape data set; must be called once at the beginning of the job
TWRITE	STRING,NBYTES	writes a varying length string to magnetic tape
TEOF	none	writes an end-of-file mark to denote the end of a file
TCLOSE	none	closes tape data set; must be called at the end of the job
EBCDIC	STRING,NBYTES	converts a character string from EBCDIC to ASCII

Command and data records are formatted and written by the following PLI constructions:

Commands:

```
NBYTES = 51;
PUT STRING(TEXT) EDIT ('PI', NPOINTS)
                      (A(2),X(1),F(4),F(4),A(40));
CALL EBCDIC(TEXT,NBYTES);
CALL TWRITE(TEXT,NBYTES);
```

Data:

```
DO N=1 TO NPOINTS;
   IVALUE = ARRAY(N) ;
   SUBSTR(DATA,N)=SUBSTR(HALFWORD,2,1);
   END;
CALL TWRITE (DATA,NPOINTS);
```

Job control statements required

```
//GO.TAPE DD UNIT=TAPE,VOL=SER=nnnn,LABEL=(j,NL),DISP=NEW,
//           DCB=(RECFM=U,LRECL=1024,BLKSIZE=1024,DEN=2,BUFNO=1)
```

No JCL is required to include these special routines, since they reside in the PLI automatic call library SYS2.PLIOBJ.

FOR FORTRAN USERS:

Specification statements required

```
INTEGER*2  COM,  ARRAY(1)
INTEGER*4  OPD1,  OPD2,  NCHAR,  NDEC,  NBYTES,  NVALS,  IVALUE
REAL*4 ·   VALUE
LOGICAL*1  STRING(1),  OPD3(40),  ALIST(1)
```

Call sequences

The DCP requires tapes containing many files, while the standard IBM practice is to use only one or two files. There is a module called TWRITE to allow the user to write records and end-of-file marks on multi-file tapes without all of the JCL cards normally required by IBM. The call sequences are:

```
CALL TOPEN    : must be done once at start of job

CALL TCLOSE   : must be done once at end of job

CALL TWRITE(STRING,NBYTES)    : to write STRING containing NBYTES
                bytes on tape

CALL TEOF     : to write end-of-file mark on tape
```

The DCP requires the processing of very large arrays which is very costly in CPU time on the IBM 360. There are two modules called CLEAR and CRUSH to allow the user to zero the array and to convert it to DCP (1-byte) format. These routines are written in Assembly Language and are quite efficient. The call sequences are:

```
CALL CLEAR(STRING,NBYTES)     : to zero NBYTES bytes of STRING

CALL CRUSH(ARRAY,NVALS)       : to convert ARRAY of NVALS half-
                word integers to 1-byte unsigned integers
                truncating values < 0 or > 255
```

The DCP requires commands to be properly formatted in ASCII character code. To assist the FORTRAN user to write proper commands on his tape, the modules COMAND, EBCDIC, and FORMAT are available. The call sequences are:

```
CALL COMAND(COM,OPD1,OPD2,OPD3))   : to write on tape a DCP
              command record for command COM with operands OPD1,
              OPD2, and OPD3.  Note that OPD3 is ignored except
              for 'TE', 'VT', and 'CO' commands; that for 'CO'
              commands,OPD2 must be the number of characters in
              OPD3, and that COM is the command mnemonic in
              EBCDIC characters.

CALL EBCDIC(STRING,NCHAR)    : to convert NCHAR characters of
              STRING from EBCDIC to ASCII

CALL IFORMT(STRING,IVALUE,NCHAR)   :
CALL FFORMT(STRING,VALUE,NCHAR,NDEC)   :
CALL EFORMT(STRING,VALUE,NCHAR,NDEC)   :
CALL AFORMT(STRING,ALIST,NCHAR)    :
CALL XFORMT(STRING,IVALUE,NCHAR)   :
              to convert a value to NCHAR EBCDIC characters at
              STRING in the specified (integer, floating point,
              exponential, alphameric, and hexadecimal,
              respectively) format
```

Job control statements required

```
//LKED.MODS  DD  DSN=GREISEN.MODS,DISP=SHR
//LKED.SYSIN DD  *
        INCLUDE  MODS(TWRITE)
        INCLUDE  MODS(CLEAR)
        INCLUDE  MODS(CRUSH)
        INCLUDE  MODS(COMAND)
        INCLUDE  MODS(EBCDIC)
        INCLUDE  MODS(FORMAT)
        INCLUDE  MODS(EFORMT)
//GO.DICOMED DD  UNIT=TAPE,VOI=SER=nnnn,LABEL=(j,NL),DISP=NEW,
//         DCB=(RECFM=U,LRECL=1024,BLKSIZE=1024,DEN=2,BUFNO=1)
```

VI. The Photographic Process and the Image Recorder

To operate the NRAO Image Recording System, the user is not required to know the material contained in this section. However, if the user is to obtain the best possible results, he should understand the nature of the photographic process.

Unexposed film consists of a large number of silver halide crystals suspended in an emulsion. When the crystals are exposed to light, a latent image, invisible to the eye, is formed. The development process converts those silver halide crystals which were exposed to light into black silver grains. The resulting density of silver grains is a function of the type of film, the exposure, and the development process. For a given film type and development process, one may plot the film density, D, as a function of the exposure, E. Such plots are called H-D curves, and a typical one is shown in Figure 7. There are three principal regions in all such curves. The "toe" (labeled A) and the "knee" (labeled C) are the regions in which the film density is only weakly dependent on the exposure. The toe is "under-exposed", and the knee is "over-exposed". Photographic film is normally useful only in the "straight-line" (labeled B) region. There the film density increases linearly with the logarithm of the exposure.

The Dicomed Image Recorder was designed with the H-D curve in mind. The minimum recorder exposure lasts 1 microsecond, while the maximum exposure lasts 30 microseconds. Thus, for 0 input intensity, the recorder exposes the film to its threshold (i.e., nearly into the straight-line region). As a result, low non-zero input intensities will not be entirely lost, since they will produce detectable changes

Figure 7. A typical H-D curve

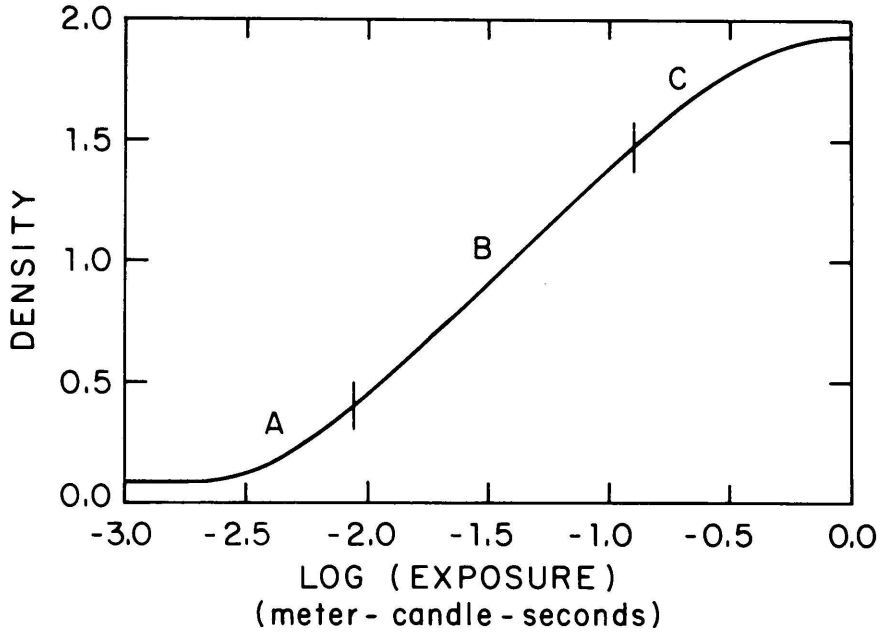
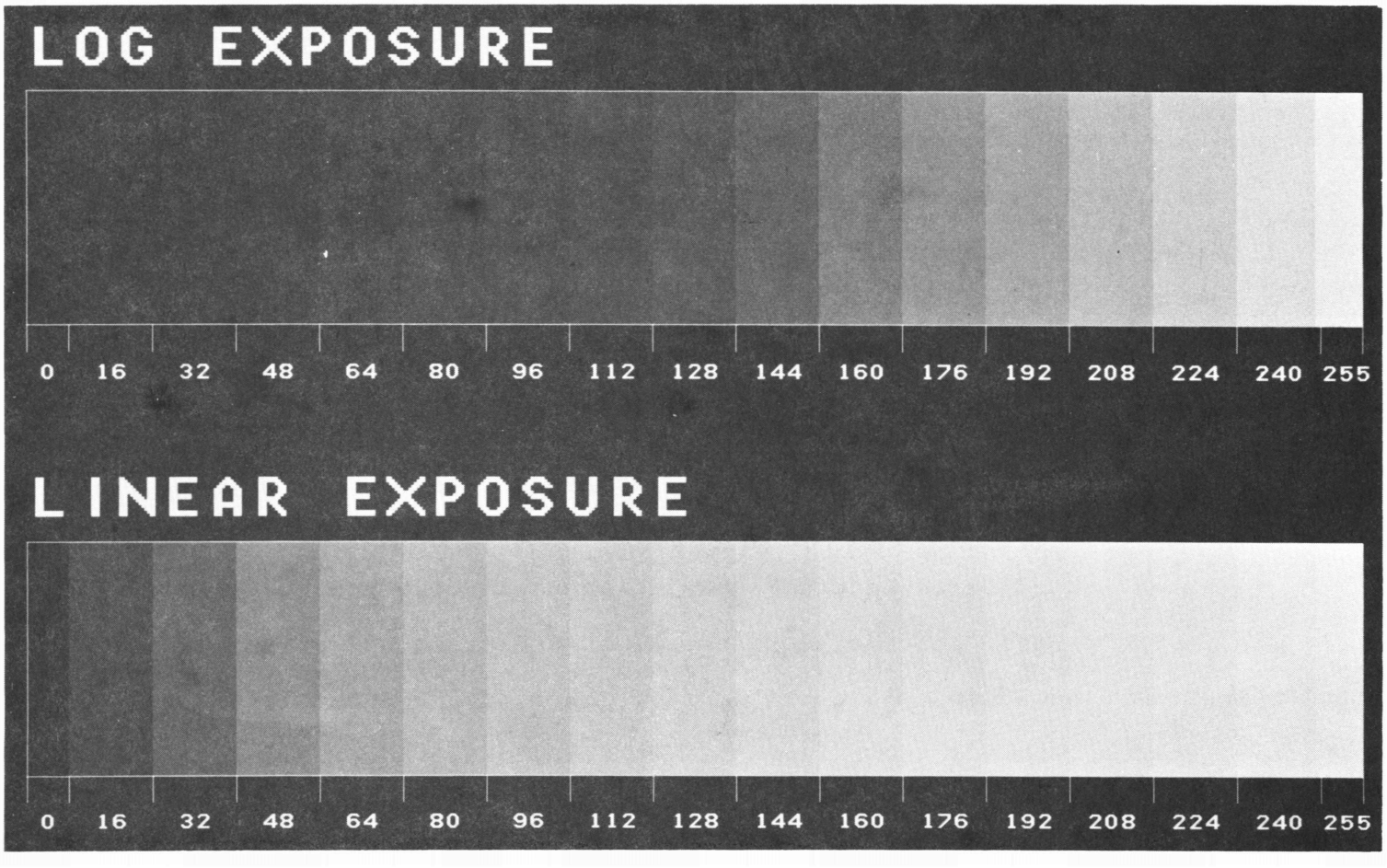


