ZAPP/PC
Operations Manual
OMP-0136

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Dear *ZAPP /PC* User:

Thank you for your purchase of *ZAPP /PC* - Enhanced Video Fringe Analysis Software. To run the software, you must first follow the instructions for hard disk installation in Chapter 1 of the manual. The files on the distribution diskette can NOT be used from the floppy disk; they must be installed first. Keep a write protect tab on the diskette in order to avoid accidental erasure of the original distribution files. Remember to place the protection key device on the parallel port (LPT1) to enable the software.

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Introduction

ZAPP /PC is a combination hardware and software package for the IBM PC microcomputer family or compatible which offers automatic fringe digitization from a video camera imaging an interference fringe pattern either from an interferometer or from a photograph of an interferogram. The digitized fringe coordinates will be automatically ordered and then further analyzed by the software to fit the fringes to Zernike polynomials. *ZAPP /PC* has been designed to enhance interferometric interpretation by offering the automatic digitization and analysis of interferograms using artificial intelligence techniques.

Capabilities of *ZAPP /PC*

Some of the outstanding capabilities of *ZAPP /PC*, the Expert in Automatic Fringe Analysis Software, are:

- Uniform fringe center sampling along highly curved fringes to the edges of the data region.
- Accurate fringe center determination along highly curved fringes.
- Wide range of acceptable fringe contrast and separation.
- Automatic and self-consistent ordering of any combination of open and closed fringe patterns.
- Fringe center positions are determined to fractional pixel values.
- High density sampling of points along the fringes retaining high slope information.
- User selectable area for data taking.
- User definable obscuration selection.
- Fringes from a wide variety of interferometers can be analyzed automatically.
- Input of fiducials for comparing data by automatically rotating and zooming data to align fiducials when subtracting, adding and averaging data.

ZAPP /PC is available from Zygo Corporation, and executes on the IBM PC family of computers. This software offers the user the most capability in interferogram analysis at an inexpensive price.

The Computer System

ZAPP /PC is an executable file which requires at least 640 kilobytes of RAM memory to run. Some functions that are memory intensive, (Diffraction Analysis, for example) will not execute in less memory although parts of the program may function properly since it allocates memory dynamically.

ZAPP /PC can be used with the Hercules, Hercules+, Hercules InColor, EGA, or VGA graphics adapters. The EGA (640x350 resolution), VGA (640x480 resolution) and Hercules InColor (720x348 resolution) adapters will support 16 colors for both the menus and high resolution graphics displays. The CGA (640x200 resolution) will support color only for the menus. The Hercules or Hercules+ (720x348 resolution) will use monochrome for all displays.

Due to the fact that interferogram polynomial fitting is calculation intensive, the software requires an 8087/80287/80387 floating-point coprocessor chip installed in the IBM microcomputer or compatible. While floating-point calculations execute at similar speeds on an IBM PC and PC/XT as they do on an IBM PC/AT, other processing such as graphics are between 2 to 3 times faster on the IBM PC/AT. For the very best performance, an IBM compatible 80386 microcomputer is recommended.

A Microsoft or compatible mouse is also required for ease of manipulating the menus and graphics. The *bus* version of the mouse, which comes with its own interface board, is recommended so that a serial port is not used for the mouse. The two computer serial ports should be used for the graphics tablet and the plotter. If you already have a serial mouse, you will have to switch the mouse and the graphics tablet when you want to digitize fringes. In most situations the keyboard cursor and function keys can be used instead of the mouse if you prefer to use the keyboard.

Graphics Tablet Setup

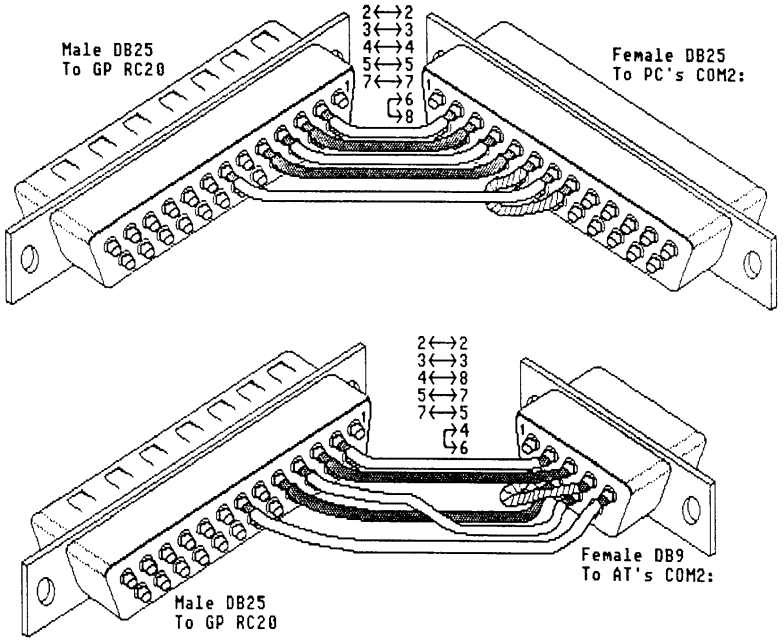
If you are supplying your own graphics tablet, you must set it up correctly. The tablet should be compatible with the Summagraphics Summasketch using a four button cursor. To set the options it may be necessary to remove the back cover of the tablet and change some jumpers. The proper options for the Summasketch tablet are:

1) AutoBaud - Jumper AA removed
2) ASCII BCD format - Jumper AB removed
3) Odd parity - Jumper AC attached

The tablet uses standard RS-232 type communication using **COM1** on your computer system. To make a cable for your tablet, only three wires are necessary (pins 2, 3 and 7). Pins 2 and 3 should be swapped so that pin 2 on one end is connected to pin 3 on the other. This is typically called a **NULL MODEM** connection. The Summasketch graphics tablet does not have a hardware reset and therefore it may be necessary to unplug the tablet to do a reset. If you have trouble digitizing using the program, exit the digitize mode by pressing **E** so that you return to the menu. Unplug the tablet momentarily to force a reset. Then try to digitize again.

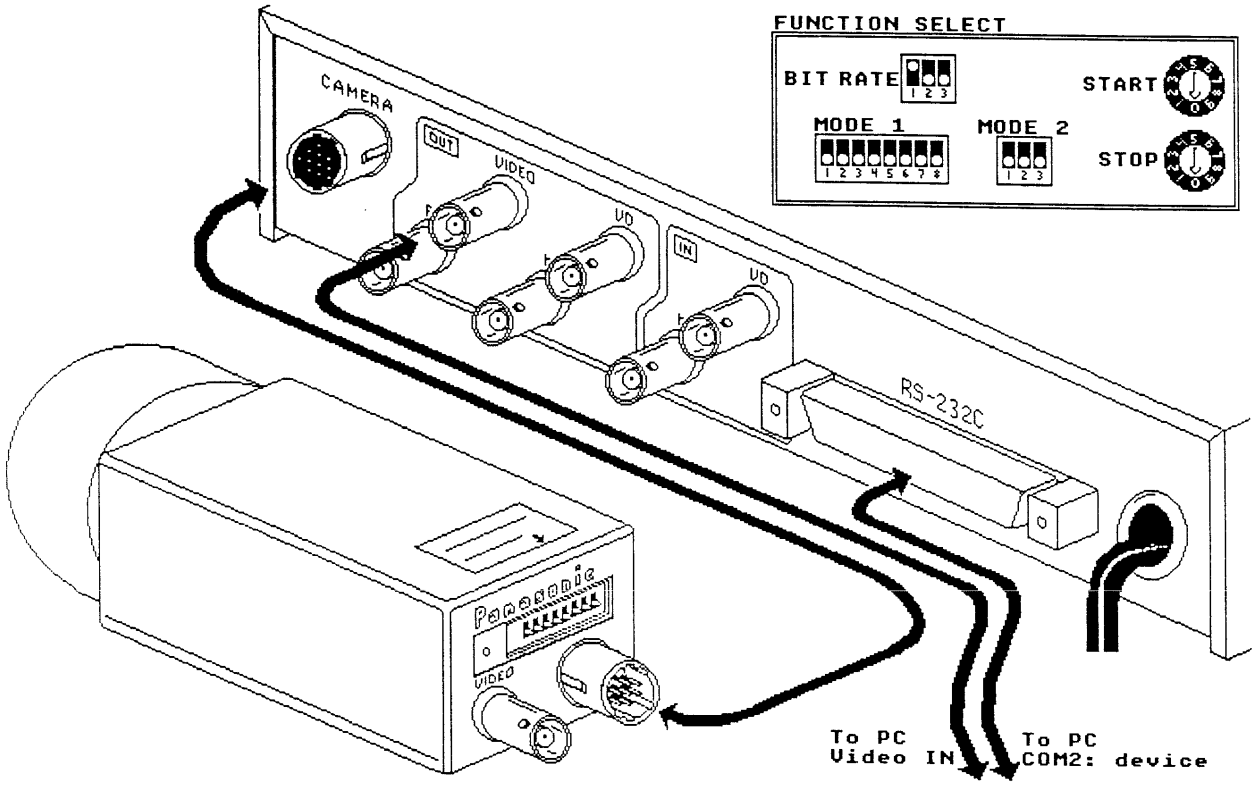
Panasonic Shuttered Camera Setup

If your Panasonic camera equipment was purchased with the *ZAPP /PC* software, we have provided an appropriate cable to connect your AT to the RC20 control unit. If not, here is a diagram to follow when making your own cable. This cable is similar to the RS-232C standard cables, but a jumper wire needs to be inserted on the end connected to the PC or AT (see the diagram below).



Turn off the RC20 unit while installing it. To connect the RC20 to the PC, plug the cable's "male" connector to the RC20's port labelled RS-232C, and plug the other end into the AT's serial port that is designated **COM2** (see your computer's manual if you are unsure which port is designated **COM2**). Also, check the small switches on the front face of the RC20 unit. The switches labeled "bit rate" should match those in the following diagram.

To connect the CD60 camera to the system, connect the thick RCU cable to the camera and the RC20. Feed the video signal from either the RC20 Video Out connector or the CD60 Video connector (there is no difference).



Now the RC20 unit may be turned on safely. Always turn it off before adjusting the small switches on either the camera or the RC20. Note that when the software selects new shutter speeds, the switches on the camera and RC20 unit become inoperative. The RC20 must be turned off before these switches operate again.

Plotter Setup

When using an HP 7470 or compatible plotter with *ZAPP /PC*, it must be connected to the **COM2** serial port. The plotter should be set for 9600 baud, 8 bits, no parity, and 1 stop bit. These settings may be found in the owners manual delivered with the plotter. To print any graphics screen to the plotter, press the **P** key while viewing the display.

Printers

The software supports the IBM Proprinter or any Epson compatible graphics dot matrix printer.

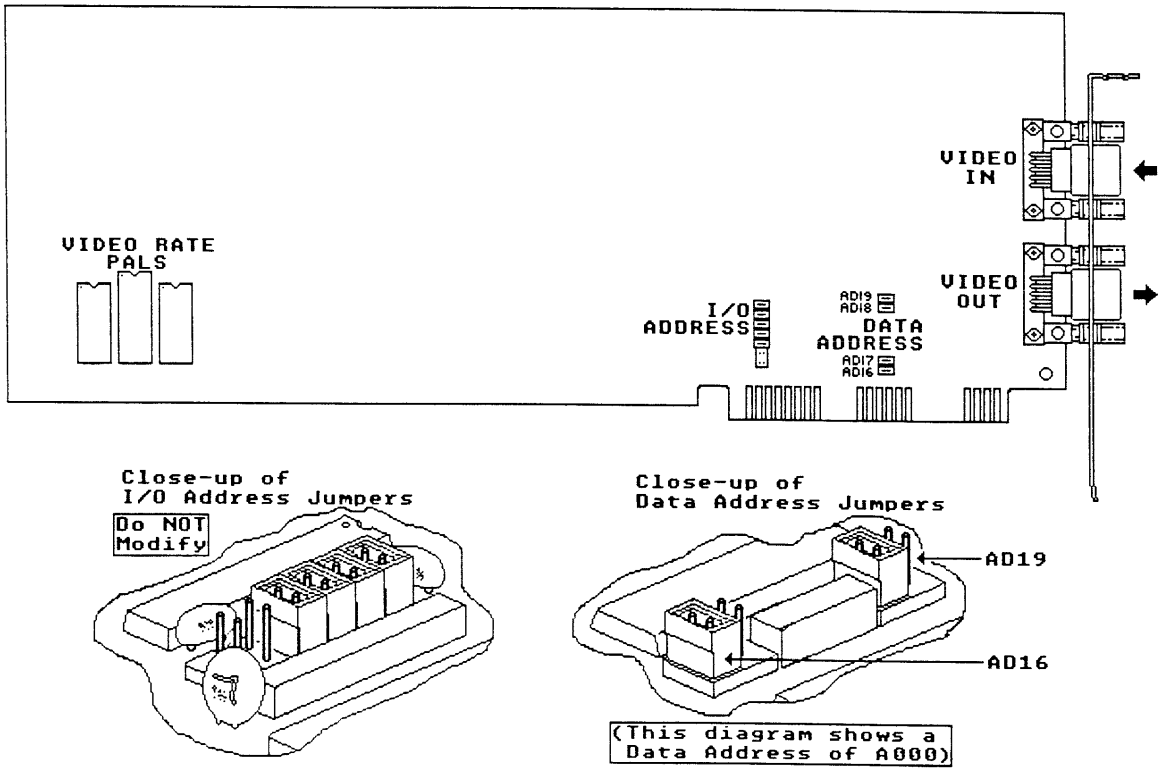
The installation of *ZAPP /PC* consists of setting the address for the video digitizer board, installing the board in your computer, installing the protection key on the printer port (**LPT1**), making backup copies of the software, copying the software to your hard disk if necessary, and then running the **System Setup** for configuration. These installation procedures are discussed in detail below.

Video Board Address Selection

> Warning: Handle the Video Digitizer board with care. Make sure you are in a static free environment to avoid damaging sensitive components on the board.

The address of the video board must be selected so that it does not conflict with other boards in the computer. The boards most likely to produce a memory conflict are the Expanded Memory (EMS) memory board or the PC display board such as the Enhanced Graphics Adapter (EGA). Note that other boards may occupy some parts of the given address space and so you must not use this space. It may be that you will have to remove another board from the computer so that you can operate *ZAPP /PC* without conflicts.

The following is a description of how to change the address of the video digitizer board. The jumpers for changing the board address are located near the gold edge connectors as shown in the diagram below.



The following list defines the jumper positions for typical addresses used for the video board

JUMPER				ADDRESS			
AD19	AD18	AD17	AD16	HEX	DECIMAL	DISPLAY	EMS
out	in	out	in	A000	40960	Hercules,CGA	YES
out	out	in	out	D000	53248	Hercules,EGA,CGA	NO
out	in	in	out	9000	36864	576K System	YES
out	in	in	in	8000	32768	512K System	YES

If addresses A000 and D000 are not available, you may use part of your DOS memory space at 8000 or 9000. You must configure your computer for 512K or 576K respectively. Refer to your computer manuals for memory setup instructions.

Save any jumper connectors that have been removed in a safe place in case they are needed again. You can place the jumper on a single pin for "out" values. Record the address of the board so you will have it handy when you run the **System Setup** for configuration of the software.

Installing the Video Digitizer Hardware

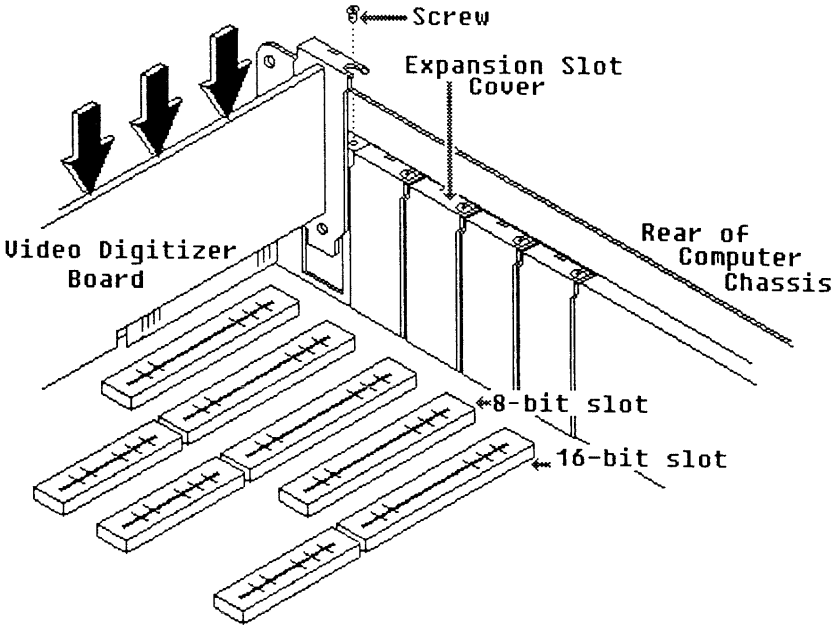
The *ZAPP /PC* interface board can be installed in any long slot on the IBM PC/XT system board and in one of the two available single edge connnector slots in an IBM PC/AT used for boards that are 8-bit PC compatible. Do *not* try to force the digitizer board into a 16-bit slot.

> CAUTION!
>
> Be sure the power is off and the power cord is removed from the computer before installing or removing any equipment. Always handle the interface cards with extreme caution. Electronic components on the boards are extremely fragile. When installing the interface cards into the computer, avoid compressing small components which could lead to shorting, and cause permanent board damage. Always use the anti-static plastic cover or aluminum foil while handling the boards to prevent static electricity from permanently damaging the electronic circuitry.

Video Digitizer Board Installation

Open the main cover of the computer chassis. To do this, you should refer to the documentation included with the computer. Follow all of the computer manufacturer's warnings to avoid personal injury or damage to system components. Specifically, disconnect any and all electrical power sources, and ground yourself by touching the edges of the chassis, before touching any of the internal components of the computer or the digitizer board.

Locate a free 8-bit slot on the system board. Do not attempt to use a 16-bit or 32-bit slot, since the digitizer board will not seat correctly into the connector. Remove the expansion slot cover on the rear panel of the computer chassis, and save the screw used to secure it.

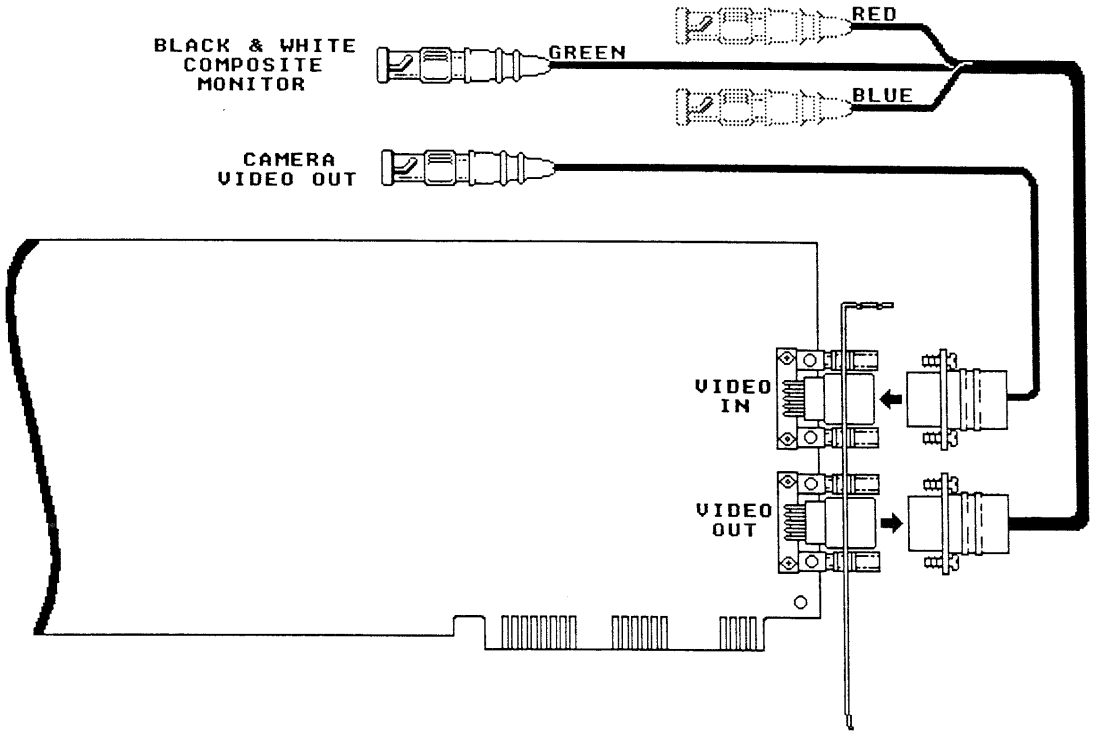


Install the Video Digitizer interface board by making sure the board slides through the plastic guide at the front of the computer chassis. It may be necessary to remove the card guide. Keeping the board level as it is lowered, align the gold edge connectors with the system board expansion slot. With evenly distributed pressure, press the board down until it is seated firmly into the slot. Be careful not to squeeze and bend down small components that are on the board. Secure the board to the computer chassis with the screw used to secure the expansion slot cover.

SUGGESTION: Due to the dense electronic structure and also the nature of the electronic components of the Video Digitizer card, the temperature of the board during normal operation is much higher than an ordinary computer card. We suggest, if possible, not placing another computer card in the slot nearest the component side of the Video Digitizer board to facilitate cooling.

After installing the interface card, reinstall the system unit cover.

Two cable assemblies are provided with the board to connect to a video source and a video monitor. The cables and connectors are made with male/female fittings so that it is impossible to plug a cable into the wrong connector. Of course you must not confuse the connectors of another board. Damage may occur if the DB9 type connectors are connected to another board in your PC. Connect the single coax cable (the end having a *white* collar near the BNC connector) to the video input source which, most likely is a TV camera. Any standard video camera can be used. Connect the other end of this cable to the male connector on the video digitizer board.



Connect the second cable assembly with three BNC cables to a video monitor (see the next section, *Installing the Video Controller Option*, if you have purchased the Video Controller optional hardware). If the video monitor is a black and white display, you must use the cable which has a *green* collar near the BNC connector. If you have an RGB color monitor (not the computer monitor) which has the capability of accepting analog video inputs, then connect the cables with the *red*, *green*, and *blue* collars near the BNC connectors to the *red*, *green*, and *blue* video inputs on the monitor. Connect the other end of this cable to the female connector on the video digitizer board.

Installing the Video Controller Option

ZAPP /PC may be purchased with the Video Controller option. This option offers the capability of video source switching and gain control so that the video fringe pattern can be seen on the TV monitor without having to turn on the computer to initialize the program.

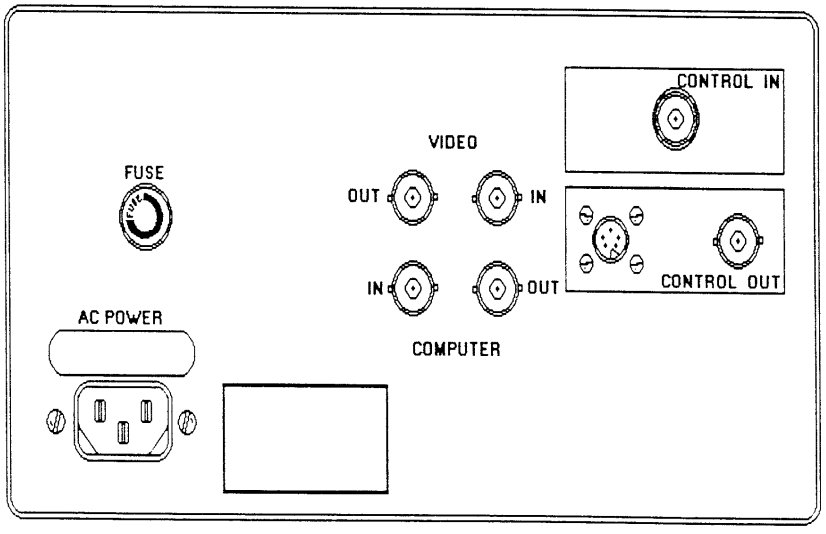
The recommended connections for the video from the interferometer, computer, and monitor to the Video Controller are shown below.

1) Connect a cable from TV monitor Video In to the Video Out BNC on the rear panel of the Controller.

2) Connect a cable from the Video Out of the interferometer to the Video In BNC on the rear panel of the Controller.

3) Connect the single BNC cable with the female DB9 connector from the video digitizer board to the Computer In BNC on the rear panel of the Controller.

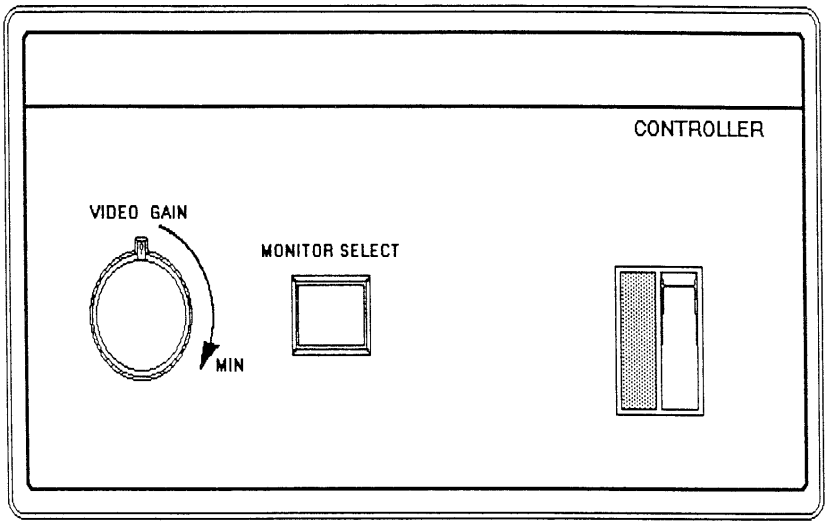
4) Connect the cable with the green collar near the BNC connector to the Computer Out BNC on the rear panel of the Controller. Connect the other end that has a male DB9 connector to the Video digitizer board at the rear of the computer.



With the Video Controller connected in this manner, the user can select the video source to be displayed on the TV monitor. When the Controller is turned off and has no power, the video source will be the interferometer video image going directly to the TV monitor. This condition is also true when power is on and the Monitor Select push button is out. By pressing the Monitor Select button to the IN position, the video source will be the computer video board and the interferometer video will be routed through the video digitizer board.

Video Gain Adjustment

Use the the video gain adjustment knob to control the strength of the video signal sent to the video digitizer board. The selected gain should be sufficient to see the fringes clearly, but not so great as to saturate the bright regions of the active data area.



The Protection Key

This device attaches to the parallel port (**LPT1**) of your computer system, without interfering with another device that connects to **LPT1**, and provides for executable protection of the software. This small attachment has a 25 pin male connector on one end and a 25 pin female connector on the other. Therefore, any device that is currently connected to **LPT1** can be connected to this adapter and function properly without interference. Simply remove the existing cable connected to **LPT1**, attach the adapter, and re-connect the existing cable to the adapter. When the software is executed, it will check for the presence of this device and continue. If the device is not found, a message will be displayed on the screen and the program will terminate. If video support is not needed, *ZAPP /PC* may be used on other compatible computers by transferring the protection key with the software.

Backing Up the Software

It is recommended that backup copies of the program disk be made. You can use the DOS program **DISKCOPY** to make backups of the diskette. Simply place the program diskette in floppy drive **A** and a new diskette in drive **B** and type

```
diskcopy a: b:
```

Please note that the *ZAPP /PC* program disk is a 360 Kilobyte diskette so you must use a 360 Kilobyte diskette for the new disk when using the DOS **DISKCOPY** command.

Hard Disk Installation

To copy the program on a hard disk, first create a directory on the hard disk for the *ZAPP /PC* software by using the DOS command **MD**. Then copy the files from the floppy disk to the hard disk. For example, from hard disk drive **C:** type

```
C> cd \              -> move to the main or "root" directory
C> md zappc          -> create a directory named zappc
C> cd zappc          -> move to the new zappc directory
C> copy a:*.*        -> copy all the files from drive A:
C> unpack            -> unpack files from archive
```

The DOS program **DISKCOPY** cannot be used to copy *ZAPP /PC* onto a hard disk. You must use the DOS **COPY** command.

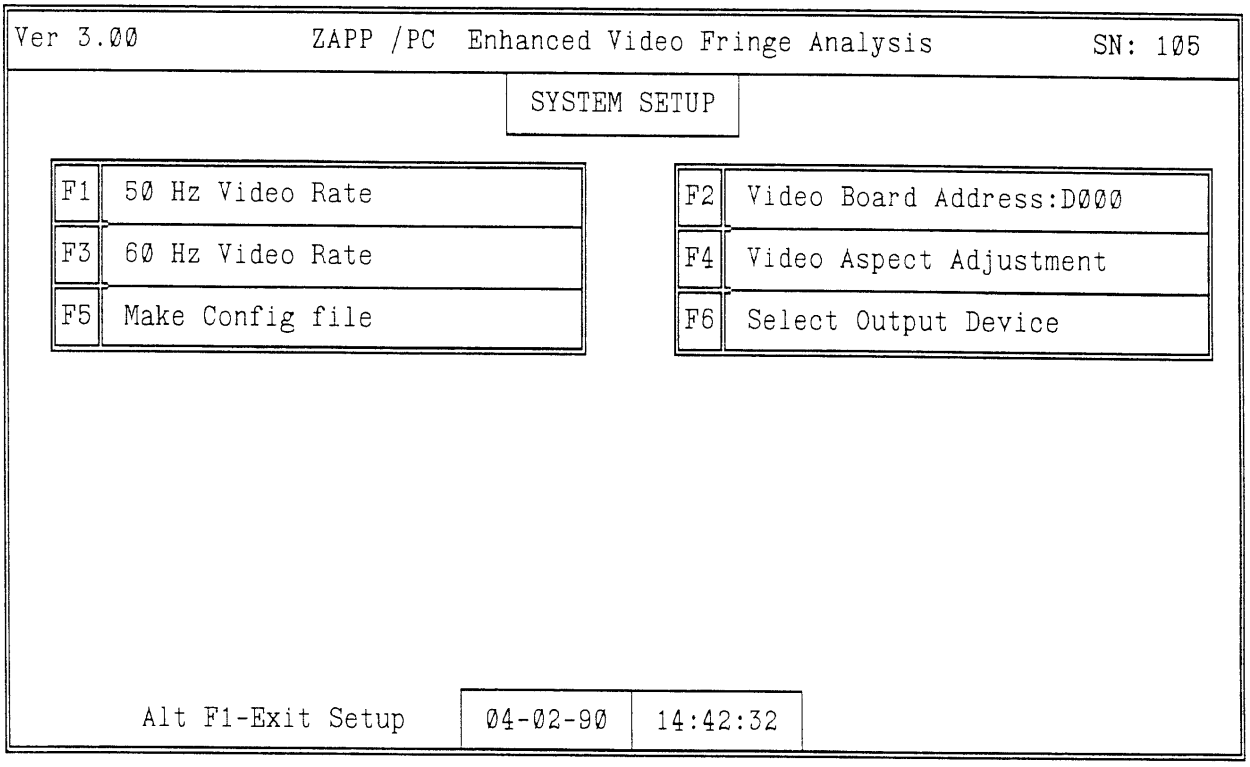
Software Initialization

Parameters concerning the video board are needed by the software and must be established before *ZAPP /PC* can be run successfully. These parameters are the video field rate standard and the video board address when it is installed in the

microcomputer. The **SYSTEM SETUP** menu will be displayed automatically the first time the *ZAPP /PC* program is run or anytime the configuration file can not be found. Change directories to the *ZAPP /PC* software directory and execute the *ZAPP /PC* program. If you would like to modify the system configuration in an existing config file, type **zappc /init**, or type **zappc** and answer affirmatively to the first question:

```
Do you wish to configure the system before continuing
(y/n)?
```

SYSTEM SETUP MENU



Video Rate

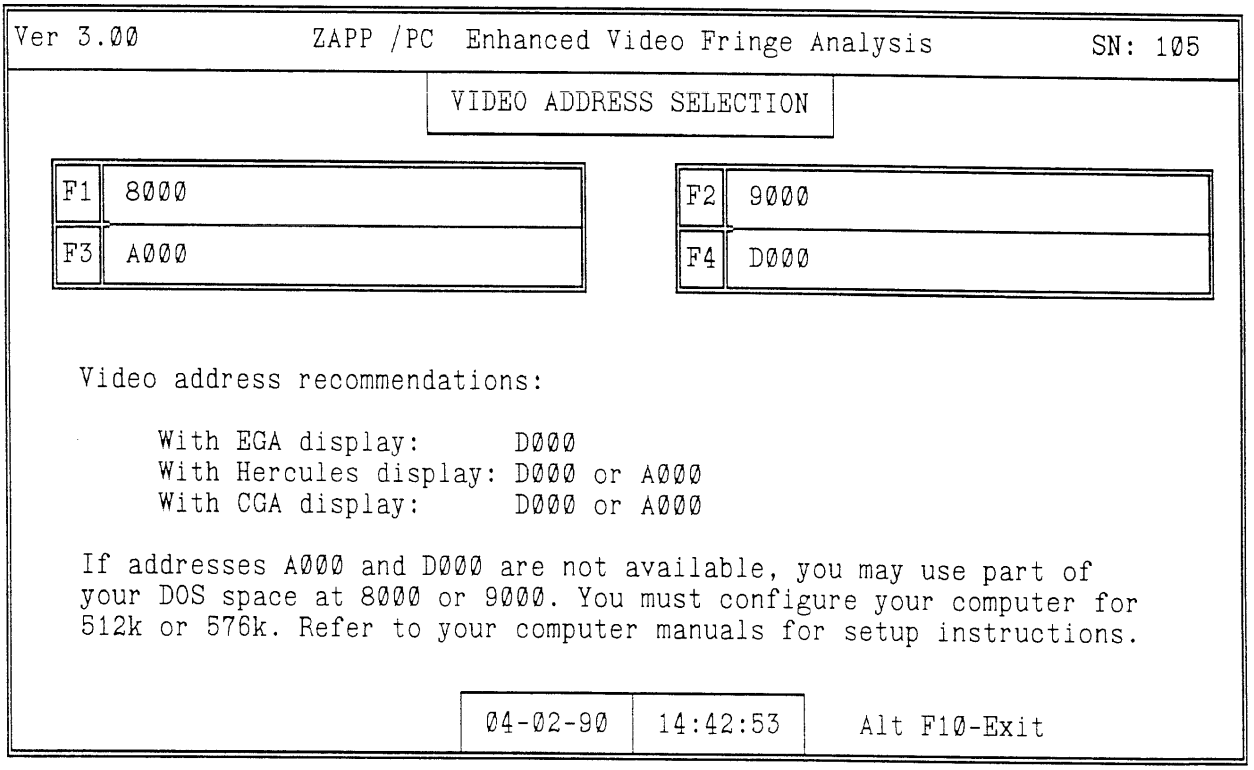
European standard video rates are based upon video frame rates of 25 frames per second, or 50 interlaced fields per second. The video digitizer board must be ordered with its timing specifically set for either 50 Hz or 60 Hz (for US and Canada video standards). Select the video rate which corresponds to the video standard in your country. If you are outside North America, most likely you should select the 50 Hz video rate. Select a 60 Hz video rate if you are using an American video camera which generates its own video timing (i.e., not based upon the AC power lines) or operates with North American standards.

Video Board Address

The software must know where the video digitizer board is addressed to properly access it. During the installation of the video board (see Video Board Address Selection), the address was selected. This address must also be selected from the **SYSTEM SETUP** menu. The initialization sequence checks for the presence of the digitizer board, and if found, it automatically sets the stated address to match the board's setting. If no board is found the address defaults to D000. An additional address check is made at the end of the initialization. If an address mismatch is found, the following warning message will appear:

```
Warning - video digitizer address detection problem!
    The configured address is not the same as the
    detected address.
    Please re-configure the software.
```

VIDEO ADDRESS SELECTION MENU

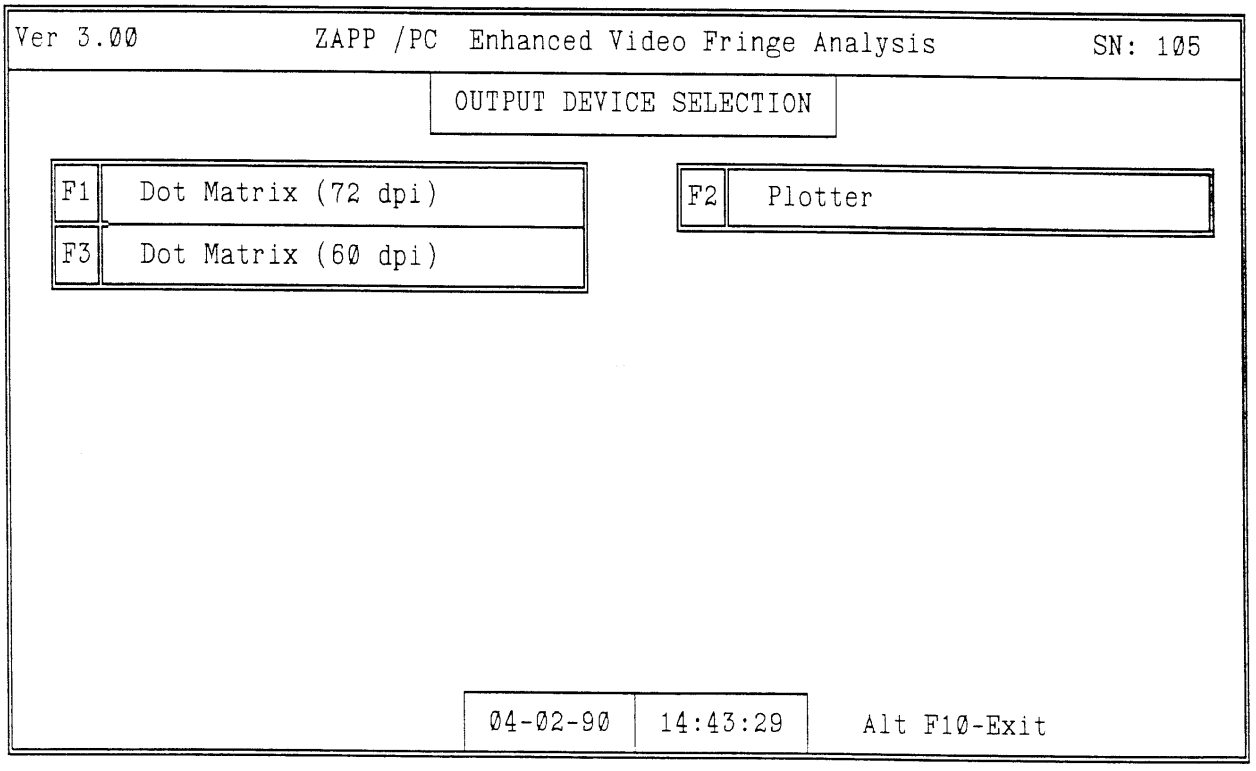


Printer Selection

The *ZAPP /PC* program supports two types of hardcopy output devices. The first type is any serial plotter that supports the common HPGL graphics language. This type must be connected as described in the *Plotter Setup* section, earlier this chapter. The second device is any parallel dot-matrix printer which supports the common Epson escape codes. This type of device comes in two different vertical resolutions, corresponding to 1/72" or 1/60" between vertical dots. The Epson FX-80 (a 9-pin printer) is an example of a 1/72" printer. The Epson LQ-510 (a 24-pin printer) is an example of a 1/60" printer. Check your printer manual to see what resolution your printer has.

The program must know what device is being used to know how to format its output. The **Output Device Selection** menu will specify these three devices, of which only one may be specified.

OUTPUT DEVICE SELECTION MENU



Video Aspect Adjustment

Due to the variations among video cameras and displays, the aspect ratio for a particular system should be established directly. The appropriate aspect ratio is obtained by imaging an object (or aperture), that is known to be circular, between matching reference and test surfaces. For best results the circular image should be large and in good focus, and the relative tilt between the reference and test surfaces should be small enough to produce well spaced fringes.

Once the circular image has been prepared, press the Enter key to mark the four points needed to compute the aspect ratio. Here a video arrow cursor is displayed (see Figure 1). Use the mouse to move the tip of this cursor to the leftmost point on the circle. Now press the *right* mouse button to mark this position. If greater positional accuracy is desired, use the *left* mouse button to generate a magnified video inset of the region about the cursor. With the inset on the screen, use either mouse button to mark this position. Cursor control will then automatically return to the full screen mode. Use a double keypress to leave the inset when no input is desired. Continue in this manner by marking the rightmost, topmost, and bottommost points of the circle's image. Program control returns to the **SYSTEM SETUP** menu with a new aspect ratio after the fourth point is entered. A double button press issued at any point in the full screen mode will abort the processing without modifying the current aspect ratio.

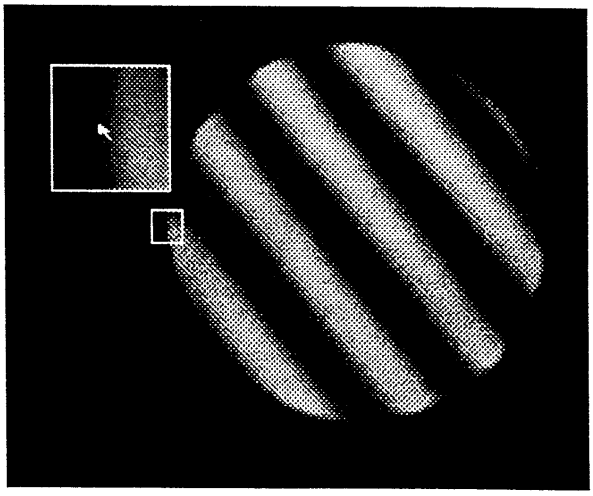


FIG. 1 - Marking extreme x,y positions for the Video Aspect Adjustment with magnified inset.

MOUSE CONTROL TABLE

	No Inset	With Inset
Right Button:	Mark Position	Mark Position
Left Button:	Produce Inset	Mark Position
Both Buttons:	Abort Aspect Adjustment	Abort Postion Input

Make Configuration File

Once the Video Rate, Address and Aspect Adjustment are properly selected, the user must create an initial configuration file for *ZAPP /PC* to use upon start-up. There is no need to use this initialization setup again if the above parameters are not changed. If you would like to modify these parameters in an existing config file, type **zappc /init**, or type **zappc** and answer affirmatively to the first question:

```
Do you wish to configure the system before continuing
(y/n)?
```

Aborting Functions

Any plot or function can be aborted by pressing **E** on the keyboard. This will exit the current operation and return to the current menu selected. If an input item is being requested, entering **E** on the keyboard and **<Enter>** will abort the input and leave the value unchanged.

Entering Input

During input of any value or item, if a default value is shown between square braces, the default value can be selected by pressing **<Enter>**. If a new value is entered, it becomes the new default next time the input is requested.

Filename Syntax

The software uses three main types of data files. Files with the extension **.MAP** indicate phase data files which store a 63x63 uniform grid. Files ending with **.DAT** are fringe center data files, and files ending with **.ZRN** are Zernike coefficient files. When the program requests a filename it will assume the appropriate extension. If a different extension is required, it must be explicitly typed.

A generic filename consists of up to a 6 character name with numbers appended, such as **SPHERE1.MAP, SPHERE2.MAP, SPHERE3.MAP**....etc. When entering a generic filename, it is only necessary to enter the common name (**SPHERE** in this case), the program assumes the files are stored under the appropriate extension such as **.MAP** so it is not required. Generic files are used for averaging **.MAP** or **.ZRN** files.

In *ZAPP /PC*, there are also pupil mask files, which are stored with the default extension **.MSK**.

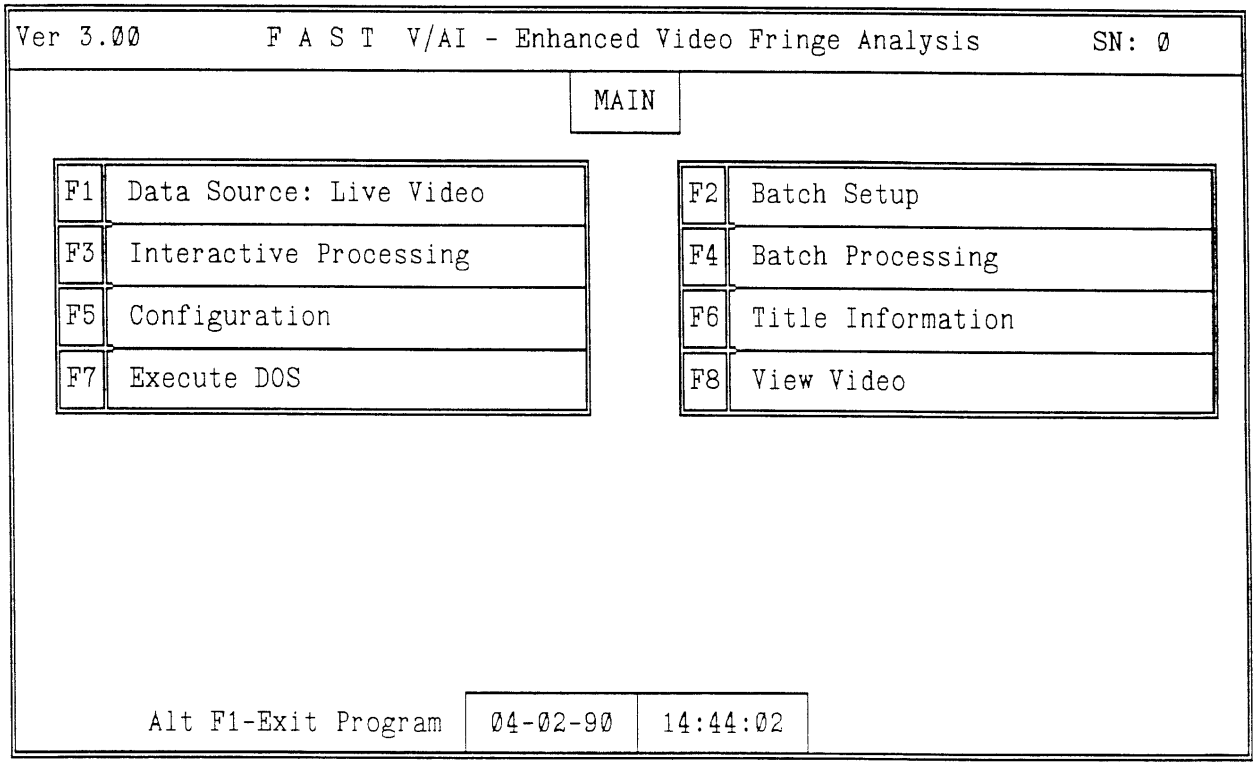
Executing *ZAPP /PC*

If a Microsoft or compatible mouse is to be used, it must be initialized properly before running *ZAPP /PC*. Refer to the manuals for your mouse for further information about installing the mouse software.

To execute the software, change directories to the *ZAPP /PC* directory and start the program by typing **zappc**. *ZAPP /PC* will try to read the configuration file **CONFIG** upon start-up. If the configuration file is not present, the program will automatically start the **SYSTEM SETUP** menu and allow creation of an initial config file.

With the interface board connected to a video monitor, upon power up of the computer, a random pattern will be displayed on the video monitor which represents the uninitialized memory of the video digitizer. When *ZAPP /PC* is loaded, the display will be cleared, and the program will check to see if a mouse is installed. If no mouse is found, then the keyboard function key labels are automatically displayed on the menus. When the program is successfully loaded, the following menu will be displayed when no mouse is present.