Figure 8. LINEAR and LOG mode exposures at several input intensities



in film density. Higher input intensities are photographed in the straight-line region, although the highest intensities may reach into the knee region. The user should scale his data with the H-D curve in mind. If most of the map is at very low intensity or very high intensity, information will be lost. Since the eye is most sensitive to changes in intensity at the low to moderate densities, the user should match the most interesting data levels to the middle intensity range. The histogram command (HS) and the intensity coding tables of the DCP are very helpful in this regard. Using the 'SC' command of the DCP, the user may photograph, along with his maps, the response of the film as a function of input intensity. Using the 'ZR' command of the DCP, the user may cause zero input intensity to receive zero exposure.

The Image Recorder has two exposure modes, illustrated in Figure 8. In the "LINEAR" mode the film exposure is proportional to the input intensities I. Thus, the film density is proportional to the logarithm of I. In the "LOG" mode the film exposure is proportional to 10**I (the anti-logarithm of I). Thus, in this mode, the film density is proportional to I. Another film parameter, the transmittance T, is proportional to the anti-logarithm of the density. Then, in the LINEAR mode, T is proportional to I and, in the LOG mode, T is proportional to the anti-logarithm of I. It is the film density to which the human eye responds.

The addition of color information to photographs causes considerable complications. As a result, there is a wide variety of materials and processes in color photography. The following discussion will concentrate on Ektachrome film, but, except for some details, will apply to most of the commonly used color films.

Ektachrome film consists of five distinct layers. The top layer is a blue-sensitive emulsion containing a yellow dye. The second layer is a blue-absorbing (yellow) filter which prevents blue light from reaching successive layers. The third layer is a green-sensitive emulsion containing a magenta dye, and the fourth layer is a red-sensitive emulsion containing a cyan dye. The final layer is a transparent backing to support the emulsions. Before the development process, the dyes are in the form of colorless "coupler" chemicals, which are immobilized and protected from the other ingredients of the photographic emulsions by being suspended in oily globules of organic material.

The first step in the development process is a normal (black and white) development which converts the latent images in each emulsion to black silver grains. Then, the film is uniformly exposed to white light producing latent positive images in each emulsion. A color developer is then used to convert the latent positive images to black silver grains and to release the dyes at the locations of the newly-developed silver grains. The final step is a bleaching of both the yellow filter layer and the silver grains (both positive and negative images) to leave positive images in the cyan, magenta, and yellow dyes.

These dyes are in colors which are complementary to those (red, green, and blue, resp.) which the human eye uses to synthesize color. Cyan dye absorbs red light, magenta dye absorbs green light, and yellow dye absorbs blue light. To explain how this "color subtraction" process, used by Ektachrome film, works, let us describe what happens

in the red emulsion. The negative image contains developed silver grains in proportion to the amount of red light received from the various parts of the photographed object. It contains the most grains where the object was the reddest. The positive image consists of all the silver grains in the emulsion which were not part of the negative image. Thus, the positive image contains the most silver grains and, hence, the most cyan dye, where the object was the least red. After the silver grains have been bleached or removed, only the cyan dye remains. Then, when white light is projected through the emulsion, the transmittance to the red portions of the light is highest where there is the least cyan dye (i.e., where the photographed object was the reddest). Similarly, the magenta dye absorbs green light where the object was not green, and the yellow dye absorbs blue light where the object was not blue.

The Dicomed Color Image Recorder also uses a three-color procedure for generating color photographs. Images of varying intensities are generated on the CRT screen in essentially white light. This light then passes through a color filter before registering on color film. By sequentially generating three different images on the CRT screen, one for each filter, a photograph containing a wide range of color may be generated. The filters pass red, green, and blue light, with spectral distributions matched to the response of Ektachrome film. The total intensities of the image points are determined by the sums of the three exposure times. If image points having the same sum of input intensities are to have the same photographed total intensity independent of color, then the exposure times must be linearly proportional to the input intensities. As described above, the image recorder has the LINEAR exposure mode for this purpose.

The three-color synthesis techniques described above provide adequate color recording, because the human eye-brain combination also uses an essentially three-color synthesis procedure. Any color can be matched by a sum of red, green, and blue colors, although two normal people may require slightly different amounts of the three primaries to produce a match. Adopting some "standard person", we may describe any color by its "tristimulus values": i.e., by the red intensity X, green intensity Y, and blue intensity Z required to match the color and its intensity. It is traditional to represent colors on a chromaticity diagram, such as that shown in Figure 9. The coordinates of this diagram represent color and are given by

$$x = X / (X + Y + Z)$$

$$y = Y / (X + Y + Z)$$

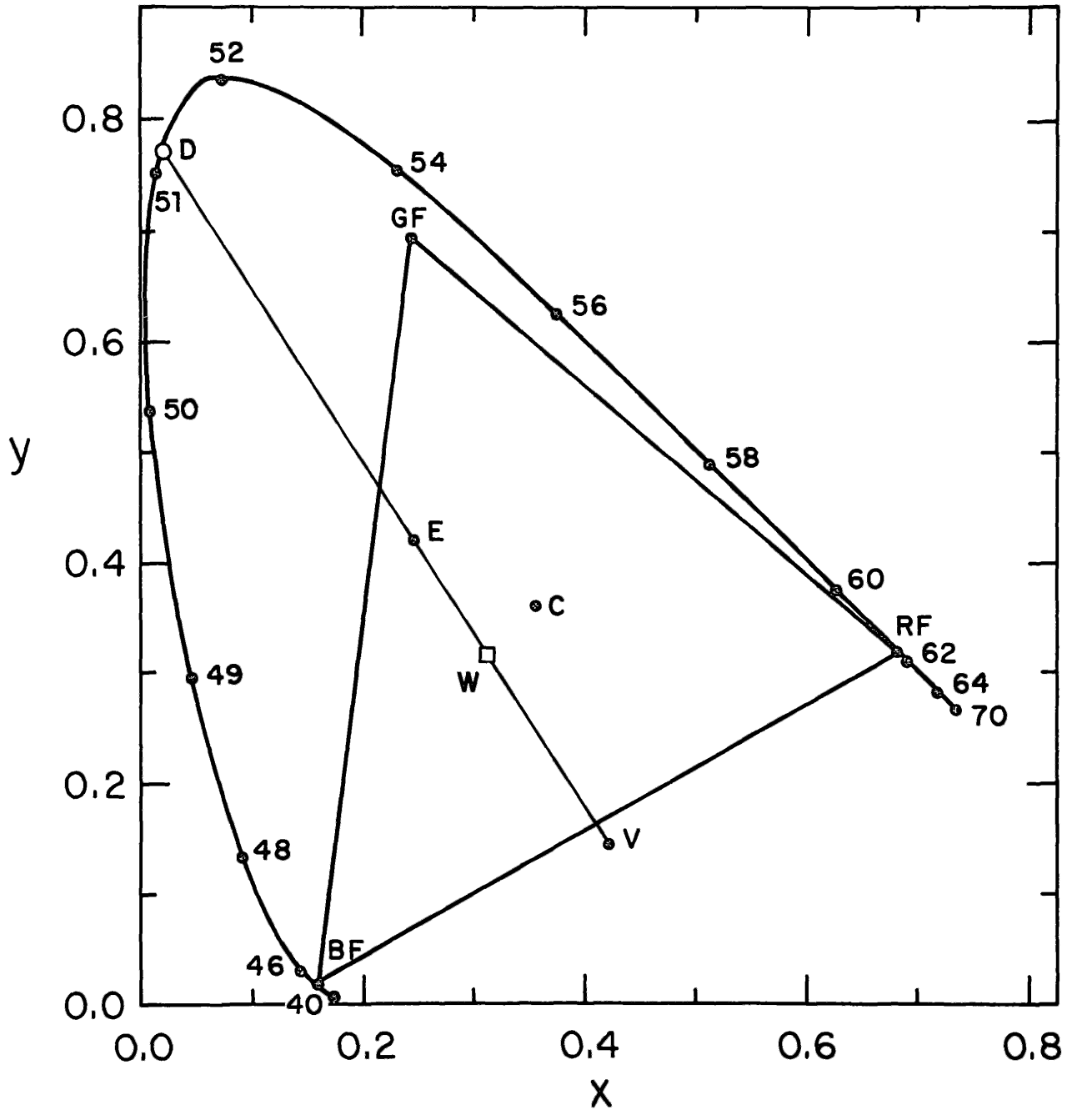
while the intensity is usually parameterized by the photometric reflectance of the material viewed in average daylight. When any two colors are added together, the chromaticity of the resulting color lies on the line in the chromaticity diagram joining the chromaticities of the two colors. The position along this line is determined by the proportions of the two colors. In general, this additive principle may be written, for the sum of a number of colors, as

$$x = \Sigma W_i * x_i / \Sigma W_i$$

$$y = \Sigma W_i * y_i / \Sigma W_i$$

where W_i is the weight of color i. Because of this additive principle, the range of possible values of (x, y) is bounded by the locus of the pure spectral colors. This locus is drawn in Figure 9, with the wavelengths of the colors expressed in hundreds of Angstroms.

Figure 9. Chromaticity diagram



The chromaticity diagram lets us illustrate several commonly used color terms. In Figure 9, the chromaticity of pure white is indicated by point W, and the chromaticity of an artists pigment, emerald green, is indicated by point E. The "dominant wavelength" (or "hue") of the pigment may be found by extending the line WE until it meets the pure color locus (point D at 5113 Angstroms). The dominant wavelength is normally not the wavelength at which the spectral distribution of the object has a maximum. In fact, the point V has the same dominant wavelength as E, but has a spectral distribution characterized by peaks in the red and the blue. The color V is complementary to E, and its dominant wavelength is normally expressed as 5113c to indicate that the sum of white light and any single spectral color cannot be used to generate the chromaticity.

The "purity" (or "chroma") of a color is a measure of how chromatic or achromatic the color is. In terms of the chromaticity diagram, the purity of the emerald green is given by the ratio of WE to WD (22.8%). The two-dimensional chromaticity diagram represents only color (i.e., the point W represents all shades of gray from black to white). The reflectance may be plotted as a third dimension, and the maximum possible reflectances as a function of x,y may be computed. However, since available pigments and dyes seldom approach the maximum reflectance, this concept is not overly useful.

The chromaticity of the filters in the image recorder are plotted in Figure 9 as points BF, GF, and RF. Because of the additive property of color, the triangle joining these points encompasses the chromaticity of all colors which may be generated by the image recorder. For example, the color V, which may be generated using pure spectral

colors, cannot be generated by the image recorder. The emerald green may be generated by having 8% of the light pass through the red filter, 54% through the green filter, and 38% through the blue filter. Unfortunately, the final stage in the image recording process is the recording of the generated colors on film. Because of the non-linear response of each emulsion within the film to its exposure and because of the complex spectral distributions of the dyes within the film, this recording will not be particularly accurate. For example, Polaroid Type 58 film is quite sensitive to yellow and blue-green, but is insensitive to red and blue. Since the Dicomed filters are matched for Ektachrome film, results with that film are more satisfactory.

Color has two principal uses in the NRAO Image Recording System. Color is often used simply to emphasize differences in the array values. Since the choice of colors is arbitrary, their exact recording is not of great importance. However, the user should not expect small color differences to be readily apparent on the film. For improved viewer comprehension, such "false color" pictures usually contain only spectral colors (i.e., the blue to green and green to red sides of the color triangle of Figure 9) and normally use red to represent the highest intensities. Color may also be used to represent a third independent variable, such as velocity. This approach appears to be useful, but only for those cases in which color is a fairly simple, single-valued function of the spatial coordinates. If the color function is double-valued, then the resulting colors may be non-spectral (complementary) colors which will be confusing to the viewer. If the color function is too complicated, then important color distinctions may be blurred by the inaccuracy of the film recording.

Appendix A. The DCP Command Vocabulary

This appendix describes the DCP command vocabulary in considerable detail. The following symbols will be used in the descriptions:

XORG	X relative coordinate origin in points
YORG	Y relative coordinate origin in points
XPOS	relative X recorder position in points
YPOS	relative Y recorder position in points
IROW	number of rows in map array
ICOL	number of columns in map array
OPD1	first numeric operand of command
OPD2	second numeric operand of command
OPD3	alphameric operand of command
RES	resolution scale factor for specified resolution: = 1 for high, = 2 for medium, = 4 for low
ZFLAG	flag for exposure of zero input intensities

The following device assignments are used by the DCP:

unit 5	manual mode command input device (terminal TEK 4023)
unit 6	output message device (terminal TEK 4023)
unit 8	false color code input device (the card reader)
unit 10	input device for data and automatic mode commands (magnetic tape drive MT1)
unit DI	output photographic device (the Dicomed)
unit TEK	output plotting device (terminal TEK 4012)

where the default assignments are given in parentheses.

AD

DESCRIPTION: Advance Film

This command will cause the Dicomed to advance the film by one frame. Note that a mechanical positioning device for roll film must be connected to the Dicomed.

OPERANDS

None.

SENSE SWITCHES

This command will be executed only if Sense Switch 7 is on. If Sense Switch 7 is off, this command will cause the DCP to enter the manual mode after writing on unit 6 the messages

"* FILM ?"

"* MANUAL MODE INPUT FROM 5"

REMARKS

The NRAO currently does not own an autcmatic roll film device.

AU

DESCRIPTION: Automatic Mode

This command will cause the DCP to enter the automatic mode and reassign the command input device to unit 10.

OPERANDS

None.

OUTPUT

On unit 6: "* AUTOMATIC MODE"

REMARKS

Unit 10 must be positioned within a file containing command records.

BF

DESCRIPTION: Blue Filter

This command will cause the Dicomed to position a blue filter in the optical path.

OPERANDS

None.

REMARKS

The DCP will pause 0.70 seconds to allow the Dicomed to complete the operation.

BR

DESCRIPTION: Border

This command will cause the Dicomed to photograph a line two points wide surrounding the rectangular map area.

OPERANDS

None.

SENSE SWITCHES

If Sense Switch 10 is on, this command will be ignored.

REMARKS

The current recorder position is taken as the upper left corner of the map area.

To draw the border, the DCP must know the map dimensions ICOL and IROW. These parameters may be entered using the 'SI' command or set with the 'PI', 'FC', or 'HS' commands.

CC

DESCRIPTION: Intensity Coding Flag

This command will set the intensity coding flag to a specified value in order to control the use of the intensity coding tables in single-color picture commands.

OPERANDS

OPD1 = desired value for the false color coding flag

ERRORS

If OPD1 is unequal to zero, the message

"CARDS OR CT/PT COMMANDS ?"

will appear on unit 6. If the DCP is in the automatic mode a further message

"PAUSE CC B DCP HOLD"

will appear on unit 6, and the DCP will enter a pause state.

REMARKS

If the intensity coding flag is not zero, the map or scale intensities will be converted using the intensity coding table of the current filter before being photographed (in commands 'SC' and 'PI') or plotted (in command 'HS').

CL

DESCRIPTION: Clear

This command will initialize the Dicomed functions and reset the coordinate origin and other DCP parameters.

OPERANDS

None.

REMARKS

This command is executed automatically when the DCP is first brought into execution.