MAIN MENU

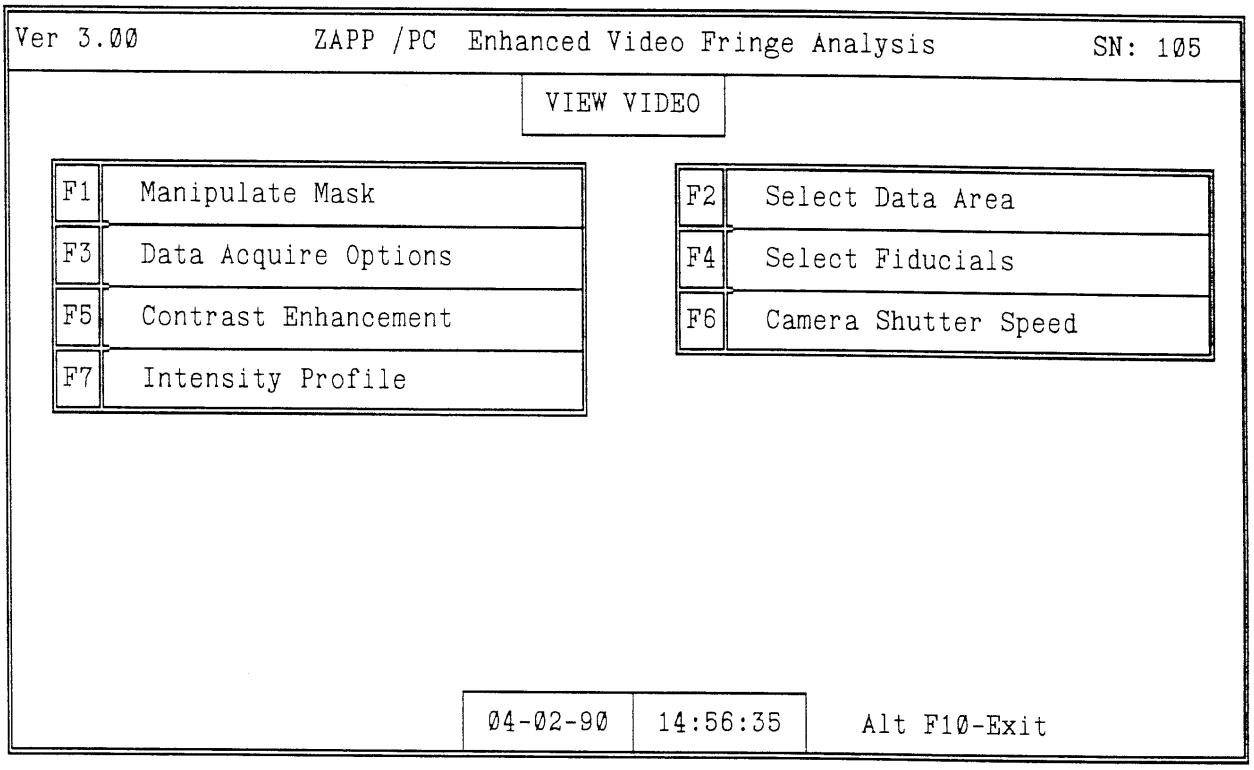


Viewing Fringes

To view the video fringe pattern (once the cables are connected to the video digitizer) you must select the **View Video** command in the **MAIN** menu.

NOTE: To view fringes without the computer you will have to disconnect the video camera from the cables and directly connect the camera to a video monitor bypassing the video digitizer in the computer.

VIEW VIDEO MENU



The following functions are described in the order in which they will most likely be selected.

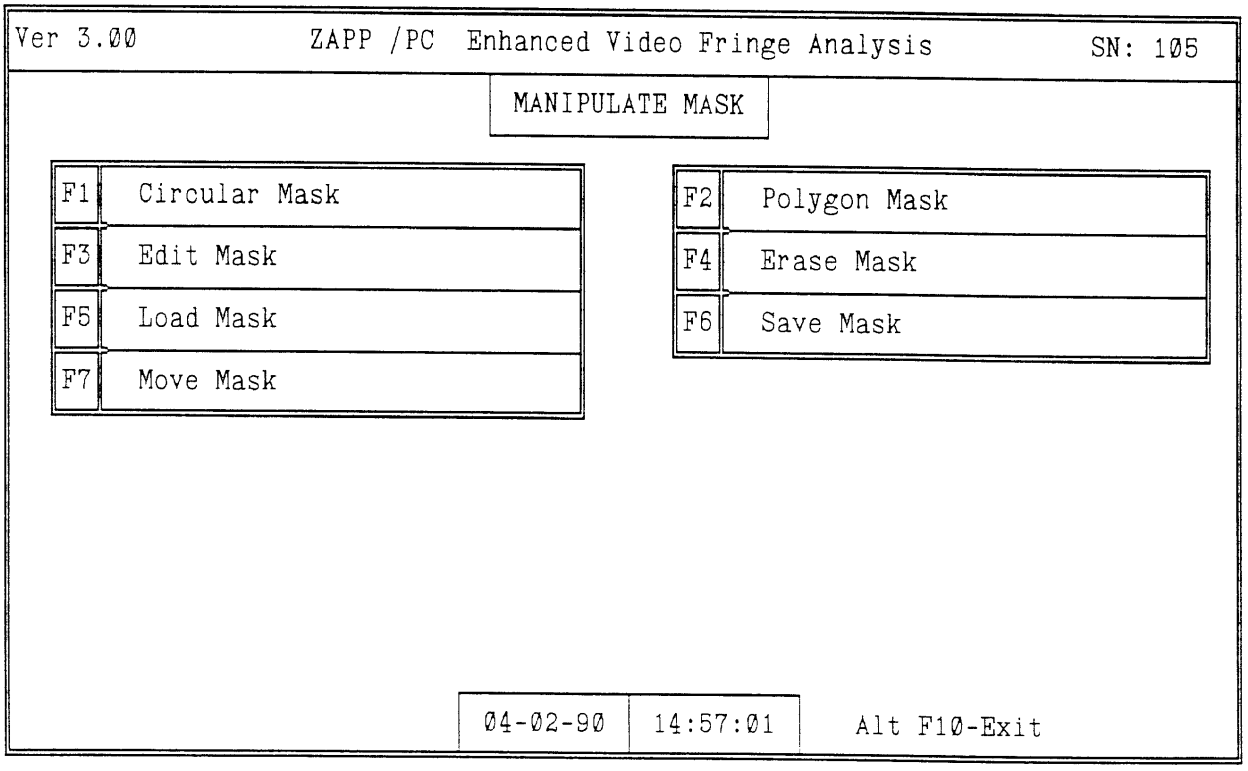
Select Data Area

This function will allow a user to select a data area anywhere on the video (grey scale) monitor. When this function is enabled, an intersecting pair of horizontal and vertical lines will appear on the video monitor which will follow the motion of the mouse. Move the intersection point to the upper left corner of the desired data area; this area should completely enclose the fringe pattern of interest. Pressing a button on the mouse will tag that position as a corner of a rectangular region. Further motion of the mouse will trace the other diagonal corner of a box. As the mouse is moved, a ***rubber-band*** box on the video monitor will indicate the data area within which analysis will be performed. Once the desired size and position are found, pressing a button on the mouse once again will define the data region.

Manipulate Mask

The Manipulate Mask option leads to the **MANIPULATE MASK** menu. Here the user can create, edit, or remove the pupil and obscuration masks which overlay the video image. Pupils and obscurations may be circular or polygonal in outline.

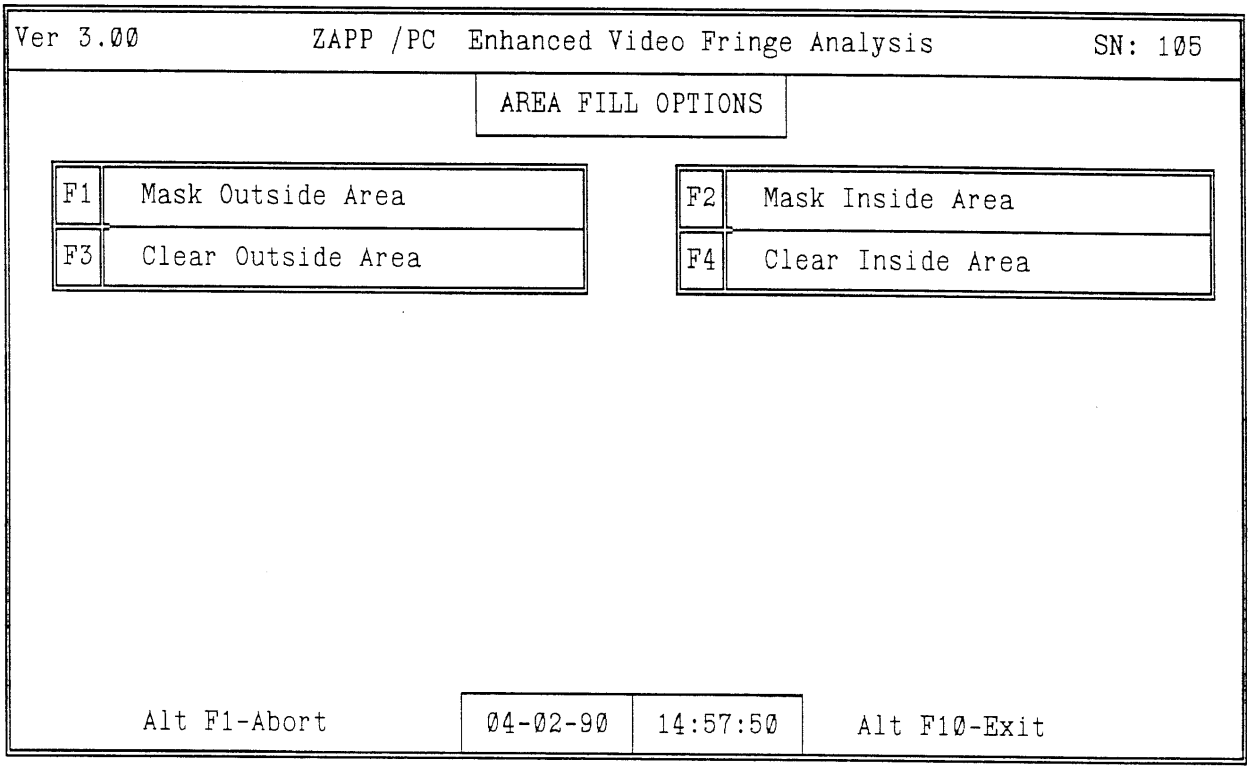
MANIPULATE MASK MENU



Circular Mask

This allows the user to define a circular or elliptical mask. Depending upon the circumstances, he may wish to mask off the area outside of a circular region (such as the area outside of an interferometer pupil), or he may want to mask off surface defects (such as a severe pit). When you choose the circular mask option, another menu provides a distinction between these possible circular masks.

AREA FILL OPTIONS MENU



Filling a region will cause it to be ignored during processing, and clearing a region will allow the interferogram image to show through to be processed.

The circular (or elliptical) boundary must now be defined. A prompt is displayed:

```
input points for Circular Mask - three fiducials:
```

A small arrow cursor will appear on the video monitor which will move when the mouse is moved. Select three positions on the circumference of a circle by moving the cursor and pressing a button on the mouse. If there is a circular pupil imaged on the detector, use the edge as a reference since the radius of the circle can be adjusted. After the three fiducials have been selected, a circle will be drawn on the video display. The following instructions will appear on the computer display:

```
-press left button to change radius
-press right button to drag circle
-press A to change aspect ratio
-press both buttons or Enter to exit

     X         Y
     70       -19

X center      Y center      Radius
    0             4            66
```

The circle's radius can be adjusted by moving the cursor to a new position and pressing the left mouse button. The previous center position is used. Due to the aspect ratio of the display and the digitizer, the X coordinates are scaled to approximate Y pixel units. Consequently, to obtain maximum precision, we recommend that the radius be defined in the Y (vertical) direction. A new center position can be defined by moving the cursor and ***dragging*** the displayed circle to the desired location while pressing the right mouse button. The previous radius is used in this case.

A display of the cursor x,y location with the center being the center of the data size area is shown on the computer screen, and is updated as the cursor is moved. Also displayed are the center coordinates and the radius in normalized pixel units.

Use the **A** command to adjust the aspect ratio of the circular outline to generate an ellipse with the corresponding eccentricity. Enter a value greater than one (but less than ten) to obtain an ellipse whose major axis is equal to the original circular radius and lies along the x-axis. Enter a value less than one (but greater than one tenth) to obtain an equivalent ellipse whose major axis lies along the y-axis.

Pressing **<Enter>** will fill the mask in the specified sense.

At this point, the video monitor will display the masking function overlayed on the active video image and the computer display will return to the **MANIPULATE MASK** menu.

Polygon Mask

This allows the user to define a general polygonal mask with up to thirty sides. As with the circular mask, the inner or outer nature of the polygonal mask must be specified. The **AREA FILL OPTIONS** menu (see the *Circular Mask* section above) will appear to provide this choice. After responding to this menu, the outline of the desired polygon may be entered. Move the mouse-controlled video arrow to the first vertex of the polygon (see Figure 2). Press either mouse button to mark this position. Now move the cursor to an adjacent vertex, noting the video line connecting the cursor with the first vertex. This line indicates the local boundary of the mask, and it is fixed when a mouse button is depressed. Continue marking adjacent vertices. After the final vertex is marked, enter a double keypress to connect the first and last vertex, and the mask will be filled in the appropriate sense. Program control will return to the **MANIPULATE MASK** menu.

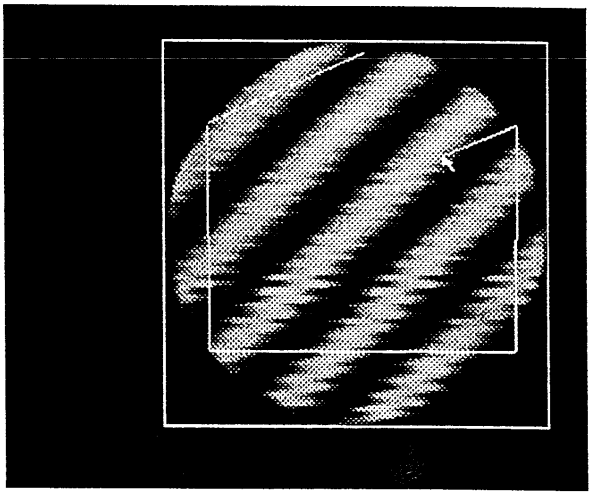


FIG. 2 - Defining a polygon mask.

Edit Mask

After the broad features of the masks have been defined it is occasionally necessary to refine the mask for irregular pupils and obscurations. The **Edit Mask** option will allow general free-form ***painting*** of the mask. The computer display will show the following message:

```
Use mouse to mask an area of pixels
   -left button to draw
   -right button to erase
   -both buttons to exit
```

A cursor which follows the motion of the mouse will appear on the video display and pressing (and holding down) the left mouse button will ***paint*** in the mask and the right button will erase parts of the mask. Any shape can be created as a mask. This feature is useful in masking out certain areas in the interferogram that may not be relevant but affect the data such as noise spikes due to spurious reflections or diffraction effects. Pressing both buttons simultaneously will exit the mask editing and return to the **MANIPULATE MASK** menu.

IMPORTANT: It is necessary to define a mask function which completely encloses the fringe pattern without any non-interference fringe areas between the mask and the fringes.

Erase Mask

This will erase any mask that has been defined. This applies to both pupil and obscuration masks.

Move Mask

Use the **Move Mask** feature to translate the current data area and mask along the x and y axes on the video screen. This movement can be controlled incrementally with the arrow keys on the numeric keypad, or more generally with the mouse. For mouse control, press either mouse button while moving the mouse. After the mask has been moved to the desired position, use a double mouse keypress to return control to the **MANIPULATE MASK** menu.

Save Mask

Once a pupil and obscuration mask have been defined, the user can save the mask with this function. A filename of up to eight characters will be requested which will be used to save the mask with the default extension **.MSK**.

Load Mask

Previously stored masks can be loaded using this command. The desired mask will be loaded to the data region on the video monitor in which it was saved.

Contrast Enhancement

If the visibility of the fringes is unavoidably low it may be difficult to trace and analyze the interferogram. When **Live Video** is the selected data source, the **Contrast Enhancement** feature may be used to improve the contrast of the digitized intensities (see Figures 3a and 3b). When activated, this feature first performs a quick sampling of the unmasked video image within the data area to establish the initial intensity distribution. Each intensity value is then converted to a new value by a histogram equalization method that is based on the initial distribution. Once sampled, the level of the enhancement is controlled by the mouse. The following instructions are displayed:

```
Move the mouse to the left to decrease contrast
Move the mouse to the right to increase contrast

Press mouse button or any key to exit
```

Exit when the desired contrast is achieved, and program control will return to the **VIEW VIDEO** menu with the contrast option highlighted. Use the **Intensity Profile** option to check for image saturation. The enhancement is deactivated by re-entering the command, and the initial intensity distribution will be restored.

Note: if you are using a Panasonic GP RC20 and GP CD60 shuttered camera setup, see how to adjust the shutter speed in the section, *Camera Shutter Speed*, before adjusting the contrast with this option.

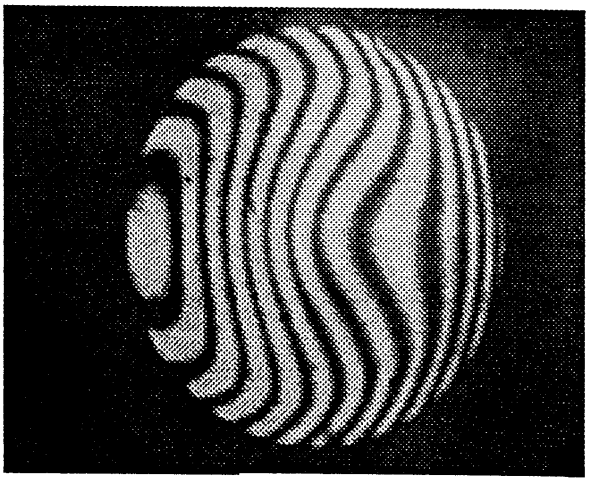


FIG. 3a - Low contrast image.

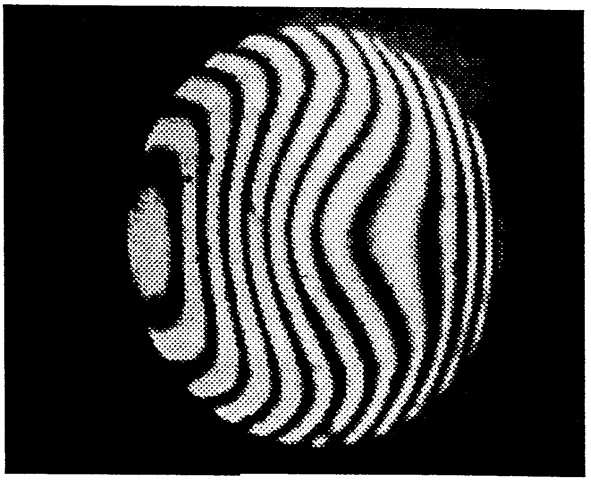
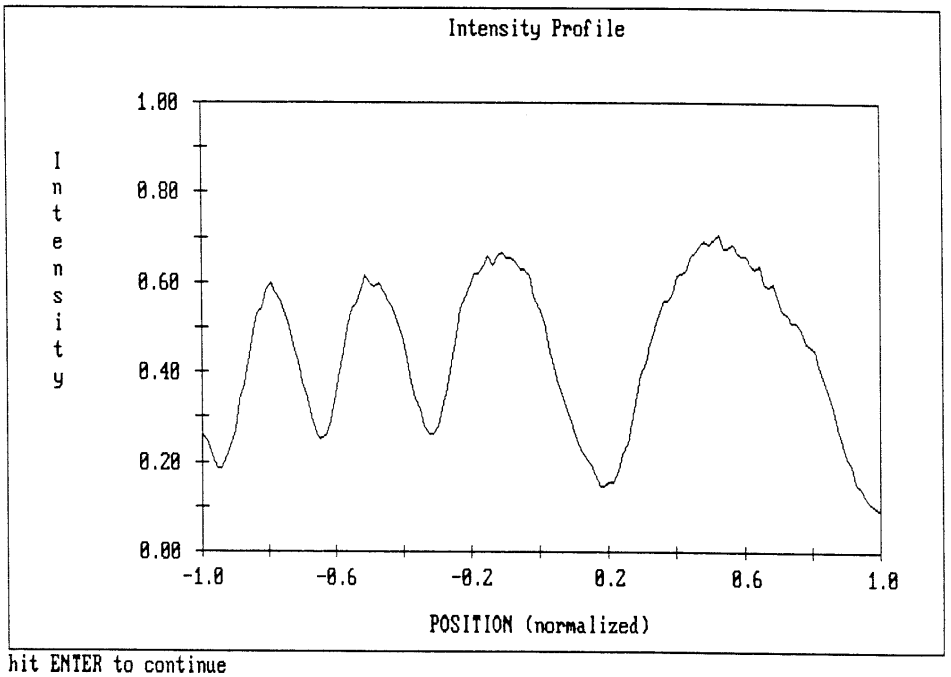


FIG. 3b - After Contrast Enhancement.

Intensity Profile

Due to the brightness and contrast controls on most video monitors, it is difficult to know the intensity levels *as seen by the video digitizer* simply by looking at the monitor itself. The **Intensity Profile** option offers the means to inspect directly the digitized intensities along a vertical or horizontal scan line. Upon entry, an X intensity profile across the current data area is plotted on the computer display (see below), and a horizontal line is drawn on the video grey scale image indicating the location of the profile.



Moving the mouse causes the horizontal indication line to move up and down the data area, changing the position of the profile. Pressing the left button on the mouse will change the line orientation to obtain the Y Intensity Profile. Here the motion of the mouse will vary the Y sample. To exit this function, press the <**Enter**> key.

The **Intensity Profile** option should be used to check for video saturation after adjusting the video gain on the Video Controller unit (if applicable) or after using the **Contrast Enhancement** option. These controls should be used to eliminate saturation (or the clipping of the bright fringes as seen in the profiles) of the video image.

Camera Shutter Speed

If your workstation is equipped with a Panasonic GP RC20 unit and a Panasonic GP CD60 shuttered CCD camera, then the **Camera Shutter Speed** option may be used to control the shutter speed of the camera. Too much (or not enough) light may produce poor image quality if the light sensitivity of the camera is not properly adjusted. The Panasonic models have electronically selectable sensitivities, "shutter speeds", which limit the amount of light registered by the camera's image surface. As in a physical film camera, slower shutter speeds result in brighter images, which may lose detail (especially if the subject is moving) and cause saturation or over-exposure. Faster shutter speeds result in a less exposed image, which may also lose contrast if the scene is dark. An optimum shutter speed is one where no saturation occurs, but good contrast is found throughout the image. Note that the shutter speed should be optimized **before** using the **Contrast Enhancement** option.