This command is equivalent to the following commands:

```
HI
LG
NO
NF
CC    0
ZR    2
OR    0   0
IV    0   2
```

and also sets a flag so that a pause will occur if Sense Switch 5 is on. This command will not alter the command mode, the current map dimensions, or the current intensity coding tables.

CM

DESCRIPTION: Command

This DCP command will cause the specified command code to be issued to the Dicomed.

OPERANDS

OPD1 = the Dicomed or character generator code (in decimal format) to be sent to the Dicomed.

ERRORS

If OPD1 < 0 or OPD1 > 254, the command is not sent to the Dicomed, and the message

"OPERAND OUT OF RANGE"

is written on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

OPD1 must be a valid Dicomed or character generator command code.

This command should be used with care and only when the user must circumvent the normal logic of the DCP. To use this command, the user must consult the Dicomed publication cited in Appendix C.

CO

DESCRIPTION: Comment

This command will write all three operands on unit 6.

OPERANDS

OPD1, OPD2, and OPD3 are written on unit 6.

REMARKS

Sense Switch 2 does not suppress the writing of this command and its operands on unit 6.

CR

DESCRIPTION: Convert Coding Tables to Contours

This command will cause the DCP to alter the current intensity coding tables by adding intervals of zero intensity in all colors.

OPERANDS

OPD1 = the number of contour intervals (with the sign indicating linear (+) or logarithmic (-) intervals)

OPD2 = 100 times the ratio of the number of bright intensities to the number of zero intensities in each contour interval

ERRORS

If OPD1 < -25, OPD1 = 0, OPD1 > 25, or OPD2 < 1, the coding tables will not be altered, and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

The intensity coding tables remain unchanged except for the addition of intervals of zero intensity.

At the conclusion of this command, the DCP will plot the intensity coding table for the current filter.

When a map is photographed using the altered tables, the zero-intensity intervals will result in black areas, giving the impression of contour lines. The widths of these lines are a measure of the gradients in the data.

CT

DESCRIPTION: Change Coding Table (Sequence Command)

This command will prepare the DCP to read change coding table parameter commands giving the desired parameters of the intensity coding table for the current filter.

OPERANDS

OPD1 = the number of parameter commands following sequence command

OPD2 = unit number of input device for parameter commands

ERRORS

If OPD1 < 2 or OPD1 > 256, the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

If OPD1 parameter commands do not follow the sequence command or if they are in error, the message

"CHANGE CODE TABLE PARAMETER CARD(S) MISSING OR IN ERROR"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

Unless OPD2 = 8 (the card reader) or OPD2 = 5 (the terminal), the DCP will set OPD2 to the current command input device.

After the intensity coding table has been changed, the DCP will execute a 'GR' command.

CT

DESCRIPTION: Change Coding Table (Parameter Command)

A set of these commands will cause the DCP to change the intensity coding table for the current filter and to plot the result on the terminal.

OPERANDS

OPD1 = input intensity value for next point on curve

OPD2 = output intensity value for next point on curve

ERRORS

If OPD1 > 255, OPD2 < 0, or OPD2 > 255 or if OPD1 $\leq$ the previous value of OPD1, the remainder of the intensity coding table will not be changed, and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

The CT parameter commands give the coordinates of a coding table consisting of a sequence of straight lines.

The commands must be entered in the order of increasing OPD1.

There must be at least two CT parameter commands.

The commands may be entered from the terminal, from cards, or, in the automatic mode only, from tape. The input unit is specified in the CT sequence command.

If the first value of OPD1 is greater than 0, the output intensity for input intensities less than the first OPD1 is set to the first value of OPD2.

If the last value of OPD1 is less than 255, the output intensity for input intensities greater than the last OPD1 is set to the last value of OPD2.

EX

DESCRIPTION: Exit

This command will cause the DCP to terminate execution.

OPERANDS

None.

OUTPUT

On unit 6: "STOP EX B DCP"

FC

DESCRIPTION: False Color Pix

This command will cause the Dicomed to photograph a map array in three colors using the appropriate intensity coding tables.

OPERANDS

OPD1 = the number of columns in the map array

SENSE SWITCHES

If Sense Switch 4 is on, the DCP, before executing the command, will enter a pause state after writing on unit 6 the messages

"CARDS OR CT/PT COMMANDS ?"
"PAUSE PIFC B DCP HOLD"

If Sense Switch 5 is on, the DCP will execute the command and then write on unit 6 the message

"* FILM ?"

after which, if it is in the automatic mode, it will enter a pause state, writing on unit 6 the message

"PAUSE FRAME B DCP HOLD"

If Sense Switch 8 is on, the DCP will execute an 'HS' command before executing the 'FC' command.

ERRORS

If both OPD1 and ICOL are less than 1 or OPD1*RES + XORG +XPOS > 4096, the DCP will enter the manual mode after writing on unit 6 the message

"OPERAND OUT OF RANGE"

continued

OUTPUT

On unit 6: "SKIPPING TO NEXT COMMAND FILE, UNIT 10", if the DCP is in the automatic mode.

On unit DI: the blue, green, and red filters will be used along with the appropriate parts of the intensity coding tables to produce a color photograph of the map array, with the current recorder position as the upper left corner.

REMARKS

If the DCP is in the manual mode, unit 10 must be positioned at the start of a data file. If the DCP is in the automatic mode, unit 10 must be positioned within a command file. (The DCP will advance unit 10 to the start of the next file before attempting to read the map data.) At the conclusion of this command unit 10 is positioned at the start of the file immediately following the data file.

The default value for OPD1 is ICOL. The DCP will then set ICOL = OPD1 and IROW to the number of rows found in the data file.

This command will switch the Dicomed to linear exposure, to the suitable filters, and to the specified resolution and exposure (normal or complement) before making the photograph. At its conclusion, this command will restore the specified filter and exposure (linear or logarithmic) and will reset the Dicomed to high resolution and normal exposure.

If ZFLAG = 1 or 2, zero input intensities (after intensity coding) will cause some exposure. If ZFLAG = 3, they will cause no exposure.

FS

DESCRIPTION: False Scale

This command will cause the Dicomed to make a three-color photograph of a horizontal bar, along which the "input" intensity increases linearly from 0 through 255, using the appropriate intensity coding tables.

OPERANDS

OPD1 = the (vertical) width of the bar in pixels (default = 32)

OPD2 = the length of the bar in pixels (default = 960)

SENSE SWITCHES

If Sense Switch 9 is on, this command will be ignored.

ERRORS

If OPD2*RES < 256, OPD1*RES + YPOS + YORG > 4095, or OPD2*RES + XPOS + XORG > 4096 points, the intensity scale will not be photographed, and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

OUTPUT

On unit DI: a photograph of an intensity scale having (OPD1*RES)/256 points at each input intensity level from 0 through 255. The intensity scale is photographed with each of the color filters (in the order red, green, and blue) after conversion using the appropriate parts of the intensity coding tables.

continued

REMARKS

The current recorder position is the uppe left corner of the intensity scale.

The actual length of the intensity scale will be ((OPD2*RES)/256) *256 points.

The intensity scale will be photographed with linear exposure, after which the specified exposure (linear or logarithmic) will be restored. The scale will be photographed in inverse exposure, if specified, after which the Dicomed will be reset to normal exposure.

If ZFLAG = 1 or 2, zero input intensities (after intensity coding) will cause some exposure. If ZFLAG = 3, they will cause no exposure.

GF

DESCRIPTION: Green Filter

This command will cause the Dicomed to place a green filter in the light path.

OPERANDS

None.

REMARKS

The DCP will pause for 0.70 seconds to allow the Dicomed to complete the operation.

GR

DESCRIPTION: Graph Intensity Coding Table

This command will cause a plot of the intensity coding table for the current filter to appear on the graphics terminal.

OPERANDS

None

REMARKS

Unit TEK must be a CRT graphics terminal.

HI

DESCRIPTION: High Resolution

This command will cause the DCP to scale input operands to high resolution (1 point/pixel) and will cause the Dicomed to record map data at high resolution.

OPERANDS

None.

REMARKS

This command sets RES to 1.

This command will change the current recorder position and the relative coordinate origin as measured in pixels, but not as measured in points.

HL

DESCRIPTION: Horizontal Line

This command will cause the Dicomed tc photograph a horizontal line two points wide of specified length.

OPERANDS

OPD1 = length of line in pixels

ERRORS

If OPD1 < 1 or OPD1*RES + XORG + XPOS > 4095, the line will not be photographed,and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode,unless Sense Switch 3 is on.

REMARKS

The line will be drawn in the direction of increasing X (to the right), with the current recorder position as the upper left corner.

HS

DESCRIPTION: Histogram of Intensities

This command will cause the DCP to read a map data file, to plot a histogram of the number of map points of intensity I as a function of I, and, optionally, to execute a 'PI' or 'FC' command on the map.

OPERANDS

OPD1 = the number of columns in the map array

OPD2 = indicator of DCP disposition at command completion

ERRORS

If both OPD1 and ICOL are less than 1 or greater than 4096, the message

"OPERAND OUT OF RANGE"

will appear on unit 6, and the DCP will enter the manual mode.