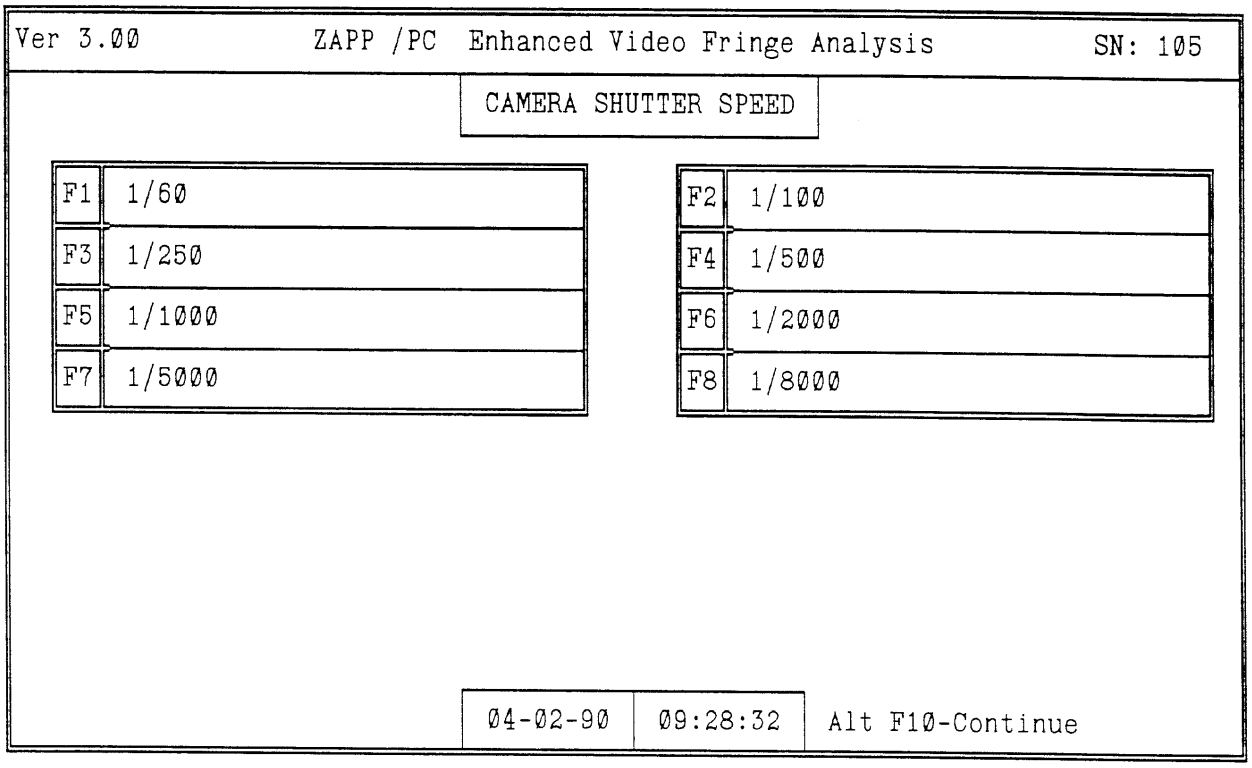
Normally, the RC20 unit controls the shutter speed with several small switches on its front panel. It also has a provision for remote control by a computer. To connect the RC20 to your computer, see the section *Computers & Peripherals* in this manual. Once the remote unit and camera are installed, the **Camera Shutter Speed** option may be used to remotely set the shutter speed of the camera without modifying the RC20's switches.

Assuming the RC20 unit is correctly installed, selecting **Camera Shutter Speed** will present another menu. One of the eight possible shutter speeds has already been selected and highlighted. If another speed is selected, the program must command the RC20 to change its internal registers. Displayed briefly will be the message:

```
Attempting communication with GP-RC20 unit...
```

It will disappear and the new speed will be highlighted on the menu. The results will immediately be seen on the auxiliary monitor. The speed may be changed any number of times. Select a speed that shows no saturation (a large milky white region near bright areas or over the whole image), and that provides good contrast (bright and dark shades in appropriate amounts).

CAMERA SHUTTER SPEED MENU

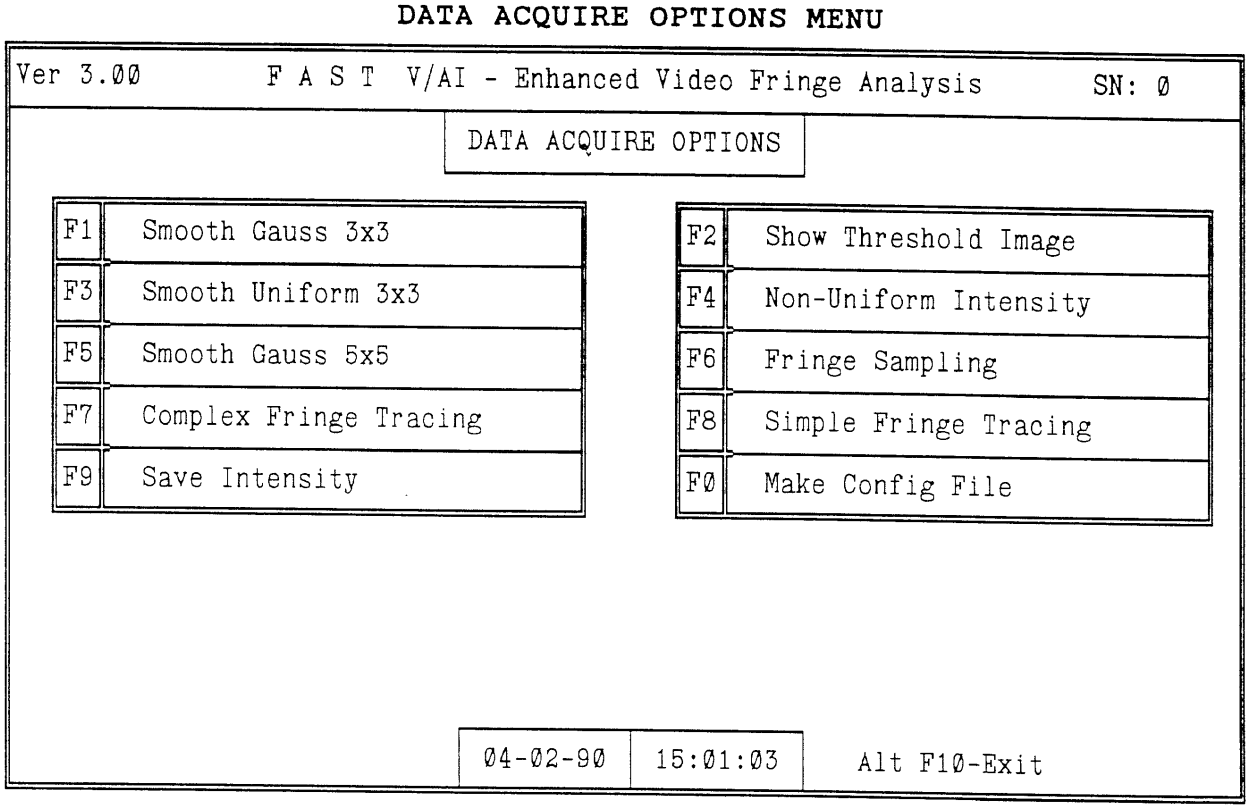


If the RC20 unit is not installed correctly, or if there is heavy interference near the cables, an attempt to command the RC20 may fail. The program automatically attempts the command a second and third time, in case the situation quickly clears up, but this may not be enough. When three failures occur, this message is displayed:

```
Attempting communication with GP-RC20 unit...
Camera controller is not responding.
Press 'e' to abort, or 'r' to retry command.
```

This is not a severe error. Use the 'R' key to try the command again. If the message recurs, you may wish to review the installation of the RC20. Check cable connections, and the baud rate switches on the RC20 unit. See the *Computers & Peripherals* section for details. Note that using the **E** key to abort will leave the **CAMERA SHUTTER SPEED** menu, but will not otherwise harm existing data or settings.

Data Acquire Options



Simple Fringe Tracing

ZAPP /PC supports two modes of fringe identification and ordering. These modes are labeled as **Simple Fringe Tracing** and **Complex Fringe Tracing**. The appropriate option for a particular case will depend on the nature of the interferogram to be analyzed. Either of these mutually exclusive modes may be selected from the **DATA ACQUIRE** menu. The selection of **Simple Fringe Tracing** allows *ZAPP /PC* to process the fringe data by generating a binary threshold image as a guide for the fringe tracing algorithm. The fringe centers are determined to sub-pixel resolution by using the grey scale intensity information. As the name suggests, this option is best for finding and ordering fringe centers from interferograms containing relatively straight and high contrast fringes with the greatest speed. Under these circumstances, the amount of binary threshold image editing (with the **Display Threshold Image** activated) should be minimal.

Complex Fringe Tracing

The full power of *ZAPP /PC* is put to work with the selection of the **Complex Fringe Tracing** option. While this option may be used for any interferogram, simple or complex, its advantages are most obvious for images containing highly curved or circular fringes. Here the fringe centers are found as the fringe is followed, and so the accuracy and uniformity of the center sampling is enhanced with respect to the simple tracing option. The necessary levels of fringe contrast and separation are lower as well. Furthermore, it is important to note that these fringe following procedures do not use a binary threshold image. The improvements in center determination would be almost meaningless, however, without a corresponding improvement in the ability to order complex fringe patterns. The **Complex Fringe Tracing** option satisfies this requirement by ordering patterns involving any combination of open, closed, wide, or narrow fringes in a self-consistent fashion. Saddle-type and circular fringes which exit and re-enter the pupil can also be ordered and interpreted.

The greater generality of the complex option does carry the cost of additional processing time. For large data sets, we recommend the use of **Simple Fringe Tracing** whenever the fringe pattern is amenable. The relative efficiency of **Complex Fringe Tracing** increases for fringe patterns of lower contrast and greater complexity. At the lower limits of fringe separation and contrast, where editing the threshold image can become tedious, the complex option can provide truly automatic results. A discussion of the use of the **Complex Fringe Tracing** is presented at the end of this chapter.

Selecting The Tracing Option

The selection of the appropriate tracing option depends on the interferogram of interest. Criteria for the recommended selection are summarized in the following table.

Use **Complex Fringe Tracing** for:	Use **Simple Fringe Tracing** for:
1) Highly curved or closed fringes	1) Relatively straight open fringes
2) Low contrast fringes	2) High contrast fringes
3) Closely spaced fringes	3) Widely spaced fringes
4) Small amount of tilt fringes	4) Large amount of tilt fringes
5) Large intensity variations	5) Small intensity variations

Any fringe whose local tangent changes by more than ninety degrees is considered to be highly curved. Fringes are taken to be widely spaced when there are many more than six pixels across each fringe. Note that once the fringe centers have been ordered, all subsequent processing is independent of the tracing selection.

Fringe Sampling

This function defines the number of fringe center sampling points along a fringe. At a value of 1, the fringe center points will be nearly continuous along a fringe. This will increase the processing time required in both finding the fringe centers and in fitting the Zernike polynomials. All these fringe center points can be used to retain high spatial frequency information in the fringes and can also be processed by *ZAPP /PC* if the **Interpolation** function is used.

The *maximum* number of fringe center points that *ZAPP /PC* can process is only limited by available memory. If you have selected a small fringe sampling interval and you have digitized a very large number of points, an error message may tell you that there are too many points. You must, in such cases, change the **Fringe Sampling** to increase the sampling interval, to reduce the number of processed points enough to fit in the available memory. A typical value for the fringe sampling is 5. A range of 2 to 10 is enforced.

Smoothing Functions

The smoothing functions are included to allow the user to reduce the effects of spatial noise on the interference fringe pattern. This noise can be due to speckle effects, diffraction ringing, or very poor beam quality. The smoothing functions operate by averaging a group of digitized pixels together to form a new value at the center of the group. For processing speed, this is done for all pixels within the specified data area selected by the **Select Data Area** option. This operation is thus a convolution of the smoothing function with the digitized video data representing the fringe pattern.

There are currently three smoothing operators, two Gaussian functions of differing width and one uniform function. The Gaussian functions perform a weighted sum over either a 3 by 3 or 5 by 5 pixel region with the weighting function being a Gaussian peak (approximately). The pixels farthest from the center pixel have less effect on the smoothing.

The uniform smoothing function weighs each pixel equally within a 3 by 3 region and thus smoothes more than the equivalent Gaussian 3 by 3 function.

Using The Smoothing Functions

Each smoothing function is enabled by either pressing its corresponding function key or by pointing to the desired function label with the mouse cursor and pressing a mouse button. The selected smoothing is performed immediately after a video image is digitized. All smoothing functions operate only within the selected data area. This minimizes the calculations required and smoothes only the area of interest.

The selection of a smoothing function is a toggle which either enables the function or disables it. When the function is enabled, it will be highlighted in reverse video on the menu. Since all the smoothing functions are toggle enabled, they all can operate on the image, one after the other. The sequence of smoothing, if all are enabled is as follows:

Gaussian 3 by 3
Uniform 3 by 3
Gaussian 5 by 5

If the interference fringes observed on the video is sufficiently noise free, then it is not necessary to enable any smoothing.

Smoothing can also be used to remove high frequency phase information from the interferogram by *blurring* the fringes. This may be useful when analyzing diamond-turned optics. If observing fringes from a scatter-plate interferometer, multiple smoothing operations may be necessary to remove the speckle noise inherent in this type of interferometer.

As a final note, Moire fringes can also be analyzed with *ZAPP /PC* by specifying an equivalent wavelength of the Moire fringe spacing. Here too, video fringes may contain the high frequency fringe pattern of the Moire gratings and therefore it may be necessary to smooth the video image.

Note: when smoothing, the spacing of the fringes should not be so close together that the smoothing operation blurs the fringe separation. This will produce erroneous results since the automatic fringe tracing and ordering routines require distinct fringes.

Display Threshold Image

This option, used when **Simple Fringe Tracing** is selected, will display the fringes in the defined data area as a binary representation after data acquisition. This information is used by the simple tracing procedures to automatically determine fringe order numbers and region of valid data. If there is a non-uniform intensity distribution across the fringe pattern that has not been compensated, the binary fringe pattern will not be indicative of the fringes and will show broken sections or parts that do not extend to the defined pupil edges. Adjustments must be made so that the binary fringes are complete and distinct; that is, do not touch each other. Adjustment can usually be done by enabling some **Smoothing** functions and the **Non-Uniform Intensity** function.

Once the pupil mask containing the binary representation of the fringe pattern is displayed, broken fringes or connected fringes can be edited by using the mouse to ***paint*** (press and hold the left mouse button) the discontinuous fringe sections or ***erase*** (press and hold the right mouse button) connections.

Non-Uniform Intensity

When using **Simple Fringe Tracing**, if the fringe pattern has a non-uniform intensity distribution, the automatic fringe ordering routines will not function properly. *ZAPP /PC* has the ability to compensate for a variation of intensity across the diameter of the interference pattern. If there exists some non-uniformity or drop-off of intensity from the center to the edges, then select the **Non-Uniform Intensity** item in the **VIEW VIDEO** menu. If the intensity distribution is fairly uniform then toggle-off the **Non-Uniform Intensity** option. Processing is slowed by the **Non-Uniform Intensity** function but may be necessary for accurate results under **Simple Fringe Tracing**.

The results of smoothing and non-uniform intensity compensation on the digitized interference fringe pattern can be observed by enabling **Display Threshold Image**.

Saving Selected Options

When a **CONFIGURATION FILE** is created, the current state of the program is stored. The various parameters in this menu, as well as other options, will be saved so that when the program is newly executed, it will be ***configured*** in that mode. The selected data area which is used by *ZAPP /PC* as the active area for analysis is also stored when a new **CONFIGURATION FILE** is created.

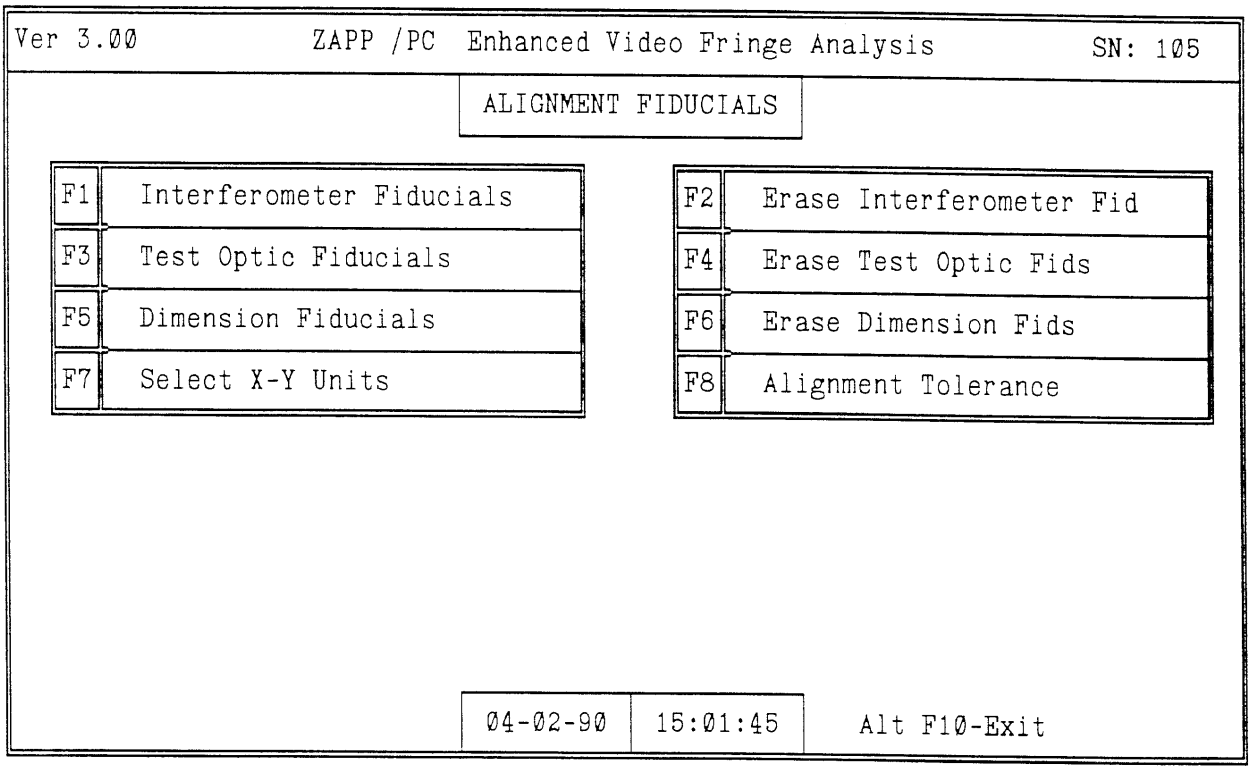
Save Intensity

It is often desirable to save the video image of an interferogram for reference or reprocessing. Activating the **Save Intensity** option will save the next video image to be acquired. Saved video frames may be processed with **Stored Video** as the selected data source. The video files have the **.INT** file extension, and the user is prompted for a filename just before the frame is grabbed. This option toggles the appearance of the filename prompt. See the *Data File Formats* chapter for an exposition of the intensity file structure. The user may thus create intensity files from other digitizers which conform to the *ZAPP /PC* format for **Stored Video** processing.

Alignment Fiducials Menu

The **ALIGNMENT FIDUCIALS** menu is used to define three types of fiducials for a given data map. These types are the dimension, interferometer and test optic fiducials. The dimension fiducials are used to define the lateral scale of the test optic in the physical units specified with the **Select X-Y Units** option. Distances in the X-Y and radial profile plots are presented in these units. The test optic fiducials are used in the **MANIPULATE DATA** menu to add or subtract data maps. The interferometer fiducials are used when subtracting a reference data map with the **Subtract Reference** option in the **CONFIGURATION** menu. Fiducial information is saved (and used) with the data map and fringe center files only when the fiducials are defined prior to the video acquisition of the fringes.

ALIGNMENT FIDUCIALS



Purpose of Alignment Fiducials

There are many instances where it is desirable to combine two phase data maps. Random influences such as turbulence and vibrations are (relatively) suppressed by averaging data maps. The variations between two surface states are highlighted by subtracting data maps. The addition and subtraction of data maps is most accurate and straightforward when the interferometric configuration is unchanged between measurements. Here an element in the first data array refers to the same surface location as the corresponding element in the second array. When the experimental configuration is altered, such as a rotation in the test surface or change in the interferometer's magnification, this correspondence is destroyed.

Alignment fiducials are used to restore the correspondence between the array elements of two data maps that overlap a common surface. A set of at least three markings, referred to here as fiducials, is placed on the test surface so that each is clearly seen against the interferogram. The position and orientation of the fiducial images will change with the optical configuration. Therefore, if the positions of the ordered fiducial images are known for both data maps, and spatial correspondence between the map elements can be determined, and the maps can be combined. The dependence on fiducials, however, can introduce new errors into the resultant data map. The mapping process will be degraded by errors in the fiducial image positions and the presence of distortion.

Fiducial Input

The dimension, interferometer, and test optic fiducials are defined by a common input scheme. After the fiducial type is selected, a video arrow cursor is displayed on the grey scale monitor (see Figure 4). Note that if fiducials of the current type have been entered previously, a prompt is given to be certain that over-writing is desired. Now, use the mouse to move this cursor to the first fiducial image. When the point of the arrow is at the fiducial center, press the right mouse button to mark its position. Each fiducial is numbered by the entry order. A double mouse keypress will return control to the **ALIGNMENT FIDUCIALS** menu. If greater positional accuracy is desired, use the left mouse button to generate a magnified video inset of the region about the cursor. With the inset on the screen, use either mouse button to enter the fiducial position, and cursor control automatically returns to the full screen. Use a double keypress to leave the inset when no fiducial input is desired. The inset feature is available only when **Live Video** is the selected data source.

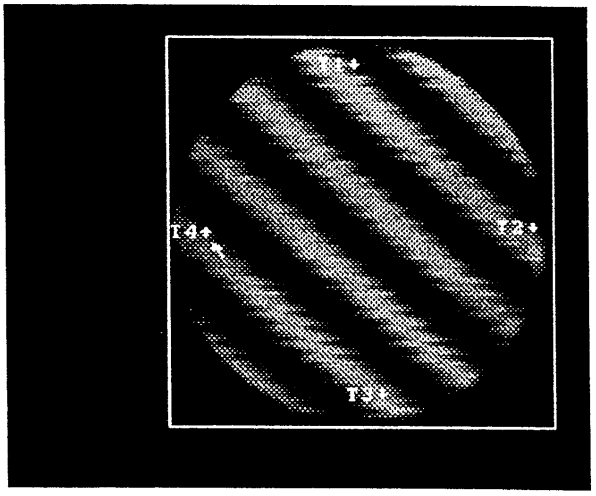


FIG. 4 - Entering Fiducials.

Dimension Fiducials

Two dimension fiducials are needed to establish the lateral scale of the surface under test. After the two positions have been established, a prompt is given for the known separation of these points in the indicated units.

Test Optic Fiducials

Up to four test optic fiducials may be entered. To use the fiducial information in the addition or subtraction of two data maps, at least three fiducials must be defined. Also be certain to assign the same number of fiducials on any two maps to be combined.

Interferometer Fiducials

Up to four interferometer fiducials may be entered. To use the fiducial information in the subtraction of a reference data map, at least three fiducials must be defined. Also be certain to assign the same number of fiducials on both maps.

Erase Fiducials

Any of the currently defined fiducial sets can be deleted with the appropriate erase fiducial option.

Select X-Y Units

This option will display a menu of the possible units for the lateral dimension. Select the desired units for your application. These units will be used when you input fiducials and for graphics displays.

Alignment Tolerance

When two or more data sets are merged (i.e., added, subtracted, averaged), and they are at different orientations, *ZAPP /PC* can use the test optic fiducials of each wavefront to align them. This option tells the program how close these fiducials have to line up after rotating and zooming one wavefront. This value is a fractional number which describes the tolerance in terms of *pixels*, or discreet data points, that the largest discrepancy may be. The default tolerance is 1 pixel. Setting the tolerance to a lower number will increase the chances that maps cannot be aligned within that tolerance. Setting it higher will allow maps to be merged which have more inaccurate test optic fiducials. A range of 0.1 pixels to 20 pixels is enforced.

Using the Complex Fringe Tracing Option

Once the **Complex Fringe Tracing** option has been selected from the **DATA ACQUIRE OPTIONS** menu, its actual use depends on the data source selection (Chapter 4). Here the **Live Video** option from the **DATA SOURCE** menu must be selected to process a new interferogram. With a properly designed pupil and obscuration mask to minimize potential errors (see below), interactive processing may begin. In the course of this processing the live image on the video (grey-scale) monitor is replaced with an intensity coded image of the fringes as they are being followed. These lines represent the path that the tracing takes: they do not correspond directly to the actual fringe centers. The fringes are ordered once the tracing is complete. A second coded image is shown on the video monitor during the brief ordering sequence; it is produced by connecting the fringe center coordinates with straight lines. This image is then replaced by the original interferogram with the fringe center positions superimposed. If the fringe ordering is entirely self-consistent, the verification map of the fringe centers will appear on the computer display. The presentation of the verification map will be interrupted by warning messages in the event any ordering inconsistencies are detected. The ordering problems which may be introduced by the presence of partial fringes and image artifacts are discussed shortly. Once the fringe verification map is displayed, the subsequent analysis proceeds according to the current configuration.

Potential Problems

To be useful, the complex tracing option must produce a fringe verification map that is well-sampled and properly ordered. The attainment of this result depends almost entirely on the accuracy of the fringe following in each case. While there are many internal checks which compensate for certain tracing errors, it is not possible to eliminate their influences altogether. In practice, serious tracing errors sharply decrease the likelihood of obtaining a correctly ordered fringe verification map. Consequently, it is advantageous to prepare the interferogram in such a way that tracing errors are minimized. To halt the tracing for any reason, simply press **E**, and program control will return to the **MAIN** menu. Suggestions for avoiding the most common tracing pitfalls are outlined here.