OUTPUT

On unit 6: a message giving the vertical scale of the plot and, if the DCP is in the automatic mode and neither a 'PI' nor an 'FC' command is to be executed, the message "* SKIPPING TO NEXT COMMAND BLOCK, FILE 10".

On unit TEK: a plot of the histogram of map values greater than 0.

continued

REMARKS

The default value for OPD1 is ICOL. The DCP will then set ICOL = OPD1 and IROW to the number of rows found in the data file.

If the intensity coding flag is unequal to zero, the map intensities will be converted using the intensity coding table of the current filter before the histogram is determined.

If OPD2 is 1 or 2, the DCP will rewind the tape and execute a 'PI' (OPD2 = 1) or an 'FC' (OPD2 = 2) command after executing the 'HS' command. If OPD2 is anything else, the DCP will revert to the normal command input procedures immediately upon completion of the 'HS' command.

If the DCP is in the manual mode, unit 10 must be positioned at the start of a data file. If the DCP is in the automatic mode, unit 10 must be positioned within a command file. (The DCP will move unit 10 to the start of the next file before attempting to read the map data.) At the conclusion of this command, unit 10 is positioned at the start of the file immediately following the data file.

IN

IN

DESCRIPTION: Inverse Exposure

This command will cause the Dicomed to photograph map arrays and intensity scales with complement exposure.

OPERANDS

None.

REMARKS

During execution of 'PI', 'FC', 'SC', and 'FS' commands the film exposure will decrease with increasing input intensity.

IV

DESCRIPTION: Intensity Value

This command will cause point plots to be done using the specified point size and intensity.

OPERANDS

OPD1 = the desired point-plot intensity

OPD2 = the desired point size in pixels

ERRORS

If OPD1 < 0, OPD1 > 255, OPD2 < 1, or OPD2 > 255, the size and intensity parameters are not reset, and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

If the 'PP' command is to be used in high resolution, OPD2 should be an even number. This will avoid the photographing of an extra "zero"-intensity point along the right hand edge of the squares. If ZFLAG = 2 or 3, this is no longer a serious consideration.

LG

DESCRIPTION: Logarithmic Exposure

This command will cause the Dicomed to switch to logarithmic exposure.

OPERANDS

None.

REMARKS

The resulting film transmittance will be proportional to the anti-logarithm of the input intensity. The film density will be linearly proportional to the input intensity.

This type of exposure has the bigger dynamic range and has the effect of emphasizing the more intense portions of the input data.

This command is ignored during execution of the 'FC' and 'FS' commands.

LI

DESCRIPTION: Linear Exposure

This command will cause the Dicomed to switch to linear exposure.

OPERANDS

None.

REMARKS

The resulting film transmittance will be proportional to the input intensity, and the film density will be proportional to the logarithm of the input intensity.

This type of exposure is recommended for all color photographs.

This type of exposure has the effect of emphasizing the lower levels in the input data.

LO

DESCRIPTION: Low Resolution

This command will cause the DCP to scale input operands to low resolution (4 points/pixel) and will cause the Dicomed to photograph map data at low resolution.

OPERANDS

None.

REMARKS

This command will set RES to 4.

This command will change the current recorder position and the relative coordinate origin as measured in pixels, but not as measured in points.

MA

DESCRIPTION: Manual Mode

This command will cause the DCP to enter the manual mode and will reassign the command input device to the specified unit.

OPERANDS

OPD1 = unit number of command input device

OUTPUT

On unit 6: "* MANUAL MODE INPUT FROM ...."

REMARKS

OPD1 is set to 5 (the terminal) by the DCP except when OPD1 = 8 (the card reader).

The 'MA' command with OPD1 = 5 is executed when error conditions are found. Except for the 'PI', 'FC', and 'HS' commands, Sense Switch 3 may be used to suppress this use of the 'MA' command.

ME

DESCRIPTION: Medium Resolution

This command will cause the DCP to scale input operands to medium resolution (2 points/pixel) and will cause the Dicomed to photograph map data at medium resolution.

OPERANDS

None.

REMARKS

This command sets RES to 2.

This command will change the current recorder position and the relative coordinate origin as measured in pixels, but not as measured in points.

NF

DESCRIPTION: Neutral Filter

This command will cause the Dicomed to place a neutral filter in the light path.

OPERANDS

None.

REMARKS

The DCP will pause 0.70 seconds to allow the Dicomed to complete the operation.

NO

NO

DESCRIPTION: Normal Exposure

This command will cause the Dicomed to photograph map arrays and intensity scales with normal exposure.

OPERANDS

None.

REMARKS

During execution of all commands the film exposure will increase with increasing input intensity.

OR

DESCRIPTION: Origin

This command will reset the origin of the relative coordinate system and will move the recorder position to that origin.

OPERANDS

OPD1 = X-axis (horizontal) origin in pixels

OPD2 = Y-axis (vertical) origin in pixels

ERRORS

If OPD1 < 0, OPD2 < 0, OPD1*RES > 4095, or OPD2*RES > 4095, the origin and recorder position are not altered, and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

This command sets

XORG = OPD1 * RES
YORG = OPD2 * RES
XPOS = 0
YPOS = 0

as measured in points.

PA

DESCRIPTION: Pause

This command will cause the DCP to enter a pause state which must be manually released.

OPERANDS

None.

OUTPUT

On unit 6: "PAUSE PA B DCP HOLD"

REMARKS

To cause the DCP to resume execution, press the console interrupt switch and type /R.

Sense Switch 0 may be turned on during the pause if a switch to the manual mode is desired.

PI

DESCRIPTION: Pix

This command will cause the Dicomed to photograph a map array using a single filter.

OPERANDS

OPD1 = the number of columns in the map array

SENSE SWITCHES

If Sense Switch 4 is on, the DCP, before executing this command, will enter a pause state after writing on unit 6 the message

"PAUSE PIFC B DCP HOLD"

If Sense Switch 5 is on, the DCP will execute the command and then write on unit 6 the message

"* FILM ?"

after which, if it is in the automatic mode, it will enter a pause state writing on unit 6 the message

"PAUSE FRAME B DCP HOLD"

If Sense Switch 6 is on, the DCP will execute an 'FC' command after writing on unit 6 the message

"EXECUTING FC NOT PI"

If Sense Switch 8 is on, the DCP will execute an 'HS' command before executing the 'PI' command.

ERRORS

If both OPD1 and ICOL are less than 1 or OPD1*RES + XORG + XPOS > 4096, the DCP will enter the manual mode after writing on unit 6 the message

"OPERAND OUT OF RANGE"

continued

OUTPUT

On unit 6: "* SKIPPING TO NEXT COMMAND BLOCK, FILE 10" if the DCP is in the automatic mode.

On unit DI: a photograph of the map array using the current filter with the current recorder position as the upper left corner. If the intensity coding flag is unequal to zero, the map intensities will be converted using the intensity coding table for the current filter before being photographed.

REMARKS

If the DCP is in the manual mode, unit 10 must be positioned at the start of a data file. If the DCP is in the automatic mode, unit 10 must be positioned within a command file. (The DCP will move unit 10 to the start of the next file before attempting to read the map data.) At the conclusion of this command, unit 10 is positioned at the start of the file immediately following the data file.

The default value for OPD1 is ICOL. The DCP will then set ICOL = OPD1 and IROW to the number of rows found in the data file.

This command will switch the Dicomed to the specified resolution and exposure (normal or complement) before making the photograph and will switch the Dicomed back to high resolution and normal exposure before the next command is read.

If ZFLAG = 1 or 2, zero input intensities (after any intensity coding) will cause some exposure. If ZFLAG = 3, they will cause no exposure.

PO

DESCRIPTION: Position

This command will reset the recorder position to the specified relative coordinates.

OPERANDS

OPD1 = X-axis relative coordinate in pixels

OPD2 = Y-axis relative coordinate in pixels

ERRORS

If the resulting position does not lie within the recording area, the recorder position will not be changed, and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

This command sets

$$XPOS = OPD1 * RES$$
$$YPOS = OPD2 * RES$$

as measured in points.

The error examination requires that

$$0 \leq XORG + OPD1*RES \leq 4095$$
$$0 \leq YORG + OPD2*RES \leq 4095$$

points.

PP

DESCRIPTION: Point Plct

This command will cause the Dicomed tc photograph a square of specified size and intensity at a specified relative position. The recorder position is left at the specified relative position.

OPERANDS

OPD1 = X-axis relative coordinate in pixels

OPD2 = Y-axis relative coordinate in pixels

ERRORS

If the resulting position does not lie within the recording area, no action will be taken, and the message

"OPERAND OUT OF FANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

The size and intensity of the photographed square are set using the 'IV' command.

The specified position is the upper left corner of the square.

This command will move the reccrder position, but not photograph the square if the specified intensity is zero.

This command sets

$$XPOS = OPD1*RES$$
$$YPOS = OPD2*RES$$

as measured in points.

The error examination requires

$$0 \leq XORG + OPD1*RES \leq 4095$$
$$0 \leq YORG + OPD2*RES \leq 4095$$

points.

PR

DESCRIPTION: Prime

This command will cause the Dicomed to carry out a priming operation.

OPERANDS

None.

OUTPUT

On unit DI: a constant intensity image covering the full recording area.

REMARKS

The analogue EXPOSURE control on the Operators Control Panel should be set at its color-film value.

This command should be used regularly to reset the hysteresis present in the image-generating system.

This command requires on the order of 13 minutes to complete execution.

PT

DESCRIPTION: Polynomial Table (Sequence Command)

This command will prepare the DCP to read polynomial table parameter commands giving the parameters of the intensity coding table for the current filter.

OPERANDS

OPD1 = the number of parameter commands following sequence command

OPD2 = unit number of input device for parameter commands

ERRORS

If OPD1 parameter commands do not follow this command, or if they are in error, the message

"POLYNOMIAL TABLE PARAMETER CARD(S) MISSING OR IN ERROR"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

Unless OPD2 = 8 (the card reader) or OPD2 = 5 (the terminal), the DCP will set OPD2 to the current command input device.

If OPD1 < 1 or OPD1 > 50, the DCP will set OPD1 to 1.

After the intensity coding table has been changed, the DCP will execute a 'GR' command.

PT

DESCRIPTION: Polynomial Table (Parameter Command)

A set of these commands will cause the DCP to change the intensity coding table for the current filter and to plot the result on the terminal.

OPERANDS

columns	format	parameter
1-2	A2	command mnemonic 'PT'
4-7	I4	maximum input intensity to which these parameters apply = IMAX
8-11	I4	maximum output intensity (default = 255)
12-19	F8.3	coefficient of (input)**0 = C0
20-27	F8.3	coefficient of (input)**1 = C1
28-35	F8.3	coefficient of (input)**2 = C2
36-43	F8.3	coefficient of (input)**3 = C3
44-51	F8.3	coefficient of (input)**4 = C4

REMARKS

The PT parameter commands give the coefficients of a coding table consisting of a set of fourth-order polynomials. For the range of input intensities from the previous IMAX + 1 through IMAX, the color coding table for the current filter will be given by

```
C(I) = C0 + C1 * X + C2 * (X**2) +
     C3 * (X**3) + C4 * (X**4)
```

where X = I / 255.0 and where I is the input intensity value. The function C(I) is truncated at zero and the maximum value given in columns 8-11.

The parameter commands must be in the order of increasing IMAX. If IMAX < 1, IMAX > 255, or IMAX ≤ the previous IMAX, the DCP will set IMAX to 255 and ignore following parameter commands (if any).

continued

A useful polynomial to expand the lower-intensity range and compress the higher intensity range has parameters C0 = 0.0, C1 = 768.0, C2 = -868.0, C3 = 355.0, and C4 = 0.0.

RC

DESCRIPTION: Read Cards

This command will cause the cards containing the intensity coding tables to be read from unit 8.

OPERANDS

None.

INPUT

On unit 8: a deck of 64 cards giving 256 intensity values for each filter. The order of the colors is red, blue, green, and neutral, and the format of each card is 16I4.

OUTPUT

On unit 6: "!CR ? B MAI" if the card reader is not ready when the command is read.

REMARKS

The intensity coding table, T(intensity, filter), is used as follows: if I(X, Y) is the input intensity of a map array or an intensity scale and F is the current filter, then the intensity sent to the Dicomed to be photographed is given by

$$P(X, Y) = T(I(X,Y), F)$$

when the intensity coding tables are used.

This command need only be issued once, unless different coding tables are desired, or the DCP task has been reinitiated.

When the DCP is initiated the intensity coding tables are set so that the output intensity equals the input intensity for all intensities and filters.

RF

DESCRIPTION: Red Filter

This command will cause the Dicomed to position a red filter in the light path.

OPERANDS

None.

REMARKS

The DCP will pause 0.70 seconds to allow the Dicomed to complete the operation.

RW

DESCRIPTION: Rewind Tape

This command will cause unit 10 to be backspaced the specified number of files.

OPERANDS

OPD1 = the number of files to be backspaced

ERRORS

If OPD1 < 0, unit 10 will not be moved, and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

Unit 10 will be moved to the start of file N - OPD1 + 1, where N is the current file number.

If OPD1 = 0 or OPD1 > N - 1, unit 10 will be positioned at the beginning-of-media.

SC

DESCRIPTION: Scale

This command will cause the Dicomed to photograph in a single color a horizontal bar, along which the "input" intensity increases linearly from 0 through 255.

OPERANDS

OPD1 = the (vertical) width of the bar in pixels (default = 32)

OPD2 = the length of the bar in pixels (default = 960)

SENSE SWITCHES

If Sense Switch 9 is on, this command will be ignored.

If Sense Switch 6 is on, the DCP will execute an 'FS' command after writing on unit 6 the message

"EXECUTING FS NOT SC"

ERRORS

If OPD2*RES < 256, OPD1*RES + YPOS + YORG > 4095, or OPD2*RES + XORG + XPOS > 4096 points, the intensity scale will not be photographed, and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

OUTPUT

On unit DI: using the current filter, a photograph of an intensity scale having (OPD2*RES)/256 points at each intensity level from 0 through 255. If the intensity coding flag is zero, the first (OPD2*RES)/768 points for each intensity level are set to zero. If the intensity coding flag is unequal to zero, the intensity scale is converted using the intensity coding table for the current filter before being photographed.

continued

REMARKS

The current recorder position is the upper left corner of the intensity scale.

The actual length of the intensity scale will be ((OPD2*RES)/256) *256 points.

The intensity scale will be photographed in inverse exposure, if specified. In this case, no points are set to zero intensity for every intensity level.

If ZFLAG = 1 or 2, zero input intensities (after any intensity coding) will cause some exposure. If ZFLAG = 3, they will cause no exposure.

SI

DESCRIPTION: Size

This command will set the map dimension parameters ICOL and IROW to specified values.

OPERANDS

OPD1 = the number of columns in the map array

OPD2 = the number of rows in the map array

ERRORS

If OPD1 < 1, OPD2 < 1, OPD1*RES > 4096, or OPD2*RES > 4096, the parameters will not be set, and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

This command will set
ICOL = OPD1
IROW = OPD2

These parameters are required by the 'BR' and 'TI' commands.

SK

DESCRIPTION: Skip Tape Forward

This command will cause unit 10 to be forward skipped a specified number of files.

OPERANDS

OPD1 = the number of files to be skipped

ERRORS

If OPD1 < 0, unit 10 will not be moved, and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

If the end-of-media is detected during the forward skip, the message

"* END-OF-MEDIA, FILE 10"

will appear on unit 6, and the DCP will enter the manual mode.

REMARKS

Unit 10 will be moved to the start of file N + OPD1, where N is the current file number.

If OPD1 = 0, unit 10 will be moved to the start of file N + 1.

ST

DESCRIPTION: Status

This command will cause the DCP to print current status information on unit 6.

OPERANDS

None.

OUTPUT

On unit 6: three lines of print, including the coordinate origin and relative recorder position in pixels, the value of RES and the current presumed map dimensions (columns, rows), the current filter, the value of the intensity coding flag, and whether the exposure is to be normal or complement.

REMARKS

This command is particularly useful in the manual mode.

TE

DESCRIPTION: Text

This command will cause the Dicomed to photograph a horizontal line of text.

OPERANDS

OPD1 = character size in multiples of 16 pixels

OPD2 = number of characters in text

OPD3 = text character string

SENSE SWITCHES

If Sense Switch 11 is on, this command will be ignored.

ERRORS

If the text will not completely fit within the recorder area or if OPD1 < 1, OPD1 > 4, OPD2 < 1, or OPD2 > 40, the text is not photographed, and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

The current recorder position is the upper left corner of the first character of the text.

The DCP will switch the Dicomed to the specified resolution if such action is required to generate the specified character size.

OPD1 = 1 is the recommended character size for normal texts.

TI

DESCRIPTION: Tick Marks (Sequence Command)

This command will prepare the DCP to read two tick mark parameter commands giving the X- and Y-axis information, respectively.

OPERANDS

None.

SENSE SWITCHES

If Sense Switch 10 is on, this command will be ignored.

ERRORS

If less than two tick mark parameter commands follow this command, or if they are in error, the message

"TICK MARK PARAMETER CARD(S) MISSING OR IN ERROR"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

The current recorder position must be the upper left corner of the map area to be labeled.

This command will draw a rectangular border around the map area. No additional 'BR' command is needed.

To draw the tick marks, the DCP must know the map dimensions ICOL and IROW. These parameters may be entered using the 'SI' command or set with the 'PI', 'FC', or 'HS' commands.

TI

DESCRIPTION: Tick Marks (Parameter Command)

This command will cause the Dicomed to photograph tick marks, numeric and alphabetic axis labels, and a rectangular border for the specified map area.