The serious fringe tracing errors fall into three broad categories: 1) following more than one fringe within a single path, 2) tracing false or partial fringes, and 3) not finding fringes or segments of fringes. The source of a tracing error may be correctable, as in the case of an improperly used obscuration mask, or not correctable, as could be the case with a very poor interferogram. The discussion of the potential errors is divided according to the most common sources.

Merging Fringes

Errors in this category can arise from defects in the interferogram; these may include image artifacts such as "dark bridges" which connect otherwise distinct fringes (see Figure 5), or areas of high noise where two fringes appear to merge. In such cases the tracing may cross into another fringe. One way to prevent severe merging errors is to place a portion of the obscuration mask over the problem area (see Figure 6). The tracing process will stop when the obscuration (or pupil) mask is encountered. In less severe cases a slight adjustment of the fringe orientation or use of the smoothing functions may improve the tracing. At times it may be useful to pass through the tracing with little or no obscuration mask with the intention of noting the problem areas as they occur. Merging errors may also occur when the pupil mask is not carefully defined. If dark gaps exist between the interferogram and the inner boundary of the pupil mask, the tracing may continue through this region and mistakenly connect two distinct fringes.

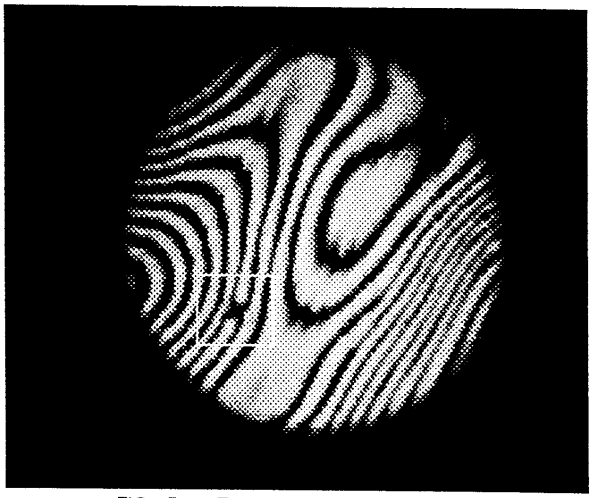


FIG. 5 - Example of merging fringes.

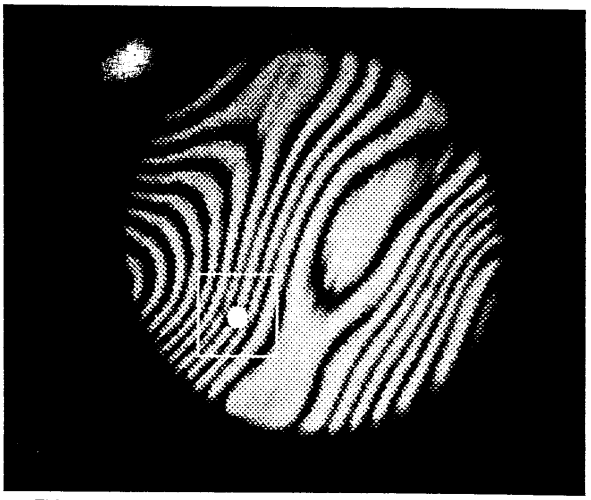


FIG. 6 - Example of obscuration on merging fringes.

Partial Fringes

At certain zero slope regions, an interfergram can contain relatively dark regions that cannot be associated with a particular fringe. Because the local intensity does not pass through the full intensity range, such a region is not a fringe, and should not be traced (see Figure 7). These partial fringe regions commonly occur at the center of closed fringes or between adjacent fringes of the same order (saddle fringes). Due to the sensitivity of the tracing functions, it is quite possible that "fringe centers" will be found in these areas. If more than five centers are found the resultant "fringe" may lead to errors in the subsequent fringe ordering. In cases where the interferogram can be altered, we recommend that the tilt and piston of the test surface be adjusted so that any false fringes are eliminated. Note that the presence of partial fringes may change due to thermal drift.

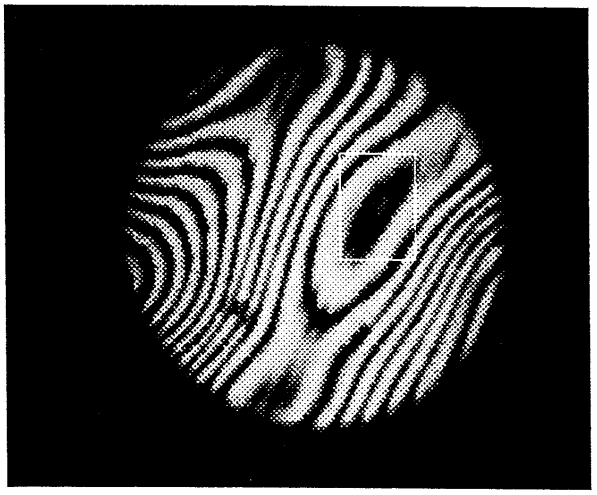


FIG. 7 - Example of partial fringe.

High Density Fringes

At least six pixels are required within each intensity cycle to conduct accurate fringe tracing and fringe center determination. In the event the interferogram of interest contains very narrow fringes it is advisable to decrease the local tilt or increase the optical magnification until the above condition is safely met. It is also helpful to orient narrow fringes along the vertical direction since the horizontal video signal is sampled at a somewhat higher resolution.

Broken Fringes

The **Fringe Sampling** setting can influence the success of the complex tracing, especially with the presence of broken fringes. As a consequence of the ordering process, each isolated fringe path (as seen on the video monitor) must contain at least five fringe center points. Fringes containing less than five center points will not be ordered and therefore will not be visible on the fringe verification map. The fringe sampling value should be set low enough so that the shortest fringe (or isolated segment of a broken fringe) will contain five center points. This fact should be kept in mind whenever a fringe-breaking obscuration mask is defined near the pupil mask. Note, however, that the sampling setting should not be so low that the 400 center per fringe limit is encroached, or that there are so many points in the interferogram that the computer's memory is exhausted.

Hard-Copy Fringes

When tracing a hard-copy interferogram (e.g., the video image of a photograph) the nature of the external lighting becomes a factor since the complex tracing algorithms are sensitive to small changes in the level of illumination. In the extreme case of sharp lighting directly above a glossy photograph, the resulting glare will make fringe following nearly impossible. We recommend that hard-copy fringes be indirectly and uniformly illuminated with a diffuse light source.

Using Pupil and Obscuration Masks

The obscuration and pupil masks may be defined on the video monitor under the **MANIPULATE MASK** menu. The design of each mask is important because it defines the regions of bad data. With respect to the **Complex Fringe Tracing** option, the tracing of a given fringe will be interrupted upon meeting either mask. Note that all unclosed fringes should begin and end at a mask boundary.

The pupil mask should only be used to define the outer boundary of the surface under study, and the obscuration mask should only be used to block out undesired interior points. Such regions may result from the presence of dust particles, fiducials, secondary optical elements and their supports, or known discontinuities on the test surface.

Obscuration masks can be divided into two categories: segmenting and non-segmenting obscurations. A segmenting obscuration is defined as one that intersects the pupil mask at more than one point, and thereby isolates a good data region within the pupil. Any obscuration that does not allow nearly segmented regions to share at least two fringes is effectively segmented as well. An obscuration for the classical spider pattern would qualify as a segmenting obscuration. The presence of such obscurations will limit fringe ordering to a single pupil segment. Commonly ordered fringes that terminate on small non-segmenting obscurations (where the obscuration ratio is less than one-half) will be linked.

Complex Fringe Tracing Warning and Error Messages

There are several ways in which the complex tracing and ordering process may terminate, leading the user back to the **MAIN** menu. Here is a listing and brief explanation of these errors. The remaining messages are warnings that the fringe center verification map to be produced by the current tracing may be less than optimal. Their occurrence, however, will not lead to a return to the **MAIN** menu.

1) **"no fringes found...processing terminated"** No fringes have been found in the search procedures.

2) **"an insufficient number of fringe center points remain...processing terminated"** A minimum of sixteen fringe center points are required on the fringe verification map. Center points within unordered fringes are not included in this total.

3) **"error allocating memory"** The final number of fringe center points was too high for the program to store internally. In this case, decrease the fringe sampling and/or the amount of tilt in the interferogram.

4) **"ordering error...processing terminated"** This message appears when a fringe has been assigned an order outside of the 1 to 60 range. This error will not occur with a good interferogram.

5) **"less than four fringes found...processing terminated"** At least four distinct fringes must be found in all cases. To obtain more fringes, increase the amount of tilt in the interferogram.

6) **"missing order error...processing terminated"** For any range of assigned orders there must be at least one fringe associated with each order value.

7) **"warning...too many center points found in fringe"** This warning will be displayed during the fringe tracing. It appears each time an attempt is made to store a fringe center beyond the 200 point limit for either "leg" of a fringe's tracing path. Processing will continue, but the sampling along the problem fringes will be incomplete. A decrease in the fringe sampling (an increase the entered value) is recommended in this case.

8) **"warning...maximum number of fringe segments found, tracing halted"** During the fringe tracing up to one hundred distinct segments may be used. Each segment is coded with an intensity that decreases slightly with each segment. After all the segments are used the tracing is stopped and an attempt is made to order the fringes that have been found. If the segment use is exhausted due to the presence of too many fringes, reduce the tilt magnitude if possible. If the exhaustion is caused by a true fragmentation of the fringes, try using the smoothing options in an attempt to merge the fringe fragments.

9) **"warning...possible ordering error between fringe orders n and m"** where n and m are the order values of two fringes having an apparent adjacency and an absolute difference greater than one. This warning typically results from either a tracing error (in which case the interferogram should be reprocessed) or poor sampling of a given fringe near the edge of the pupil. The fringes on both sides of the poorly sampled fringe are therefore locally adjacent, but not truly adjacent, and processing may proceed. If this warning is presented, hit any key to display the fringe verification map.

Introduction

The fringes in an interferogram are lines of constant optical path difference (OPD) between the wavefront under test and a reference wavefront. Adjacent fringes differ in OPD by a constant amount, usually one wave or one-half wave depending on the type of interferometer and the test set-up. Each fringe is assigned an order number which represents the integral number of waves in phase between fringes.

Input data consists of triplets of numbers (**x,y,m**), where **m** is the fringe order number and **x,y** are the coordinates of the data points. The fringes should be sampled as evenly as possible with points always taken at the edges of the pupil. In regions where data is sparse the Zernike polynomials are only weakly constrained and in areas of no data the polynomials are unconstrained and may lead to erroneous results. For example, if no data is taken at the edge of the pupil, the polynomial is relatively free to deviate from the correct representation of the wavefront and may appear to have high slopes near the edges. On the other hand, if the data is more highly concentrated in a region, that region will be more heavily weighted in various calculations. These calculations include the RMS wavefront departure from the reference wavefront, the values of third-order aberrations, and parameters defining the reference surface.

The assignment of fringe order numbers will determine the sign of the Zernike terms, i.e., what will be *high* and *low* with respect to the reference surface. The interferogram itself does not contain the wavefront polarity information. The assignment of the direction of increasing fringe order number in the interferogram reduction is also arbitrary and must be independently verified with respect to the sign of the OPD (and the Zernike coefficients) of the wavefront or surface. Empirically, it has been found if the *down* direction (toward the wide portion of the wedge) in an interferogram has been determined and the fringes are assigned increasing order numbers in this same direction, then the resulting Zernike coefficients and corresponding contour map will have the proper sign. In the interpretation of any result generated by *ZAPP /PC*, there is no better guide to its general validity than common sense.

The 'Ideal' Interferogram

The accurate reduction of interferograms depends to some extent on the quality of the interferogram as judged by the requirements of the *ZAPP /PC* numerical analysis routines. The "ideal" interferogram would have the following characteristics:

(1) It would be as large as possible so the fringe centers can be located with precision. This will help to decrease the random fitting error due to the scattering of points about the true fringe centers. The resolution of the graphics digitizing tablet is typically 0.001 inches, and so the limitation is with the human operator digitizing the fringe center positions. Fringe centers found automatically from video data are known to better than one-half a pixel.

(2) It would be as sharp as possible, i.e., in focus at the exit pupil so diffraction at the pupil is minimized. If this is not the case phase variations due to diffraction may alter the pupil phase front, i.e. bend the fringes near the edges of the pupil, and the interferogram is not completely indicative of the aberration due to the optical system under test. If fiducials are placed in the exit pupil they will appear in sharp outline when the proper focus is attained.

(3) Fiducials would be placed at the exit pupil, preferably of various shapes to identify the clear aperture and the orientation of the emerging wavefront. The fiducials can also be used to define a pupil coordinate system so that the resulting OPD map can be mapped accurately onto the optic.

(4) If the wavefront is reasonably smooth, 12-15 fringes will usually assure that the wavefront will be adequately sampled. Higher spatial frequency variations will require more fringes. The fringes should be made as "straight" as possible, avoiding closed fringes that would leave gaps in the data near the centers of the closed fringes. Tilt should be adjusted to add fringes as near to the edge of the pupil as possible so that the fitting of polynomials have constraining data points across the whole pupil.

(5) Several interferograms should be taken for each test with their results averaged to reduce the random digitization error as well as air turbulence, vibration, and other noise in the individual interferograms. This random error is seen in the random spread of the values of each of the Zernike coefficients. The averaging routines are based upon averaging points on the uniform grid so spline fitted wavefront maps as well as Zernike polynomial fitted wavefront maps can be used in the averaging process. The fitted Zernike coefficients can also be averaged. If there is a systematic error in the test it will not be averaged out. If the systematic error can be evaluated and translated into a wavefront map, the error may simply be subtracted from the averaged phase map.

Fitting Interferograms Using Zernike Polynomials

The Zernike polynomials are used in optics to describe optical aberrations in precise mathematical terms. A summary of the features of this polynomial set, relevant to the fitting of interferometric data, is presented below.

(1) The Zernike polynomials form an orthogonal set of polynomials over a normalized circular aperture; this implies that each term is independent from all others. Therefore, neither the inclusion or exclusion of a given term will affect the values of the other terms. This is strictly true only for continuous data, but it is approximately true for data that is uniformly spaced over a circular aperture. Most interferograms, however, will have some degree of irregularity that will cause the individual coefficients to vary slightly depending on the order of the fit. This effect will be small for reasonably distributed data.

(2) These polynomials are constructed so that every term used in the fit is minimized with respect to the RMS error (departure) from a given reference surface. This means that the fit will be "best-fit" in a least squares sense so that the volume between the Zernike surface and the reference surface is minimized. Since each term is RMS minimized, if any term is deleted it can only decrease the remaining RMS error. If the reference surface is a sphere centered at the diffraction focus, then each term is balanced so that it is minimized with respect to this surface. Deleting a term, then, can only increase the intensity at the diffraction focus if the aberrations are sufficiently small.

(3) The first two terms in the series, C1 and C2, describe the tip and tilt of the surface (or wavefront). These describe tilt in two orthogonal directions which can be combined in linear combination to describe the tilt of the surface in any orientation. Since this aberration is generally due to a misalignment, it can be removed easily by setting these two coefficients to zero.

(4) The third term, C3, is a focus term and represents a shift in focus from the diffraction focus. Again, it is removed easily by setting the coefficient to zero.

(5) The fourth and fifth terms, C4 and C5, describes two astigmatic surfaces. The first is oriented along the X axis and the second is oriented at 45 degrees to the first; this permits mutual orthogonality due to the first due to the four-fold symmetry of the aberration. Third order astigmatism in any orientation can then be described as a linear combination of these two surfaces.

Fitting Interferograms Using Zernike Polynomials

(6) The sixth and seventh terms, C6 and C7, describe third order coma. These two surfaces are oriented at 90 degrees to each other and form an orthogonal pair which can be linearly combined to describe coma in any orientation. Notice that the Zernike coma terms contain a component of tilt which is necessary to minimize the RMS difference between the comatic surface and the reference surface. Coma is quite often the result of a misalignment and can be deleted by simply setting these two coefficients to zero.

(7) The eighth term, C8, describes third order spherical aberration. This term has a component of defocus whereby the spherical aberration will be "best-fit" to the specified reference surface.

The first and third order Seidel aberrations can be calculated from the Zernike coefficients. *ZAPP /PC* will do this automatically whenever the Zernike polynomials are fitted to the data.

The remaining polynomials describe surfaces of higher order which, due to their symmetries, can be classified as higher order astigmatism, coma, or spherical aberration.

Polynomials used in *ZAPP /PC*

C1	$R \cos\theta$
C2	$R \sin\theta$
C3	$2 R^2 - 1$
C4	$R^2 \cos 2\theta$
C5	$R^2 \sin 2\theta$
C6	$(3R^2 - 2) R \cos\theta$
C7	$(3R^2 - 2) R \sin\theta$
C8	$6 R^4 - 6 R^2 + 1$
C9	$R^3 \cos 3\theta$
C10	$R^3 \sin 3\theta$
C11	$(4 R^2 - 3) R^2 \cos 2\theta$
C12	$(4 R^2 - 3) R^2 \sin 2\theta$
C13	$(10 R^4 - 12 R^2 + 3) R \cos\theta$
C14	$(10 R^4 - 12 R^2 + 3) R \sin\theta$
C15	$20 R^6 - 30 R^4 + 12 R^2 - 1$
C16	$R^4 \cos 4\theta$
C17	$R^4 \sin 4\theta$
C18	$(5 R^2 - 4) R^3 \cos 3\theta$
C19	$(5 R^2 - 4) R^3 \sin 3\theta$
C20	$(15 R^4 - 20 R^2 + 6) R^2 \cos 2\theta$
C21	$(15 R^4 - 20 R^2 + 6) R^2 \sin 2\theta$
C22	$(35 R^6 - 60 R^4 + 30 R^2 - 4) R \cos\theta$
C23	$(35 R^6 - 60 R^4 + 30 R^2 - 4) R \sin\theta$
C24	$70 R^8 - 140 R^6 + 90 R^4 - 20 R^2 + 1$
C25	$R^5 \cos 5\theta$
C26	$R^5 \sin 5\theta$
C27	$(6 R^2 - 5) R^4 \cos 4\theta$
C28	$(6 R^2 - 5) R^4 \sin 4\theta$
C29	$(21 R^4 - 30 R^2 + 10) R^3 \cos 3\theta$
C30	$(21 R^4 - 30 R^2 + 10) R^3 \sin 3\theta$
C31	$(56 R^6 - 105 R^4 + 60 R^2 - 10) R^2 \cos 2\theta$
C32	$(56 R^6 - 105 R^4 + 60 R^2 - 10) R^2 \sin 2\theta$
C33	$(126 R^8 - 280 R^6 + 210 R^4 - 60 R^2 + 5) R \cos\theta$
C34	$(126 R^8 - 280 R^6 + 210 R^4 - 60 R^2 + 5) R \sin\theta$
C35	$252 R^{10} - 630 R^8 + 560 R^6 - 210 R^4 + 30 R^2 - 1$
C36	$924 R^{12} - 2772 R^{10} + 3150 R^8 - 1680 R^6 + 420 R^4 - 42 R^2 + 1$

Zernike Polynomial Fitting to Fringe Data

When using either current digitized data or stored fringe data, 36 Zernike polynomials may be fit to the fringe data. The various fit orders are displayed along with the RMS fit error. This indicates how well the Zernike polynomials represent the real data. For smooth surfaces the RMS error is typically less than 1/50th of a wave. The fitted coefficients change slightly from one fit order to the next because the data is not quite orthogonal with respect to the polynomials. Also calculated are the Seidel coefficients derived from the Zernike coefficients. Statistics of the fit with respect to the actual data points and over a uniform grid are also presented.

Quality of Fit of Fringe Centers for Different Polynomial Orders

Term	N	Rms fit	Zernike Polynomial Coefficients (in waves)					
Plane	2	Ø.041	1.789	-Ø.268				
Sphere	3	Ø.035	1.787	-Ø.268	Ø.021			
4th Order	8	Ø.026	1.788	-Ø.267	Ø.022	-Ø.016	-Ø.022	Ø.009
			-Ø.004	Ø.011				
6th Order	15	Ø.025	1.789	-Ø.266	Ø.023	-Ø.014	-Ø.023	Ø.010
			-Ø.002	Ø.012	Ø.001	Ø.002	Ø.005	-Ø.001
			Ø.004	Ø.011	Ø.003			
8th Order	24	Ø.024	1.788	-Ø.265	Ø.019	-Ø.020	-Ø.025	Ø.008
			-Ø.001	Ø.007	Ø.001	Ø.005	-Ø.003	-Ø.003
			Ø.002	Ø.012	-Ø.001	-Ø.007	-Ø.007	Ø.001
			Ø.005	-Ø.009	-Ø.005	-Ø.005	-Ø.003	-Ø.006
Complete	36	Ø.022	1.788	-Ø.267	Ø.019	-Ø.020	-Ø.022	Ø.007
			-Ø.005	Ø.006	-Ø.006	Ø.001	-Ø.004	Ø.001
			Ø.000	Ø.007	-Ø.002	-Ø.007	-Ø.000	-Ø.008
			Ø.000	-Ø.011	-Ø.002	-Ø.003	-Ø.008	-Ø.005
			-Ø.005	-Ø.002	Ø.001	Ø.014	-Ø.012	-Ø.005
			-Ø.001	-Ø.002	Ø.008	-Ø.008	Ø.004	-Ø.000

SEIDEL ABERRATION

COEFFICIENTS FROM FRINGE CENTERS

Magnitude waves	Angle deg	Aberration
1.8Ø8	-8.5	TILT
Ø.Ø43		FOCUS
Ø.Ø54	-63.Ø	ASTIGMATISM
Ø.Ø31	-24.2	COMA
Ø.Ø64		SPHERICAL

	Wedge	Wavelength
TEST:	Ø.5Ø	Ø.633
USER:	Ø.5Ø	Ø.633

Terms Subtracted From Data
Tilt

Residual Wavefront Variations Evaluated at Fringe Centers

Number of pts	Peak	Valley	P-V	RMS	Strehl Ratio
151	Ø.Ø59	-Ø.Ø44	Ø.1Ø2	Ø.Ø21	Ø.983

Residual Wavefront Variations Over Uniform Grid (in waves)

Number of pts	Peak	Valley	P-V	RMS	Strehl Ratio
2989	Ø.1Ø9	-Ø.Ø38	Ø.147	Ø.Ø19	Ø.987

Seidel Coefficients

The third order Seidel coefficients can be calculated from the Zernike coefficients. The Seidel coefficients used in *ZAPP /PC* do not strictly follow the definition for the third order Seidel aberrations. The coefficients used are minimized in an RMS sense and are more or less orthogonal (the true Seidels are not). Therefore, for example, the coma term also contains a portion of tilt which minimizes the RMS wavefront error. Removing coma will also remove the required amount of tilt to minimize the RMS wavefront error. Similarly, the spherical coefficient will also contain a focus term which also will produce a minimum wavefront error in an RMS sense.

The Seidel Coefficients used in *ZAPP /PC* are defined with respect to the fitted Zernike polynomial coefficients as shown below.