OPERANDS

columns	format	parameter
1-2	A2	command mnemonic 'TI'
4-7	I4	offset in pixels from the current recorder position of the first tick mark on the axis
9-12	I4	distance in pixels between tick marks
14-16	I3	number of tick marks on the axis
18-21	I4	length of tick marks in pixels
23-25	3A1	axis labeling code (see below)
26-38	E13.6	data value in radians (or integer units for V code) corresponding to the first tick mark on the axis
39-51	E13.6	the difference between tick marks in the same units as columns 26-38 (labeled values increase to the right and down the picture, if this parameter is > 0)

SENSE SWITCHES

If Sense Switch 10 is on, this command will be ignored.

OUTPUT

On unit DI: a rectangular border line 2 points wide is drawn around the map area. If the number of tick marks for an axis (columns 14-16) is greater than zero, tick marks for the axis will appear on both sides of the map area. Under control of the labeling codes, the left and lower tick marks, when drawn, will have numeric and/or alphabetic labels.

continued

REMARKS

The first letter (col. 23) of the labeling code specifies the nature of the axis data parameter as:

R	"RIGHT ASCENSION"
D	"DECLINATION"
L	"LONGITUDE"
B	"LATITUDE"
V	"VELOCITY"

where the text in quotation marks above is used, unless suppressed, as the axis alphabetic label.

The second letter (col. 24) of the labeling code specifies the significance desired in the labeled values as:

blank	integer format for V code
H	hours only
D	degrees only
M	minutes of arc (or time for R code)
blank or S	seconds of arc (or time for R code)

where, other than for V code, the first tick mark will be labeled in full sexagesimal format (e.g., ±DD MM SS) to the specified significance, and all other tick marks will be labeled with the specified least significant portion of the sexagesimal format.

The third letter (col. 25) of the labeling code specifies the portion of the labeling desired as:

blank	ticks, numeric and alphabetic labels
N	ticks and numeric labels only
L	ticks and alphabetic labels only
T	ticks only

For proper operation of this command sufficient space must be provided for the specified labels. The X-axis labels require 0 (T), 24 (N,L), or 48 pixels below the map area. The Y-axis position coordinate labels require 0 (T), 24 (L), 56 (H or D with N), 80 (H,D), 104 (M), or 152 (S) pixels to the left of the map area. The Y-axis velocity labels require 0 (T), 24 (L), 8 + 16*K (N), or 32 + 16*K pixels to the left of the map area, where $1 < K \leq 6$ is the maximum number of characters to occur in the specified numeric labels.

Since Polaroid film does not cover the full recorder area, the user is advised to leave additional space on all sides of the map area.

If the number of tick marks (columns 14-16) is set ≤ 0 for an axis, no tick marks or labels will be photographed for that axis.

VE

DESCRIPTION: Vector

This command will cause the Dicomed to photograph a line between the current recorder position and a specified position and will move the recorder position to that specified position.

OPERANDS

OPD1 = X-axis relative coordinate of result position in pixels

OPD2 = Y-axis relative coordinate of result position in pixels

ERRORS

If the result position is not within the recorder area, the line is not photographed, the recorder position is not altered, and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

The line will have a horizontal width of two points.

The user is advised to use the 'HL' and 'VL' commands where possible.

The command will set

XPOS = OPD1 * RES
YPOS = OPD2 * RES

as measured in points.

The error examination requires

$0 \leq XORG + OPD1*RES \leq 4095$
$0 \leq YORG + OPD2*RES \leq 4095$

points.

VL

DESCRIPTION: Vertical Line

This command will cause the Dicomed to photograph a vertical line two points wide of specified length.

OPERANDS

OPD1 = length of line in pixels

ERRORS

If OPD1 < 1 or OPD1*RES + YPOS + YORG > 4095, the line will not be photographed, and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

The line will be drawn in the direction of increasing Y (downwards) with the current recorder position as the upper left corner.

VT

DESCRIPTION: Vertical Text

This command will cause the Dicomed to photograph a vertical line of text.

OPERANDS

OPD1 = character size in multiples of 16 pixels

OPD2 = number of characters in text character string

OPD3 = text character string

SENSE SWITCHES

If Sense Switch 11 is on, this command will be ignored.

ERRORS

If the text will not completely fit within the recorder area or if OPD1 < 1, OPD1 > 4, OPD2 < 1, or OPD2 > 40, the text will not be photographed, and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

The current recorder position is the upper left corner of the first character of the text.

Each character is oriented horizontally.

The DCP will switch the Dicomed to the specified resolution, if such action is required to generate the specified character size.

The spacing between characters is 20*OPD1 pixels.

OPD1 = 1 is the recommended character size for normal texts.

ZR

DESCRIPTION: Zero exposure

This command will set ZFLAG to control the exposure given to zero input intensities.

OPERANDS

OPD1 = desired setting of ZFLAG

ERRORS

If OPD1 < 1 or OPD1 > 3, ZFLAG will not be reset, and the message

"OPERAND OUT OF RANGE"

will appear on unit 6. The DCP will enter the manual mode, unless Sense Switch 3 is on.

REMARKS

If ZFLAG = 1, zero input intensity (after any intensity coding and complementation) always causes some exposure.

If ZFLAG = 2, zero input intensity causes some exposure only on 'PI', 'FC', 'SC', and 'FS' commands. In particular, zeros cause no exposure during use of the character generator ('TE', 'VT', 'TI') and drawing of odd length lines.

If ZFLAG = 3, zero input intensity never causes exposure.

Appendix B. INTERFACE

INTERFACE is a special-purpose program to prepare tapes for the Dicomed from input which is similar to that of the General Purpose Contour Program (GPCP). Although INTERFACE was written for use by several of the standard packages, other programmers may also find it useful. INTERFACE may be run as a separate job. However, it is normally run as the last job step in the job which formats the commands and data which are input to INTERFACE. These commands appear on one data set, called TEXT, as 80-column card images. This data set may reside on disk or tape or it may be, as shown in the JCL listing below, in the form of cards. The map data appear on another data set, called DATA, which normally resides on disk. Each record of this data set consists of 25 floating-point (REAL*4) numbers written without format control. Each row contains as many records as are needed to encompass the row with excess points in the last record of <u>each</u> row being ignored. A method by which the GPCP may be used to create this data set is described at the end of this appendix.

The commands used by INTERFACE are, in the order in which they must appear,:

JOB	precedes each picture
SIZX	gives map dimensions
PIX	provides information on the map and how it is to be photographed
BRDR	causes a border to be drawn around the map
SYMB	causes textual information to be photographed
TICK	draws and labels the map axes
END	causes the program execution to terminate

These commands are described in detail below. To retain uniformity with the commonly-used Calcomp contour programs GPCP and ACKONTOUR, the program INTERFACE will accept all commands of these programs as valid commands. However, INTERFACE uses only those listed above.

The typical JCL used to execute this program is:

```
//PICTURE  EXEC  PGM=PIX
//STEPLIB   DD   DSN=AUTOCORR.NEWLIB,DISP=SHR
//          DD   DSN=PL1.LINKLIB,DISP=SHR
//SYSPRINT  DD   SYSOUT=A,DCB=(RECFM=FA,LRECL=133,BLKSIZE=133)
//TEXT      DD   *

         (cards giving the commands)

//DATA      DD   DSN=dsname,DISP=(OLD,DELETE),UNIT=DISK,
//               DCB=(RECFM=VS,LRECL=104,BLKSIZE=108)
//TAPE      DD   UNIT=TAPE,VOL=SER=nnnn,LABEL=(j,NL,OUT),DISP=NEW,
//               DCB=(RECFM=U,BLKSIZE=1024,DEN=2)
//WORKFILE  DD   DSN=&WORKFILE,UNIT=DISK,DISP=(NEW,DELETE),
//               SPACE=(CYL,(5,2)),DCB=(RECFM=U,BLKSIZE=1024)
```

The data set TAPE is the output tape to be processed on the Dicomed. The user must provide the suitable DSN for the map array data set DATA and the number of the tape. If the input data set TEXT is not in the form of cards or if the input data set DATA does not reside on disk, the user must revise the JCL accordingly. If the output maps are to have rows exceeding 1024 pixels in length, the user should consult the authors.

The input commands to INTERFACE are described in detail below.

JOB

DESCRIPTION: Picture Initiaticn Command

This command causes INTERFACE to initiate the production of the command and data files for a picture.

OPERANDS

columns	format	information
1-4	A4	'JOB '

REMARKS

This command must be given once for each picture and must precede all other commands for that picture.

SIZX

DESCRIPTION: Map Sizes

This command gives the map array dimensions to INTERFACE and sets the ratio of the X to Y map scaling.

OPERANDS

columns	format	information
1-4	A4	'SIZX'
6-10	F5.0	map units/pixel in the X direction (XPPI)
11-15	F5.0	map units/pixel in the Y direction (YPPI)
41-50	F10.0	number of columns in input map array
66-75	F10.0	number of rows in input map array

REMARKS

This command must be given immediately following the first JOB command and immediately following any other JOB command for which the operand values differ from those of the preceding picture.

The operands XPPI and YPPI are used only in their ratio. The output map array dimension in the X direction is determined without regard for these parameters. The output Y-direction dimension is then determined using the ratio of YPPI to XPPI.

PIX

DESCRIPTION: Picture Parameters

This command causes INTERFACE to read the map array and to prepare the output array after scaling and interpolation. This command also causes specified Dicomed functions to appear on the output tape.

OPERANDS

columns	format	information
1-4	A4	'PIX '
6	A1	if 'A', an advance film command will appear at the start of the output command file
8-11	I4	X coordinate origin in pixels (default = 128)
12-15	I4	Y coordinate origin in pixels (default = 48)
19	A1	filter: 'N' neutral (= default) 'R' red 'G' green 'B' blue
21	A1	exposure polarity: 'N' normal (= default) 'C' complement
22	A1	exposure scaling: 'L' linear (= default) 'O' logarithmic
29-38	F10.0	minimum data value
39-48	F10.0	maximum data value
50-51	I2	number of interpolated columns inserted in map array to produce output array (IC)
52-53	I2	number of interpolated rows inserted in map array to produce output array (IR)
55-56	I2	number of repetitions of map columns to produce output array (IRC)
57-58	I2	number of repetitions of map rows to produce output array (IRR)
59	A1	if 'S', an intensity scale will be photographed

continued

REMARKS

This command must be given once for each picture and must precede any BRDR, SYMB, or TICK commands for the picture.

IC (IR) is the number of columns (rows) in the output array produced by linear interpolatien between each column (row) of the input array. If IC < 0, the program resets IC to the maximum value which yields a horizontal picture size less than 896 pixels. If IR < 0, the program resets IR using the ratio of XPPI and YPPI (given on the SIZX card) to yield the desired length to width ratio.

IRC (IRR) is the number of columns (rows) in the output array produced by repetition of the input columns (rows) between each column (row) of the input array. If both repetition and interpolation are requested, the repetition occurs after the interpolation. If IC < 0, no repetition is allowed.

The mimimum and maximum data values (columns 29-48) are used to scale the map intensities to Dicomed intensities. These parameters are not required to be the actual minimum and maximum, but may be used to expand (and truncate) or to compress the range of map intensities.

BRDR

DESCRIPTION: Border

This command causes INTERFACE to place the necessary commands on the output tape to cause a border line around the map area to be photographed.

OPERANDS

columns	format	information
1-4	A4	'BRDR'

REMARKS

This command is optional and should not be used if the TICK command is used. The TICK command will also cause a border to be photographed.

SYMB

DESCRIPTION: Photograph Text

This command causes INTERFACE to place the necessary commands on the output tape to have a textual string photographed.

OPERANDS

columns	format	information
1-4	A4	'SYMB'
11-15	F5.0	absolute X ccordinate of text in pixels
16-20	F5.0	absolute Y coordinate of text in pixels
26-30	F5.0	height of phctographed text (H)
31-35	I5	number of characters in text (< 31)
51-80	30A1	alphameric textual string

REMARKS

This command is optional.

The coordinates given are the absolute coordinates of the upper left corner of the photographed text.

The height of the photographed string is 16*J pixels, where

$$J = IFIX (10.0 * H + 1.0)$$

and where J is set so that $1 \leq J \leq 4$.

(SYMB must follow TICK in ACKONTOUR.)

TICK

DESCRIPTION: Tick

This command causes INTERFACE to place the necessary commands on the output tape to have tick marks drawn and labeled and a border drawn around the map area.

OPERANDS

columns	format	information
1-4	A4	'TICK'
6-10	F5.0	length of tick marks in pixels
12-13	2A1	horizontal axis labeling code
14-26	E13.6	value of the X coordinate at the leftmost map point
27-39	E13.6	value of the X coordinate at the rightmost map point
40-45	F6.0	change in the X coordinate between tick marks (absolute value)
47-48	2A1	vertical axis labeling code
49-61	E13.6	value of the Y coordinate at the uppermost map point
62-74	E13.6	value of the Y coordinate at the lowest map point
75-80	F6.0	change in the Y coordinate between tick marks (absolute value)

REMARKS

This command is optional.

(This command is handled differently by ACKONTOUR.)

continued

The first letter (columns 12 and 47) of the axis labeling code gives the nature of the coordinate using

R	right ascension
D	declination
L	longitude
B	latitude
V	velocity

The second letter (columns 13 and 48) of the axis labeling code gives the degree of accuracy of the axis numeric labeling as

D	degrees
H	hours (R only)
M	minutes of arc (of time for R)
blank or S	seconds of arc (of time for R)
blank	km / sec (V only)

The units of the coordinate values (columns 14-26 and 27-39 or 49-61 and 62-74) are radians or km / sec (for V code only). The changes in the coordinate values between tick marks (columns 40-45 and 75-80) are in the units specified by the second letters of the axis labeling codes.

END

DESCRIPTION: Program Termination

This command causes INTERFACE to cease execution.

OPERANDS

columns	format	information
1-4	A4	'END '

REMARKS

This command must be given once in the job step as the last card image in the data set TEXT.

Sample command card deck:

```
JOB
SIZX   1.0  1.0                                    365.                400.
PIX     128  48   N NO              0.      200. -1-1  0 0
TICK   25. V -0.160000E+03 0.600000E+02   50. BD 0.174533E+00-0.174533
  E+00   1.0
SYMB       26.0 26.0      0.19    9              L = 130.0
JOB
PIX  A               0              0.      200. -1-1
TICK   25. V -0.160000E+03 0.060000E+03   50. BD 0.174533E+00-0.174533
  E+00   1.0
SYMB       26.0 26.0      0.19    9              L = 135.0
JOB
SIZX   2.0  1.0                                    285.                140.
PIX  A               0              0.    20000. -1-1
BRDR
END
```

Note - the printing format of this report has prevented the authors from placing all operands in the example above in the proper columns. The user, however, must carefully follow the correct formats.

Using GPCP to create the map array data set:

A special command has been added to the GPCP so that the gridding, interpolating, and blanking capabilities of the GPCP may be used to prepare the map array data in a format suitable for input to INTERFACE. This formatting may be the user's sole purpose in running the GPCP or it may be incidental to the production of Calcomp contour maps. The powers of the GPCP are most useful for irregularly-spaced map data and for blanking parts of the maps. This special GPCP command is:

PIX

with no arguments. PIX is a PHASE 3 command. If blanking is desired, the GPCP command sequence is

```
.....
BLNK  1 .....
BND   .....
BND   .....
.....
PIX
BLNK  0
```

The blanked portion of the array is set to zero if the minimum map value is greater than zero, and set to a value less than the minimum map value if the minimum map value is less than zero. The user must provide suitable JCL for the output data set using DDNAME = FT02F001. For example, if the gridded and formatted map array is to be written on tape, use

```
//FT02F001  DD  UNIT=TAPE,DISP=NEW,VOL=SER=nnnn,
//              DCB=(RECFM=VS,LRECL=104,BLKSIZE=108)
```

where the proper tape number must be entered.

Appendix C. References

Data reduction programs using the NRAO Image Recording System

(1) Continuum interferometer

Reference: Blankenship, L. C., Hjellming, R. M., Meredith, B. L., and Schwab, F. R. 1976, "User's Guide to 360/65 Interferometer Data Processing Programs", Computer Division Internal Report Number 25, National Radio Astronomy Observatory, Green Bank, West Virginia.

(2) Spectral-line interferometer

Reference: Greisen, E. W. 1975, "The NRAO Line Interferometer: A Manual", Edition 2, National Radio Astronomy Observatory, Green Bank, West Virginia.

(3) Spectral-line single-dish

Reference: Cram, T. R. and Stobie, E. B. 1976, "TPOWER and SPOWER User's Manual", Edition 4, Computer Division Internal Report Number 10, National Radio Astronomy Observatory, Green Bank, West Virginia.

(4) Continuum single-dish

Reference: Cram, T. R. and Stobie, E. B. 1976, "The NRAO CONDARE User's Manual", Computer Division Internal Report Number 15, National Radio Astroncmy Observatory, Green Bank, West Virginia.

Dicomed-related publications

(1) "Image Recorders Models D46 and D47 Operation and Programming Manual" 1974, Dicomed Corporation, Minneapolis, Minnesota.

The photographic process

(1) Hunt, R. W. 1973,"The Reproduction of Colour in Photography, Printing, and Television", International Pubns. Service, New York, New York.

(2) Mees, C. E. and James, T. H. 1966, "Theory of the Photographic Process", edition 3, Macmillan Publishing Company, Inc., New York, New York.

(3) Neblette, C. B. 1962, "Photography: Its Materials and Processes", edition 6, D. Van Nostrand Company, Inc., Princeton, New Jersey.

(4) Wright, W. D. 1969, "Measurement of Colour", edition 4, D. Van Nostrand Company, Inc., Princeton, New Jersey.

(5) Yule, J. A. 1967, "Principles of Color Reproduction", John Wiley & Sons, Inc., New York, New York.