SEIDEL COEFFICIENTS

	Magnitude	Angle
TILT	$\sqrt{C_1^2 + C_2^2}$	$\Theta = \tan^{-1}(C_2/C_1)$
FOCUS	$2\ C_3$	
ASTIGMATISM	$2\sqrt{C_4^2 + C_5^2}$	$\Theta = \frac{1}{2}\tan^{-1}(C_5/C_4)$
COMA	$3\sqrt{C_6^2 + C_7^2}$	$\Theta = \tan^{-1}(C_7/C_6)$
SPHERICAL	$6\ C_8$	

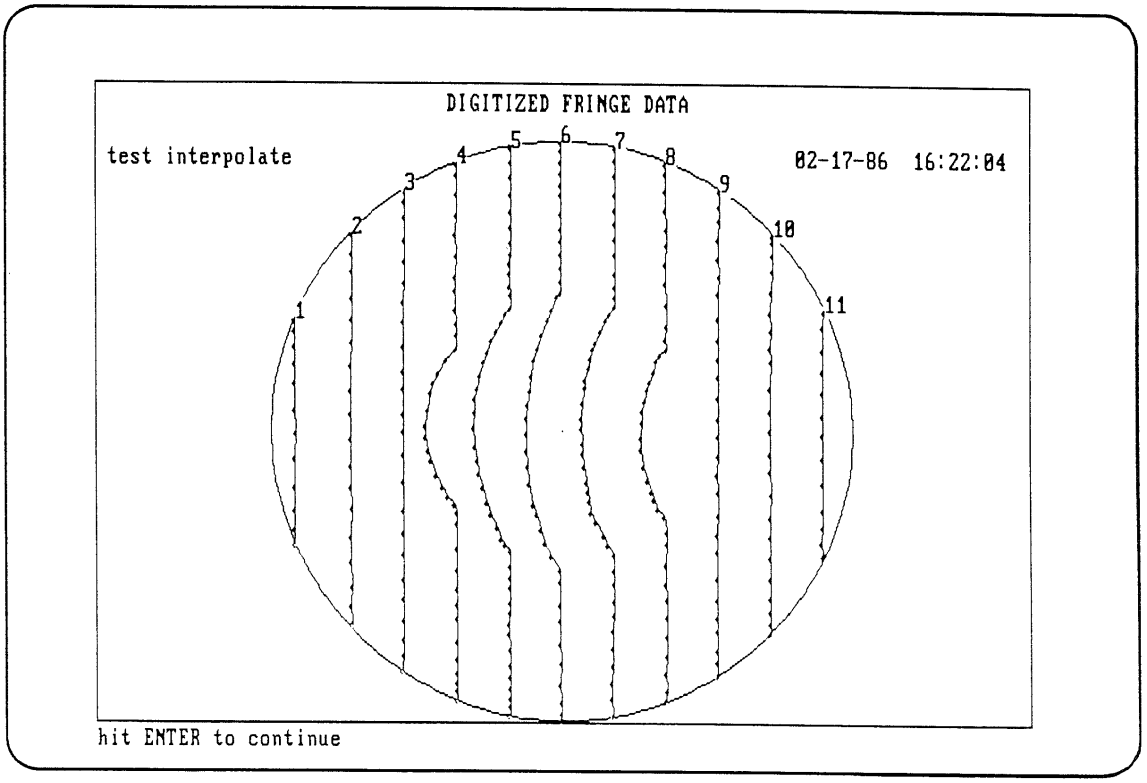
Interferogram Fringe Interpolation

There is an option in *ZAPP /PC* that will use an interpolation scheme instead of the Zernike polynomials to generate a uniform grid. The interpolation routine will create a 63 by 63 uniform array of phase data only up to where there is fringe center data within the pupil. To extrapolate out to the edge of the pupil, the **Extrapolate** option (see below) must also be selected.

The **Interpolate Fringes** feature can be selected from the **CONFIGURATION** menu and can be used with stored fringe data or data entered with the graphics tablet.

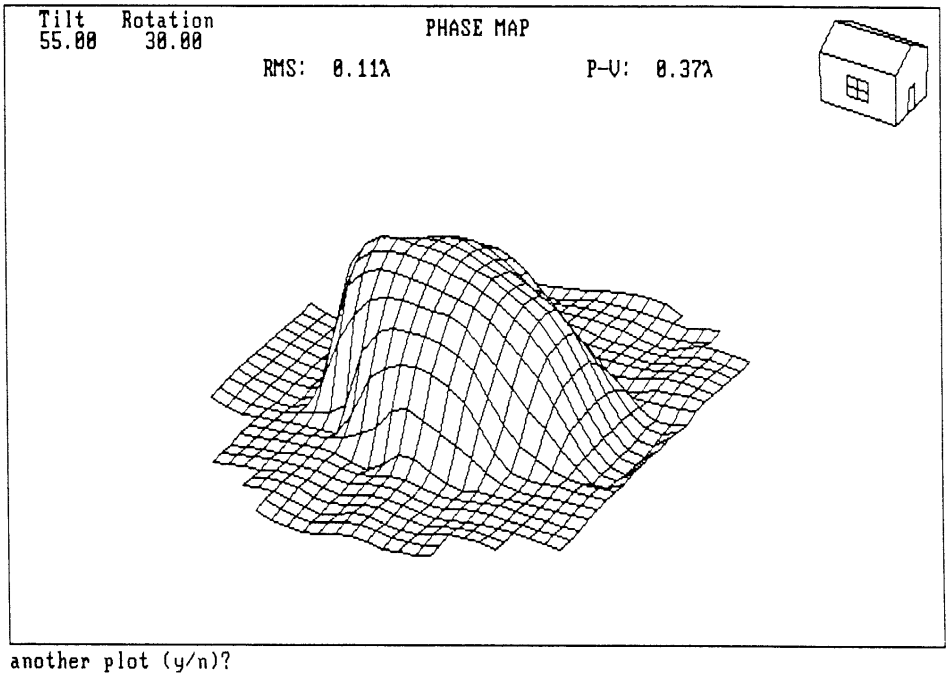
When the interpolation routine has completed creating a uniform data array, the selected aberrations or polynomials will be fitted and subtracted from the data. Care should be exercised in subtracting terms (**Tilt** and **Focus** are typical) from the interpolated data due to the high slope information preserved in the data and the possible lack of data out to the edges of the pupil. Consequently, the polynomial fit over these regions may be poor, and may therefore introduce errors in the resultant phase map after subtraction.

As an example of the interpolation of an interferogram, a digitized fringe data file with a sudden bump on the surface is presented below.

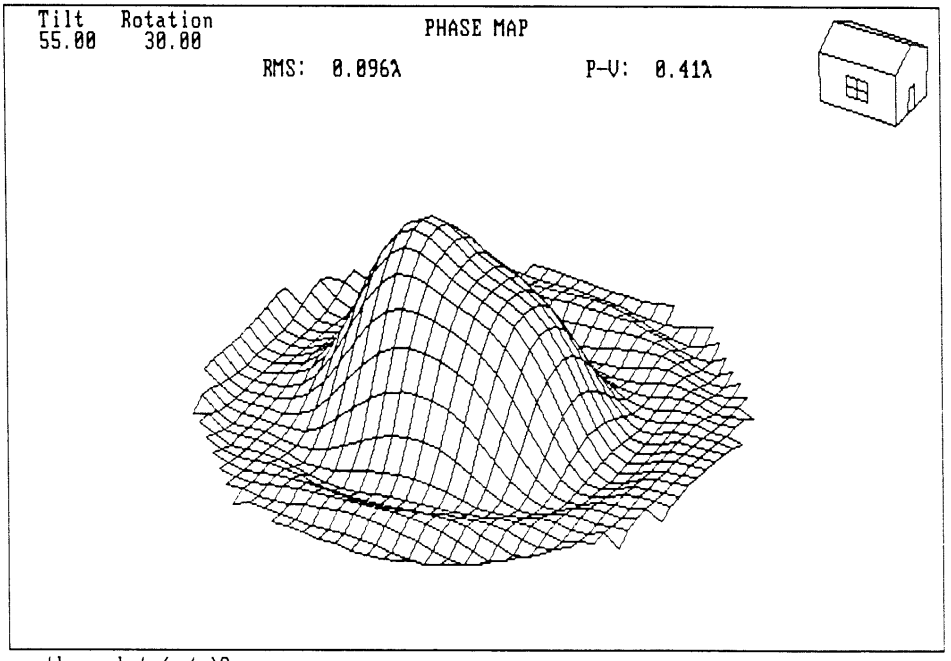


Interpolation Versus Polynomial Fitting

The first plot below is the result of interpolating the fringe data with overall tilt removed. This phase data map preserves the high slope information in the fringe pattern. In contrast the second plot is the same fringe data file processed again by fitting to the 36 Zernike polynomials with only tilt removed. The resultant phase data map does not retain the high slopes of the original data due to the smoothing effect of using a limited number of polynomials to describe this surface.



another plot (y/n)?



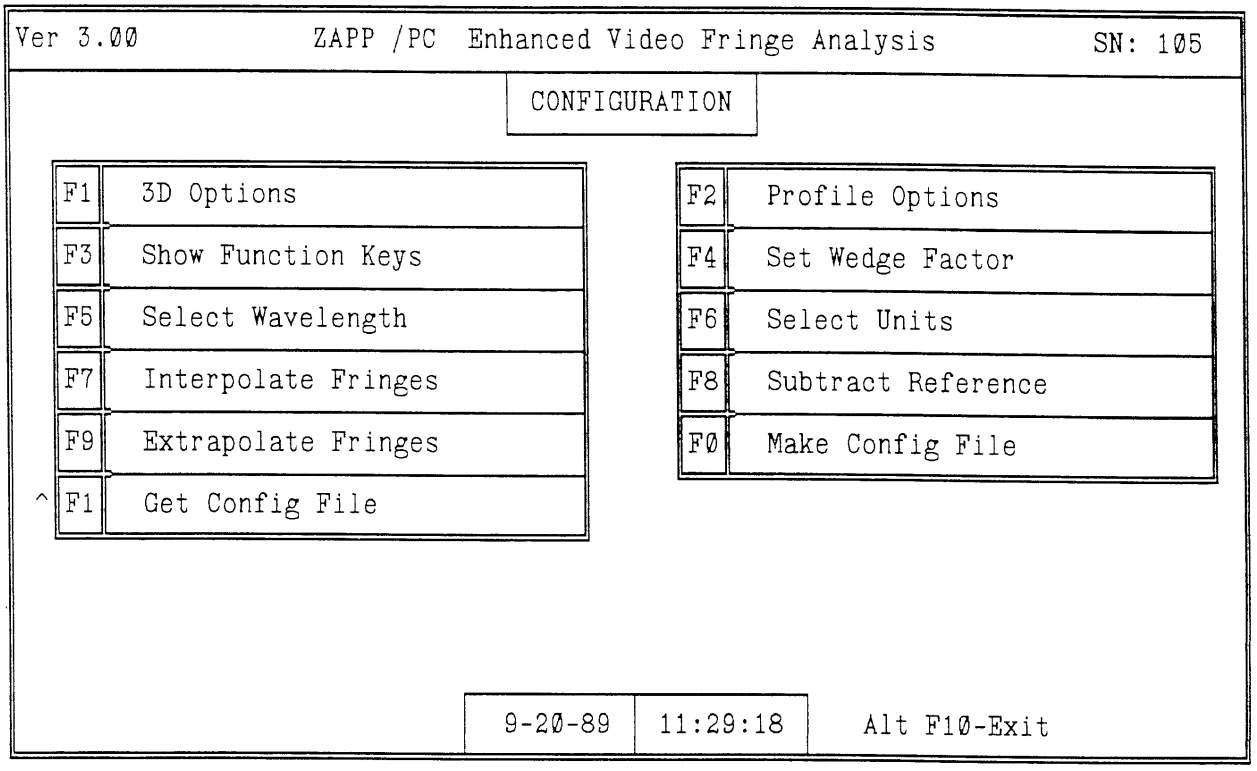
another plot (y/n)?

Setting up a Configuration

The configuration menu is used to select various options and features that are available in *ZAPP /PC*. These features include selecting the units that will be used by most of the numerical output displays, the wavelength used to generate the fringes, and other display and control parameters.

The following configuration options affect both the **INTERACTIVE** and **BATCH PROCESSING** modes.

CONFIGURATION MENU



Displaying Function Keys

A mouse device allows rapid selection of functions within menus. At times however it may be desirable to use the function keys at the left or top of the IBM PC keyboard. Or you may not have installed a mouse on your system, in which case the function keys are automatically the default. (The mouse is highly recommended for ease of operation and required for some tasks.)

Function key labels can be displayed on the menus by selecting **Show Function Keys** in the **CONFIGURATION** menu and then exiting that menu. Now all menus will have the function key labels to the left of the commands/functions. You can remove the labels by disabling the **Show Function Keys** command.

Function key selections can be made at any time whether or not the function key labels are being displayed. If there are more than ten options within a menu, they can be accessed by pressing the **Shift** key and then the function key. The function key label in the menu display will have a small up arrow to the left of the label indicating the **Shift** key is required to access that option.

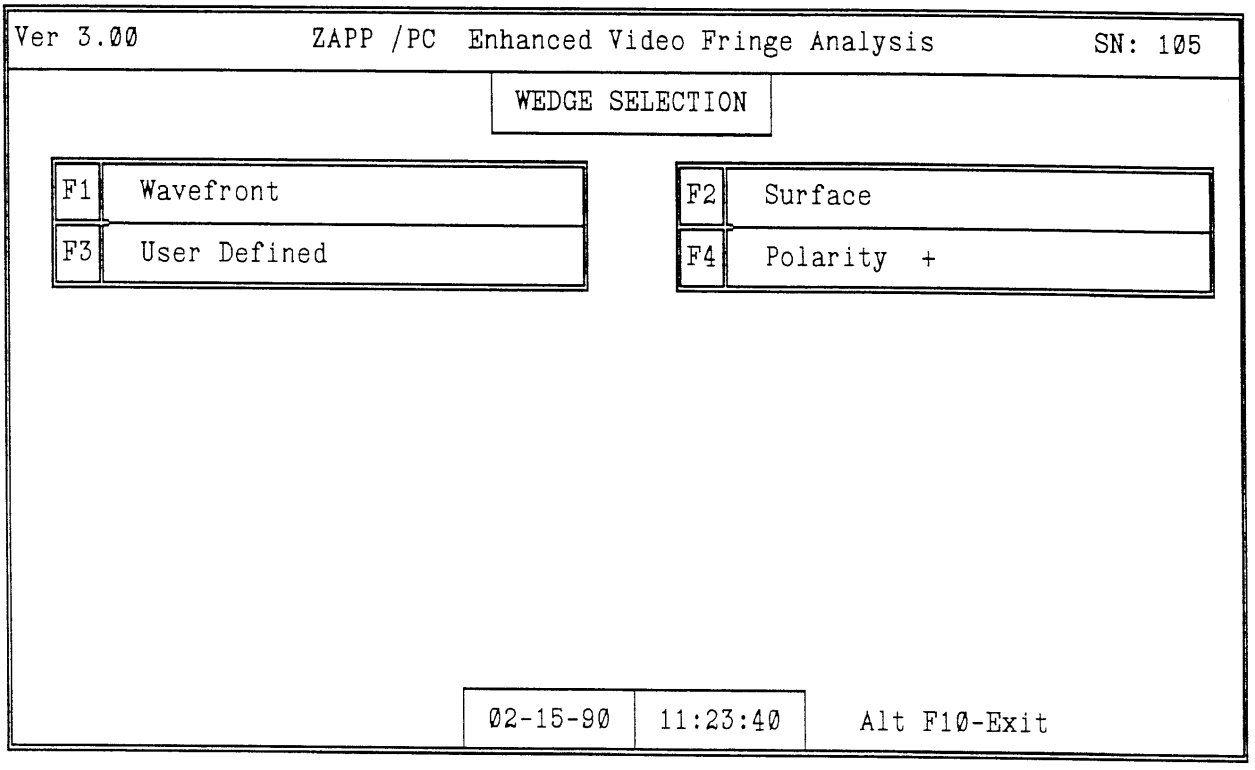
Interferogram Wedge Factor

The polarity of wavefront heights cannot be automatically determined by digitizing a single interferogram. The user must indicate a *Wedge Factor* to the software, in order to determine the scale of features of an interferogram. The wedge factor may be changed or selected on the **WEDGE SELECTION** menu. This wedge factor is a positive or negative number; the sign of the wedge factor determines the direction (increasing or decreasing) that the fringe order numbers change, and the magnitude determines the number of waves per fringe. A wedge factor of -1.0, +1.0, -0.5 or +0.5 are typical but others are sometimes appropriate. The value +0.5 is the default wedge factor.

For example, an interferogram taken from a double-pass test should use a wedge factor of +0.5 or -0.5 to examine surface deviations (as opposed to wavefront deviations). The sign of the wedge factor will determine whether a particular surface feature is recognized as a *bump* or as a *hole*, and which part of the surface represents the *highest* or *lowest* part. Similarly, if the features of the wavefront (instead of the surface) are of interest, a wedge factor of +1.0 or -1.0 should be used.

The **Wavefront** option will automatically change the wedge factor's magnitude to 1.0 (the polarity is unchanged). Likewise, the **Surface** option will automatically change the wedge factor's magnitude to 0.5, leaving the polarity unchanged. If, after processing the interferogram, the surface representation looks incorrect, use the **Polarity** option to toggle the sign of the wedge factor (the current sign is shown on the menu option). For special interferometer setups (grazing or nonperpendicular incidence, four-pass tests, etc.), other values may be entered with the **User-defined** option. Note that if the value of a user-defined wedge factor is 1.0 or 0.5, the **Wavefront** or **Surface** options automatically activate instead. The **Polarity** option will automatically reflect the user-defined value, and the value which appears on the **User-defined** option is the magnitude of that value entered.

WEDGE SELECTION MENU



To increase the sampling resolution in the pupil of the interferogram, one can digitize not only the center of the dark fringes, but also the center of the bright fringes when using the graphics tablet. (Of course, one can increase the amount of tilt in the fringe pattern to obtain similar results.) If both bright and dark fringes are digitized, then use a wedge factor of 0.5 to obtain the wavefront and a wedge factor of 0.25 if surface deviations are desired. In oversampled cases you can digitize every other fringe, and set the wedge factor to 2 for wavefront or 1 for surface.

Determination of Wedge

To determine whether a fringe deviation is due to a bump or a hole, you must know the relationship between the direction of the deviation with respect to the direction of the wedge. For a Fizeau type interferometer, if the fringe moves toward the thin portion of the wedge, this indicates a hole. If the fringe moves toward the thick portion of the wedge, then there is a bump. If the surface is a concave sphere the fringes will curve toward the thick portion of the wedge. For a convex sphere, the fringes will curve toward the thin portion of the wedge.

Subtract Reference

A reference file will be automatically subtracted from a new measurement when this option is activated. This is useful when known wavefront errors are to be removed from a measurement. The computer will ask for a file to subtract; this may be a phase (**.MAP**) file or a Zernike (**.ZRN**) file. The default file type is **.MAP**.

```
Input Reference to subtract
     (type none for no file) []:
```

The program will verify that the specified file exists. If there is an error the following message will be displayed.

```
error opening file!
```

If you make a mistake, re-type the entry or type an **E** and press **<Enter>** to abort and return to the menu.

The specified reference map is subtracted directly (with no manipulation) if the measured data contains less than three interferometer fiducials. Otherwise, if the number of interferometer fiducials on each map is the same, the fiducials will be used to manipulate (scale, rotate, translate, or invert) the reference data map so that the subtraction of the phases at corresponding points is performed. If the fiducial sets cannot be manipulated to match (e.g., from unequal fiducial number or poor positioning), a warning message will appear and the current data map is unaffected. Fiducial based subtraction is not available with **.ZRN** files.

Extrapolating Fringes

The **Extrapolate Fringes** option is located below **Interpolate Fringes** on the **CONFIGURATION** menu. The activation of the extrapolation feature is of significance only when the interpolation option is on. Interpolation by itself produces phase values across the uniform grid estimated by spline interpolation as opposed to the least-squares weighting of the leading Zernike polynomials over the unit circle. As such, the interpolation, can estimate only those phase values at grid points interior to the fringe centers. The extrapolate feature, however, allows the phase values at the exterior pupil boundary to be estimated so that the wavefront (surface) may be examined over the entire pupil. Caution must be exercised when quoting the peak-to-valley values when the extrapolation option is active: in cases where the extrapolating fit is not ideal, this value (and to a lesser extent the RMS deviation) can be inflated. For questionable instances, quote the non-extrapolated values.

Make Configuration File

When all the options from the configuration have been selected, this command will create a file to save the current state of these options. This makes it easy to setup a configuration just by reading this file instead of manually selecting them each time *ZAPP /PC* is executed. Therefore the options most used can be saved as a configuration file which is loaded on start-up. This configuration file not only saves options from the **CONFIGURATION** menu, but also the **BATCH SETUP** menu, and other items such as the current data source. After all the desired features are selected (such as which aberrations to subtract), use the **Make Config File** option to save the current selections. This option will prompt for a filename to save the configuration. The default file is named **CONFIG** and is loaded automatically when *ZAPP /PC* is executed. If a different filename is specified, the *ZAPP /PC* program must be executed as follows:

zappc *filename*

where *filename* is the new configuration file.

Get Configuration File

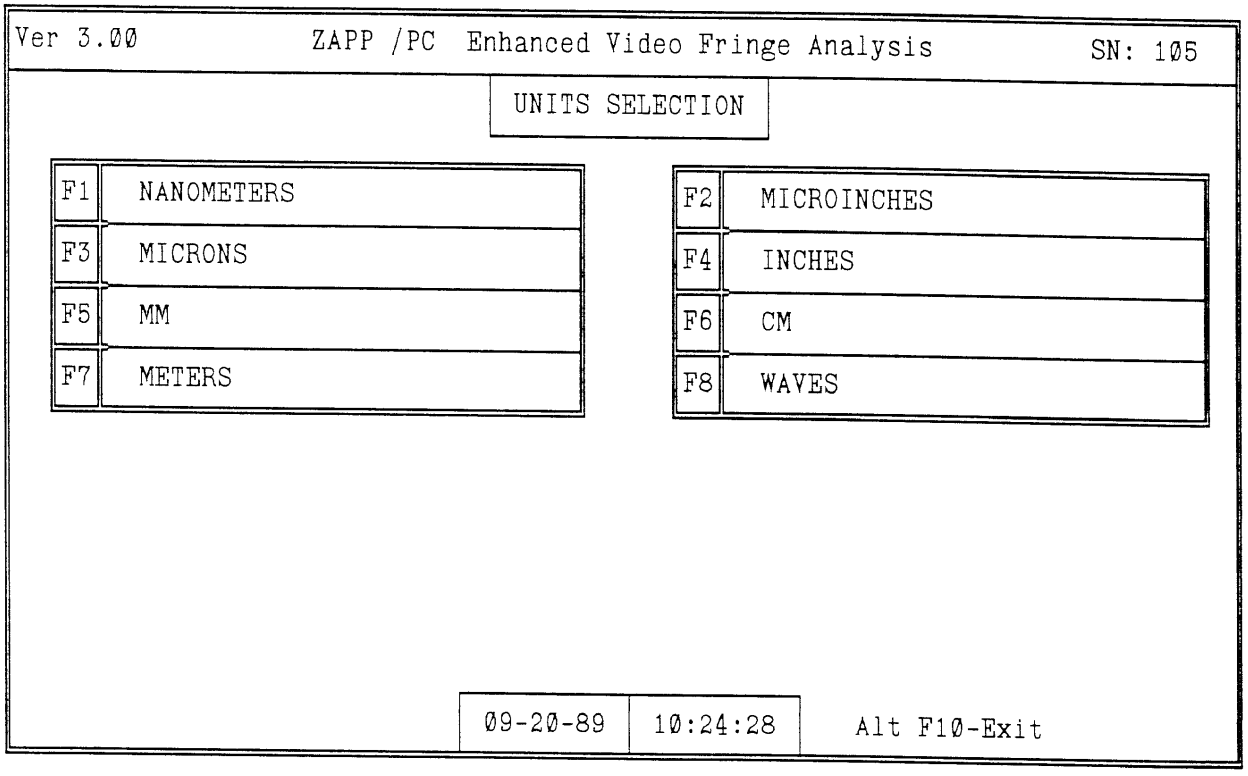
The **Get Configuration File** option allows the user to load a configuration file that was saved with a filename other than **CONFIG**. A prompt will be given for this filename, and the new configuration file will be loaded, if found, after pressing <**Enter**>.

Units

Numeric quantities in *ZAPP /PC* are represented internally as phase values in units of waves. The user can specify the presentation of analysis and graphics quantities in a variety of units.

The interactive nature of *ZAPP /PC* allows one to display a graphics plot (for example a Radial Profile) in one set of units and then exit, select the **CONFIGURATION** menu, then **Select Units**, and then choose another set of units and return to re-display the plot with the new units.

SELECT UNITS MENU

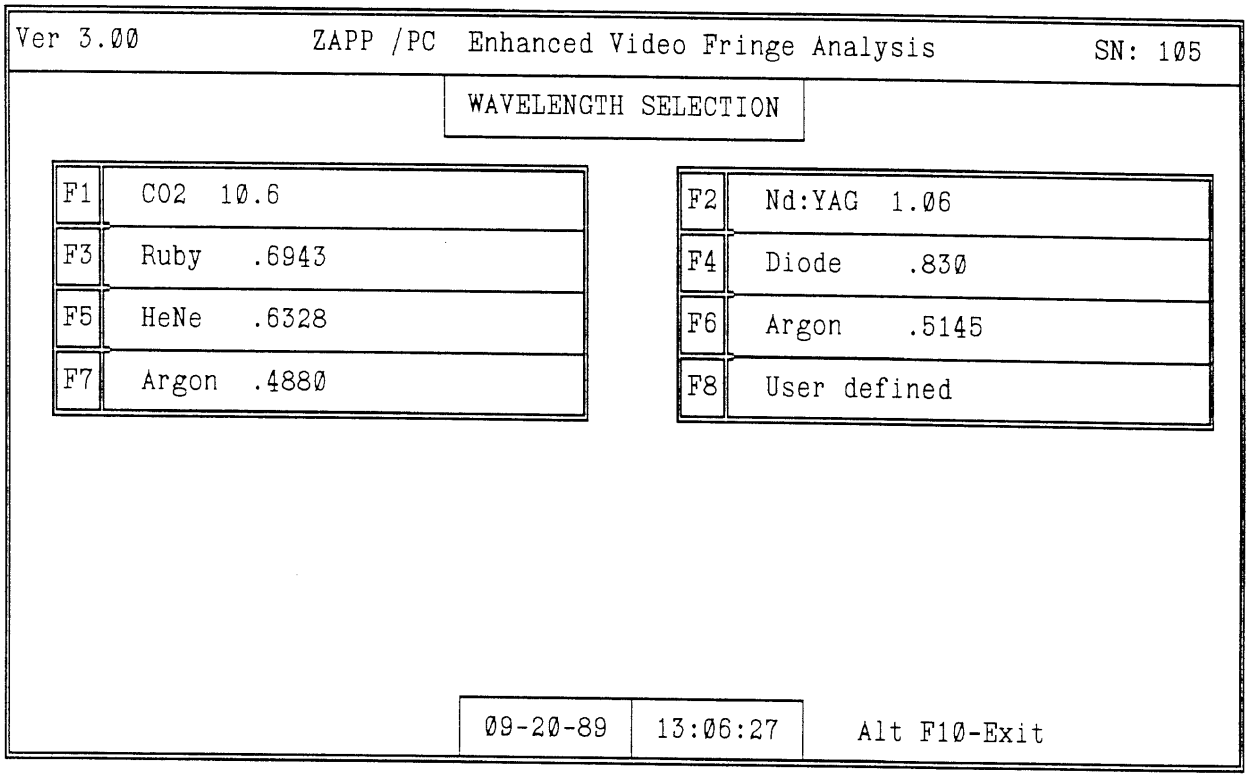


Wavelength Selection

From the **CONFIGURATION** menu, **Select Wavelength** offers the user the ability to choose a wavelength upon which he wishes the analysis to be based. Typical laser wavelengths are given for quick selection. If the desired wavelength is not shown in the menu, the user can enter any wavelength (in microns). The pre-defined laser wavelengths are also presented in microns.

The entered wavelength along with the selected units and wedge factor define the scale factor which a fringe represents.

WAVELENGTH SELECTION MENU

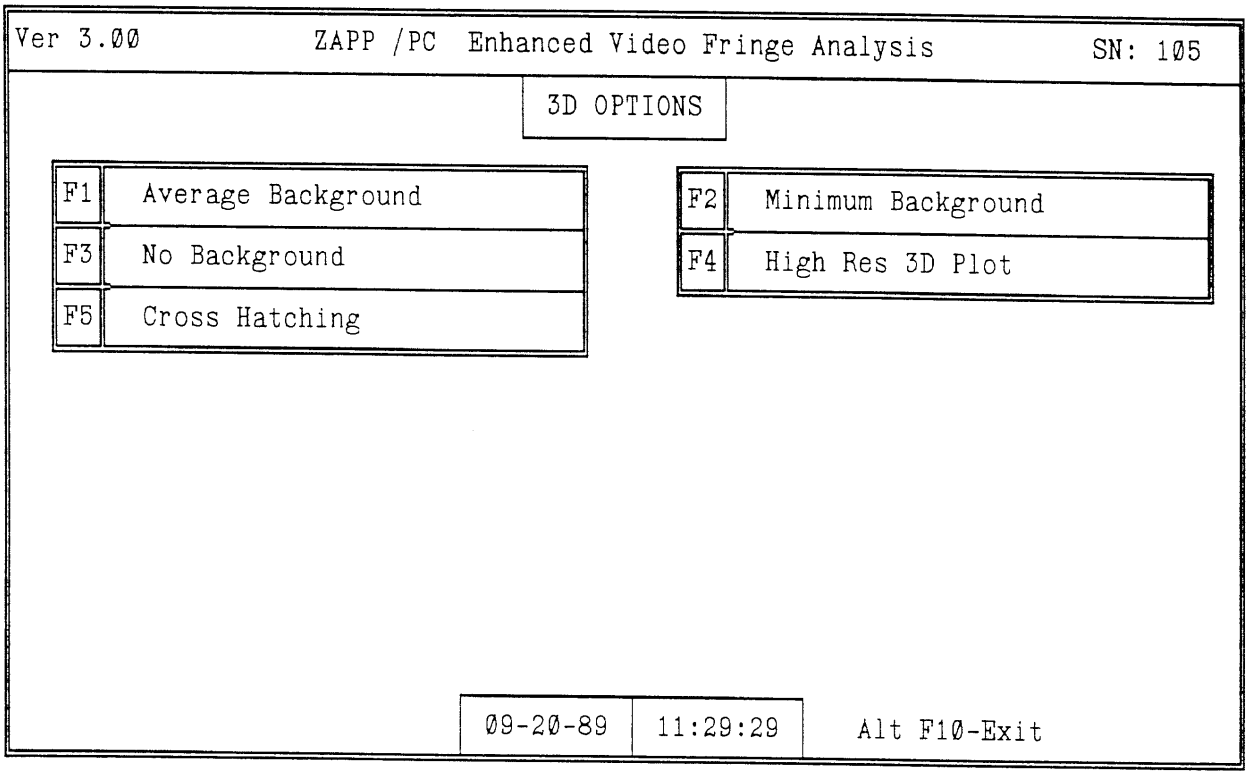


The selected wavelength value will be stored when the data is saved to a disk file. This wavelength remains with the data set as the *test* wavelength. If, for example, one tests an optical surface at the Helium-Neon wavelength and wishes to determine the quality at 10.6 microns, then before digitizing the user should select a wavelength of 0.633 microns. After analyzing the data, the user can then select 10.6 as the wavelength and then re-analyze the data. Now the data is rescaled by the ratio of the test wavelength to the user wavelength. Be careful when data is being digitized because the current selected wavelength will be used as the test wavelength and stored with the data.

3D Plot Options

The options in this menu change the way the 3D plot will be displayed by affecting resolution as well as the background reference plane.

3D OPTIONS MENU



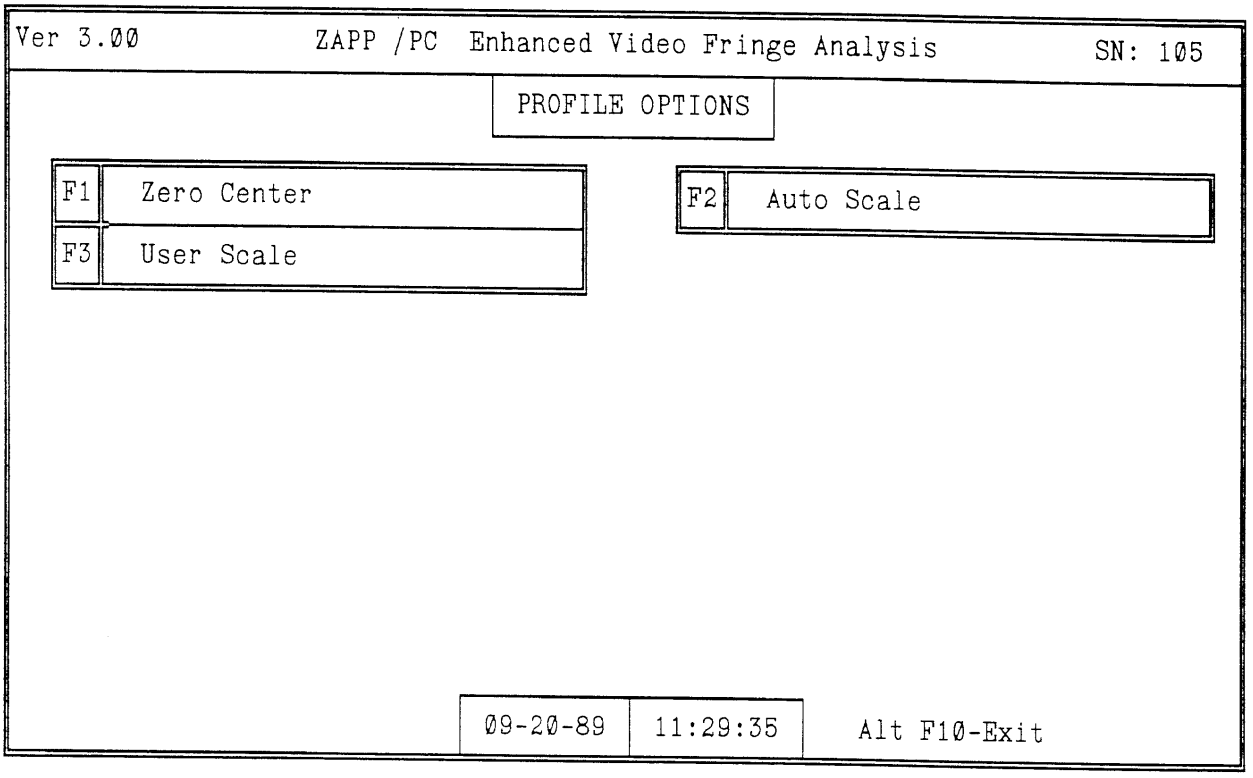
Cross Hatching, 3D Resolution, and Background

These options select display parameters that control the 3D perspective plot. Refer to the section that describes the 3D plot in Chapter 8 for information about these options.

Profile Options

These options select display parameters that control the profile plots. Refer to the section that describes the profile plots in Chapter 8 for information about these options.

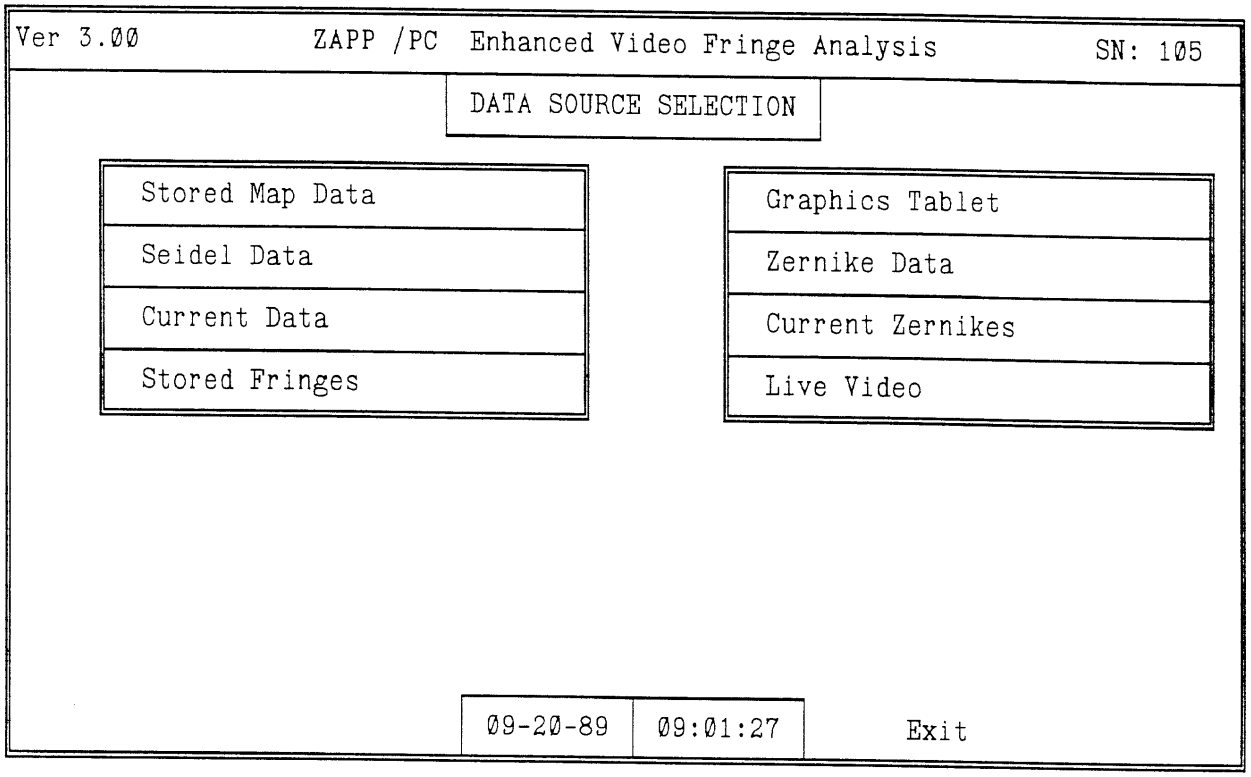
PROFILE OPTIONS MENU



Introduction

The *ZAPP /PC* program can analyze data from different sources. Most often the user will either take new data from the graphics tablet or video fringes, or analyze a stored data map of fringes or a phase map. However, there are several other methods to generate data that can be used to subtract aberrations from a given data set or that may be used simply as a learning aid.

DATA SOURCE SELECTION



The Graphics Digitizing Tablet

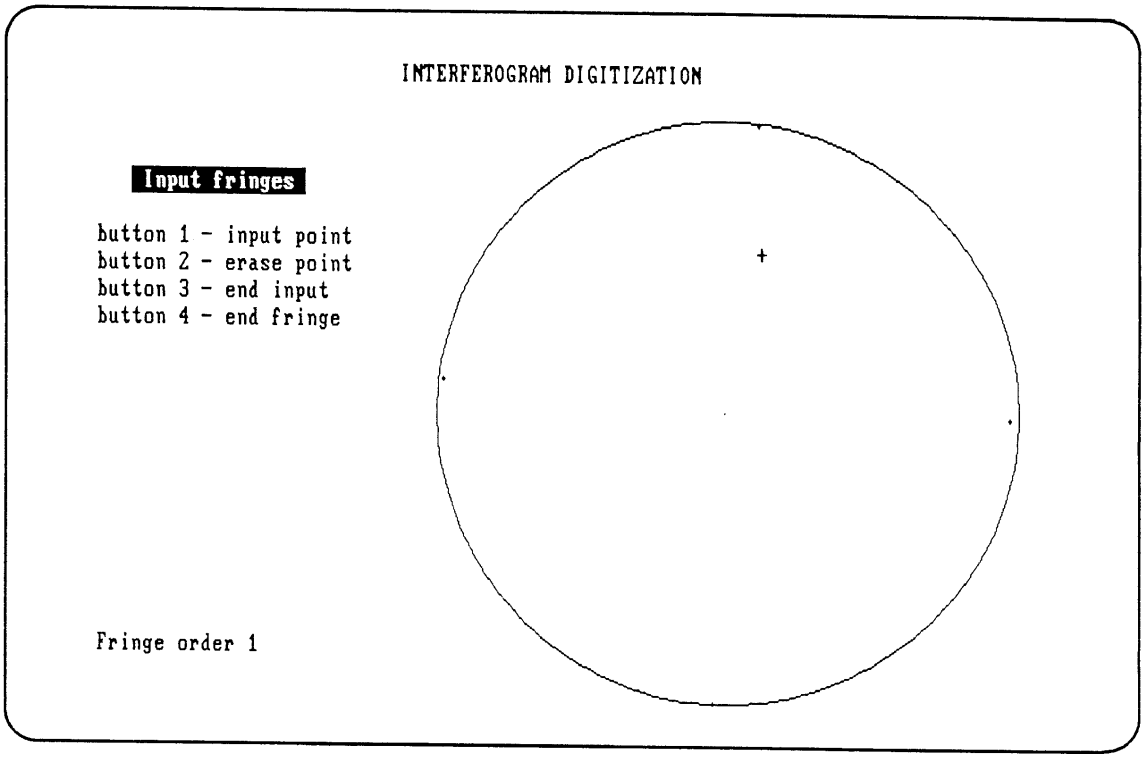
The graphics tablet along with a four button cross-hair cursor allows the user to input **x,y** coordinates to the microcomputer. The program will expect to input fringes from a tablet connected to the serial port on **COM1**. Refer to the *Computer & Peripherals* section for information about setting up the graphics tablet. The PC must have a serial port addressed to **COM1** (refer to the documentation on the specific serial interface used). The *ZAPP /PC* software will automatically program the baud rate of the **COM1** port so there is no need to use the DOS **MODE** command.

Setting up the Interferogram

Use paper tape to attach a photograph of the interferogram to be digitized on to the surface of the graphics tablet with any orientation. The interferogram can be placed anywhere on the active surface of the graphics tablet.

An interferogram can be digitized using the graphics tablet by selecting the **Graphics Tablet** data source from the **DATA SOURCE** menu. Then from the **MAIN** menu, select either the **Interactive Processing** or **Batch Processing** option. Program control will enter the **INTERFEROGRAM DIGITIZATION** mode. Now the fringe center digitization process can begin.

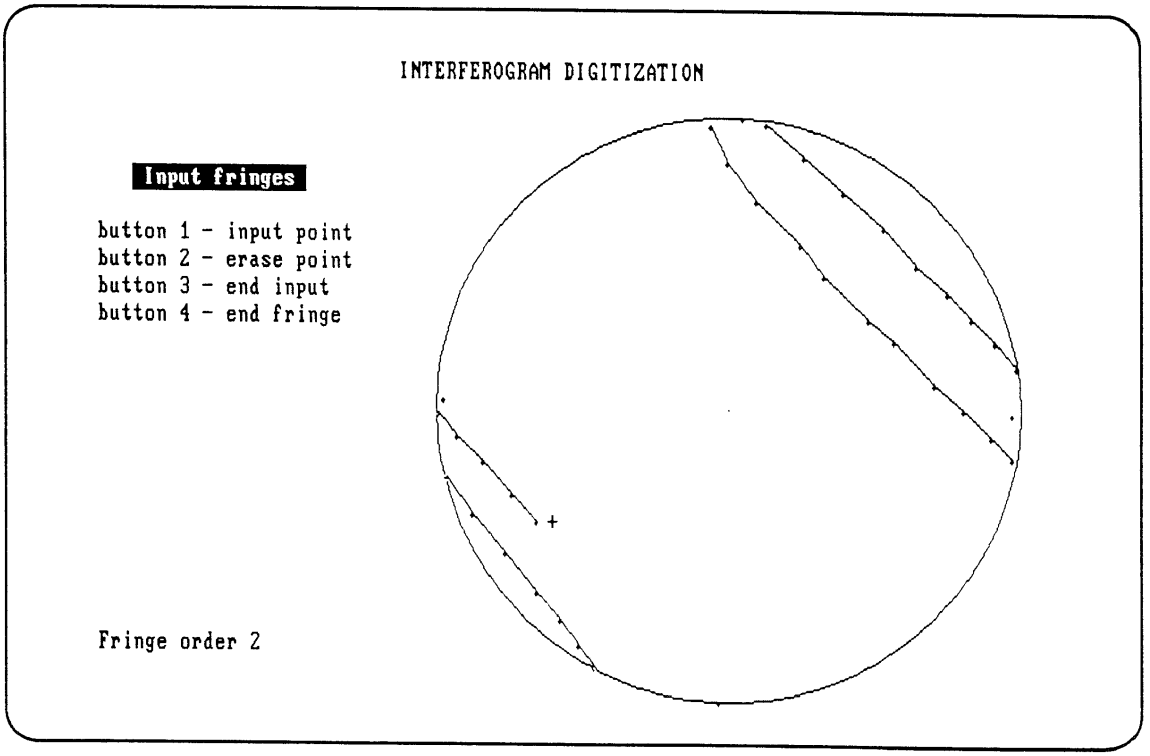
Four fiducial locations need to be entered for coordinate normalization. Pick fiducial locations at the edge of the interferogram pupil, equally spaced around the pupil. Preferred fiducial entry is the maximum and minimum vertical and horizontal extent of the interferogram pupil. Position the graphics tablet four button cursor at each fiducial location and press button 1 (top button). After the last fiducial has been entered press button 3 (bottom button). A circle will be drawn delineating the edge of the circular pupil with tick marks indicating the position of the fiducials.



Digitizing Fringes

To digitize fringe center positions, move the graphics tablet four-button cursor cross-hair over the fringe center. To input a coordinate, press button **1** (top button). A beep will sound indicating an entered point. If a mistake is made, previous digitized points can be erased by repeatedly pressing button **2** (left button). While the orientation of the fringes and the starting fringe position may be at the user's discretion, the first fringe digitized is of fringe order 1, with following fringes increasing in order number (see **WEDGE FACTOR** to adjust for this convention). Try to digitize fringe center points as close to the edge of the pupil as possible. This aids in better polynomial fits to the data. Sample the fringe centers along a fringe as evenly as possible, entering approximately as many points as there are fringes in the pupil. For example, if there are 14 fringes across the interferogram, digitize about 14 points along the longest fringe. This also aids the fitting process. Once a fringe has been entered, press button **4** (right button) to start the next fringe order number. Press button **3** (bottom button) when all the fringes have been entered. Press **E** at any time on the keyboard to abort digitization.

If there are closed fringes in the interferogram, or if more than one fringe has the same order number, then a new location fringe can be digitized with the same order number by pressing **S** and continue digitization. This will inhibit the connection of a line through the points.



Stored Map Data

A Data Map previously stored to disk will be analyzed when processing data. The Data Map is loaded and further processing (depending on whether the user selects **INTERACTIVE PROCESSING** or **BATCH PROCESSING MODE**) will be done.

Current Data

If during the processing of data the user exits to the **MAIN** menu, but wishes to further process the existing Data Map, the selection of **Current Data** followed by a processing mode will restore the existing data set.

Stored Fringes

A previously digitized interferogram stored on disk will be processed by fitting 36 Zernike polynomials to each digitized fringe point. The sequence of output will be the same as if **Data Source:Graphics Tablet** was used but now there is no need to actually digitize the interferogram. The fringe data files are stored using the **.DAT** extension.

Stored Map Data

A Data Map previously stored to disk will be analyzed when processing data. The Data Map is loaded and further processing (depending on whether the user selects **INTERACTIVE PROCESSING** or **BATCH PROCESSING MODE**) will be possible.

Zernike and Seidel Data

These data sources allow the user to generate data sets based on a set of polynomials. These polynomials can represent different characteristics of aberrations of an optical surface. Refer to the section titled *Generating Aberrated Wavefronts* and *Subtracting Aberrations* in Chapters 12 and 13 for more information about these data sources.

Live Video

Processing this data source will capture fringes from the video digitizer and automatically trace and order fringe centers. Before processing live video fringes, the options under **View Video** from the **MAIN** menu should be selected. Refer to Chapter 1 for more information about automatic video fringe digitization.

Stored Video

Any previously saved video image can be loaded prior to entering the **View Video** menu and just before video fringe processing. A filename prompt is presented at these points to load the appropriate **.INT** file. The **Stored Video** source is identical to the **Live Video** source in all other respects with two exceptions: 1) Contrast Enhancement is not possible with a stored image; 2) the magnified video inset feature for precise fiducial positioning is not implemented under **Stored Video**.

Wavefront Data Formats

There are three data formats with which wavefront data can be represented and stored by *ZAPP /PC*. The first is fringe data. This data, generated by digitizing an interferogram from the graphics tablet or video digitization, consists of a file of triplets (**x**,**y**,**m**) where **x**,**y** represents the coordinate of a point on a fringe and **m** is its corresponding order number. Each fringe is represented by an order number which is just the phase value in multiples of a wave.

The second data format is a 63 by 63 phase array which is usually generated from the fringe data. Digitizing a fringe pattern creates data points only where fringes exist. Recall that fringes represent contour intervals of the wavefront. Thus the data exists only where there are fringes; this can therefore change from one interferogram to the next. Fitted polynomial coefficients from this fringe data can then be used to interpolate between these data points to a uniform sampling array. *ZAPP /PC* creates a uniform array of data points over a circular pupil within a 63 by 63 array.

The third data format is a set of polynomials that can be manually input or generated from the uniform phase array. The phase data can be fitted to a set of 36 polynomials called Zernike polynomials. The Zernike polynomials have been used in optics due to certain properties of these polynomials which aid in describing optical aberrations. These polynomials can also be used to generate a phase map (uniform phase array).

The fourth data format is the intensity file format. The data in this file is a byte array of grey level values which compose the video image. As mentioned earlier, these files may be saved and retrieved as stored video.

See the *Data File Formats* chapter for a detailed description of the composition of these data formats.

Introduction

After the fringe centers of the interferogram have been found and ordered the fringe verification map will appear on the screen of the computer display. The fringes and their center points may be modified with the editing functions listed at the base of the screen. These functions include the addition and subtraction of individual center points, and the splitting and order reassignment of entire fringes.

The desired editing function is selected with the use of the right-hand mouse button. The current function is highlighted and "moves" to the right one item each time this mouse button is pressed. The left-hand mouse button is used to perform the selected function.

Remove Point

To remove a fringe center point, select the **Remove Point** function and position the tip of the mouse cursor within the verification map next to the point to be removed. Press the left mouse button to remove the point from the verification map. The point is erased from the video monitor screen if **Live** or **Stored Video** is the current data source. Once a point is removed there is no way to restore it (exactly) to the verification map. If **Stored Fringes** is the selected data source, deleted points can be restored by reloading the original fringe file (so long as it is not overwritten) during interactive processing.

Add Point

Fringe center points may be added to the verification map if **Live** or **Stored Video** is the current data source. After highlighting the **Add Point** function depress the leftmost mouse key and notice the mouse controlled video cursor within the interferogram image. Position this cursor so that it is closest to the fringe that will include the added center. Now depress the left mouse button without releasing. The bright point that appears at the tip of this cursor may be *dragged* across the video image while holding down the mouse button. Release this button after arriving at the desired location. The new center point is then seen on the video screen and the verification map. Additional points may also be added in this manner. Use the rightmost mouse button to exit this function. Any improperly placed center can be erased with the **Remove Point** function.

Change Order

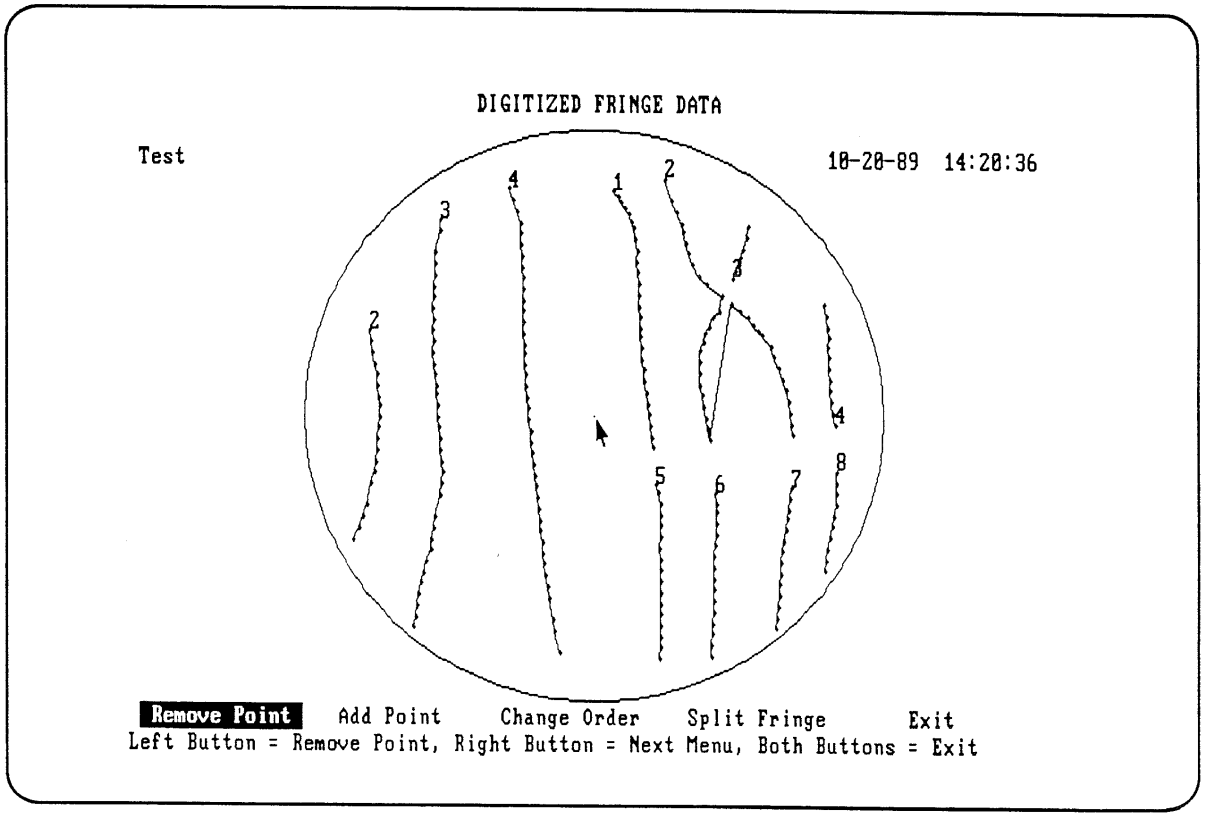
To change the order of a fringe, simply select the **Change Order** function and place the mouse cursor at the fringe whose order is to be changed. Now depress and release the left mouse button. A prompt for the new order number will appear with the current order of the selected fringe. Enter the new order value if the current order number matches the desired fringe; if not, simply hit **<Enter>** and the original ordering will be preserved. The direction of the wedge (increasing orders) can be inverted by entering a negative order value at this prompt. Once a fringe order has been altered a second prompt is given for fringe order resequencing. Respond affirmatively (**Y**) if the offset determined by the difference between the new and old order should be added to the remaining fringe orders. Note that resequencing is not allowed if a negative fringe order would result.

Split Fringe

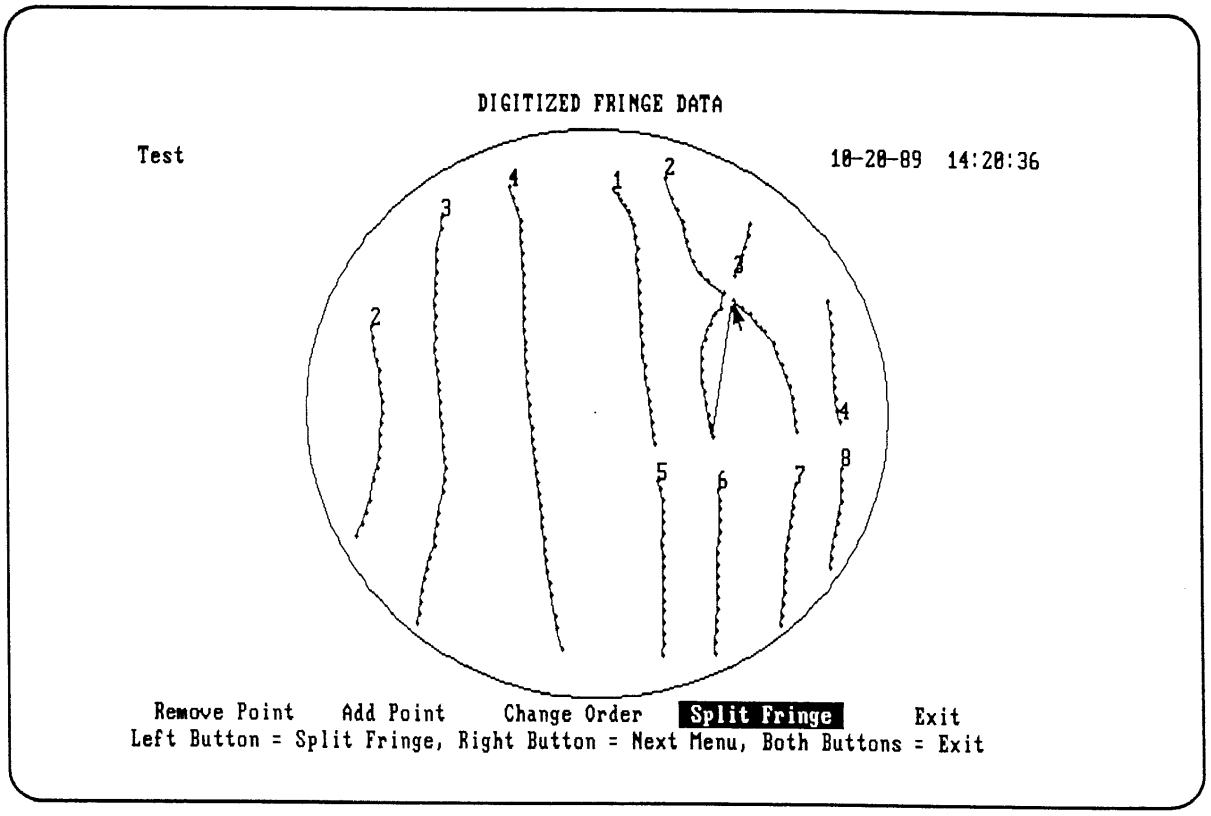
A given fringe may be divided into two by selecting the **Split Fringe** function. To split a fringe simply move the mouse cursor to the point on the fringe that you wish to break. By depressing the left mouse button the center point nearest the cursor's tip will become the first point on the new fringe. The program will label the new fringe with its current order number. This fringe may be manipulated as any original fringe. After the fringe editing has been completed, continue processing by exiting the verification map by pressing both mouse keys or by using the **Exit** function.

Fringe Editing Example

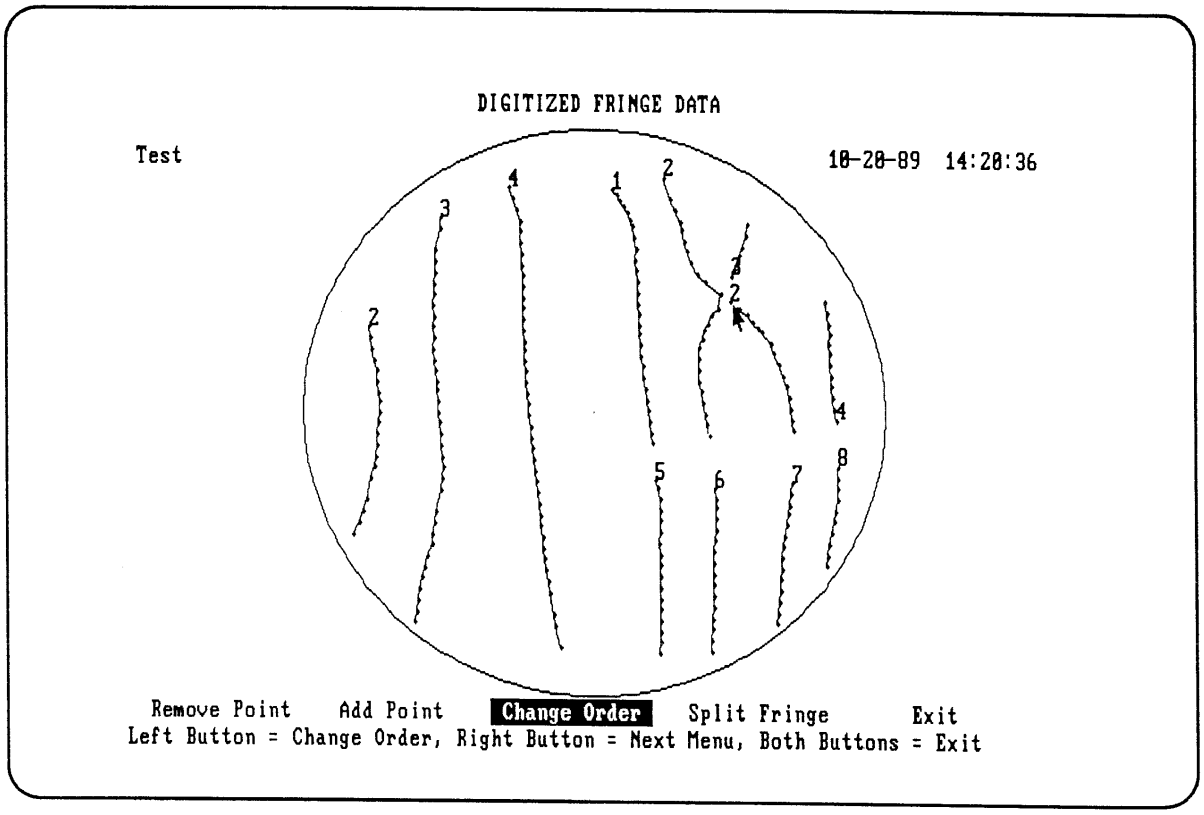
Here the fringe editing capabilities within *ZAPP /PC* are presented by example. Notwithstanding our efforts to minimize fringe editing, there are circumstances in which a level of editing is unavoidable. In order to illustrate several of the editing features at once we must begin with a somewhat contrived interferogram. The diagram below is the verification map for a segmented interferogram with merging fringes (see *Using Complex Fringe Tracing*) in the upper right quadrant. Notice that some fringe reordering is almost always required in the case of a segmented pupil since fringe ordering is not consistent across segment boundaries. In this example a fragment of the third fringe in the quadrant segment has been ordered and connected to the second fringe. This type of tracing error might occur in a very noisy interferogram.



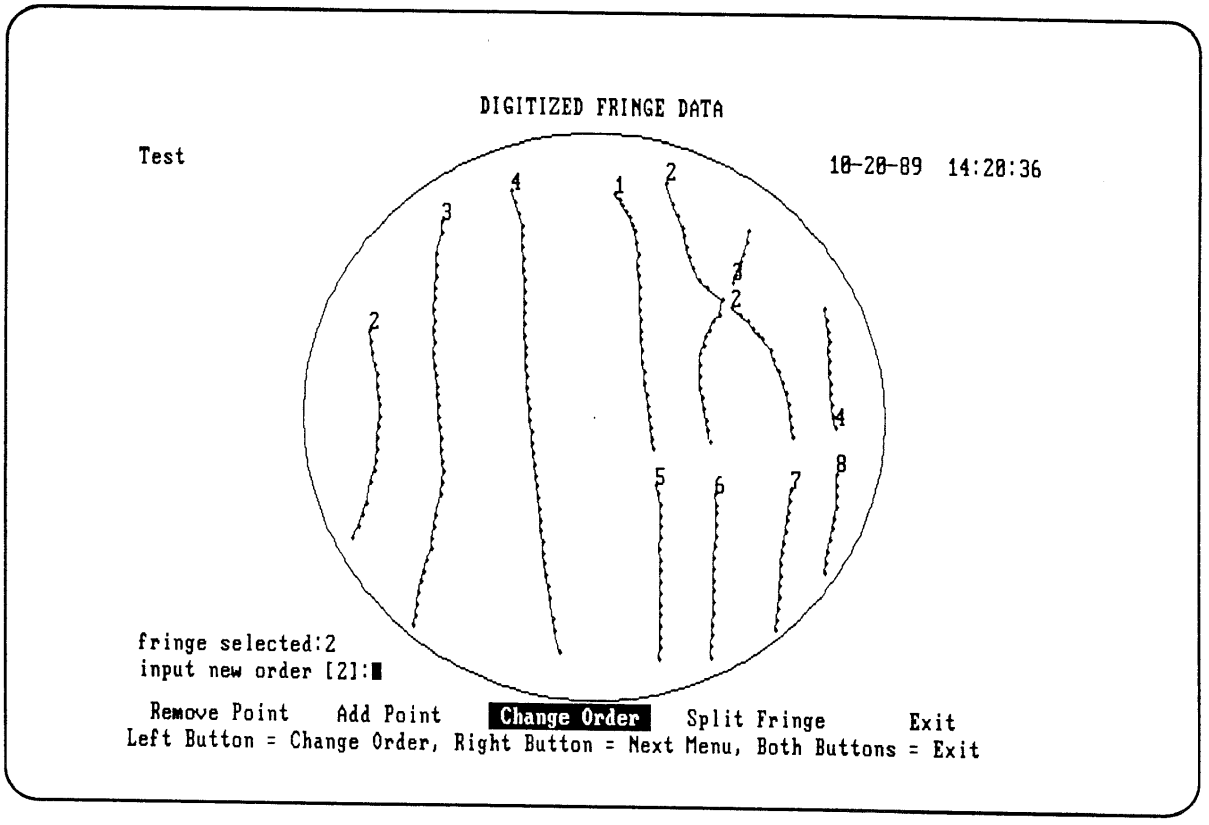
Use the right-hand mouse key until the **Split Fringe** option is highlighted. Use the mouse to position the arrow cursor on the center point which will become the first point on the newly formed fringe.



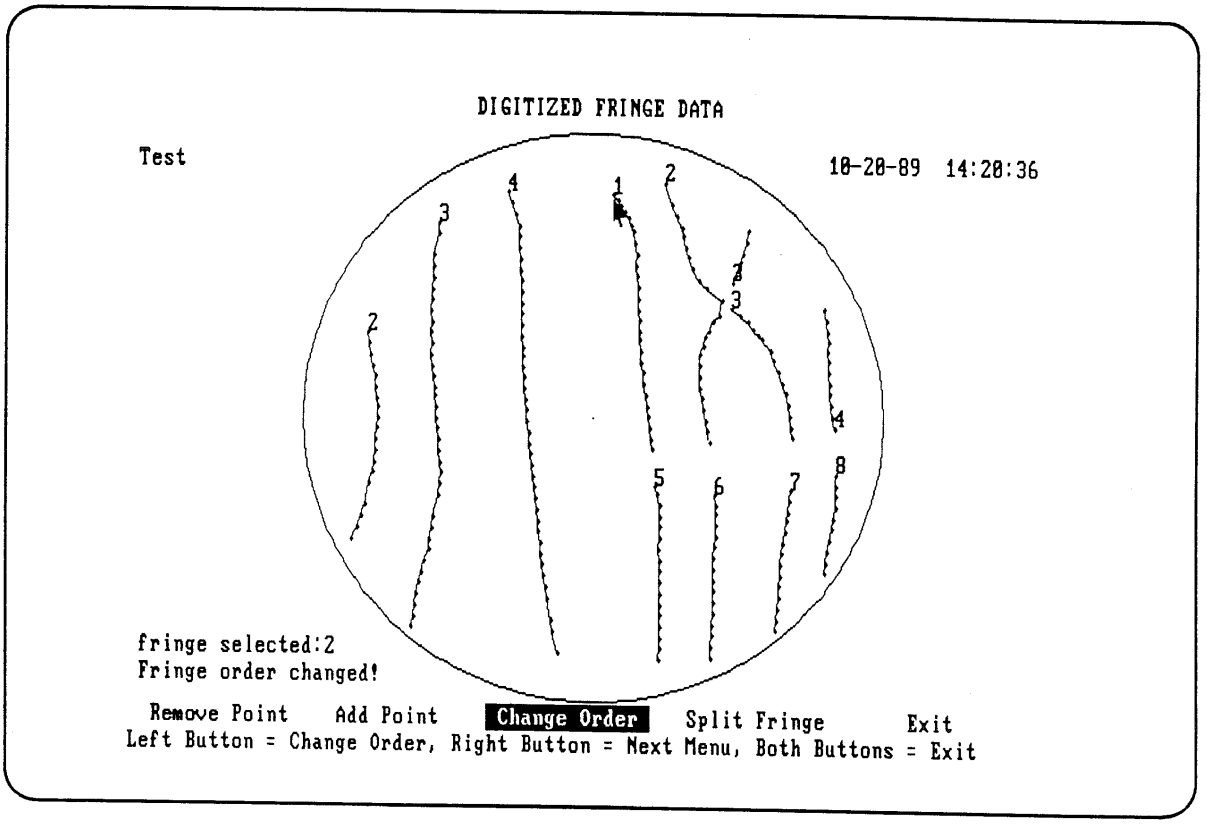
Now use the the leftmost mouse button to split the fringe. The line connecting the relevant points is now removed and the new fringe is labeled with its old order (two).



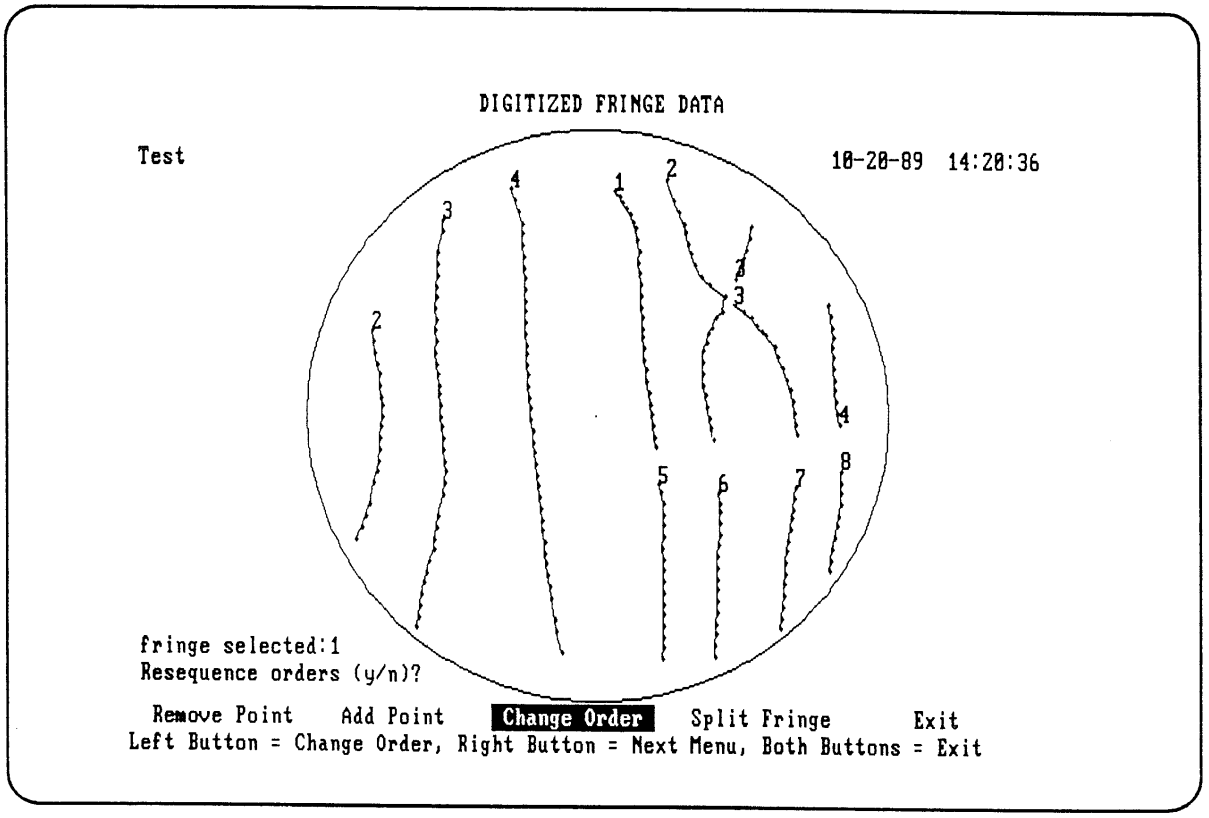
The new fringe is still improperly ordered with respect to the fringes in the upper-right quadrant. The order value of two should be changed to three. Use the rightmost mouse button to wrap around the function line and highlight the **Change Order** option. Position the mouse cursor to the first point in the new fringe (as before) and depress the leftmost mouse button. At this point a prompt for the new order number will appear:



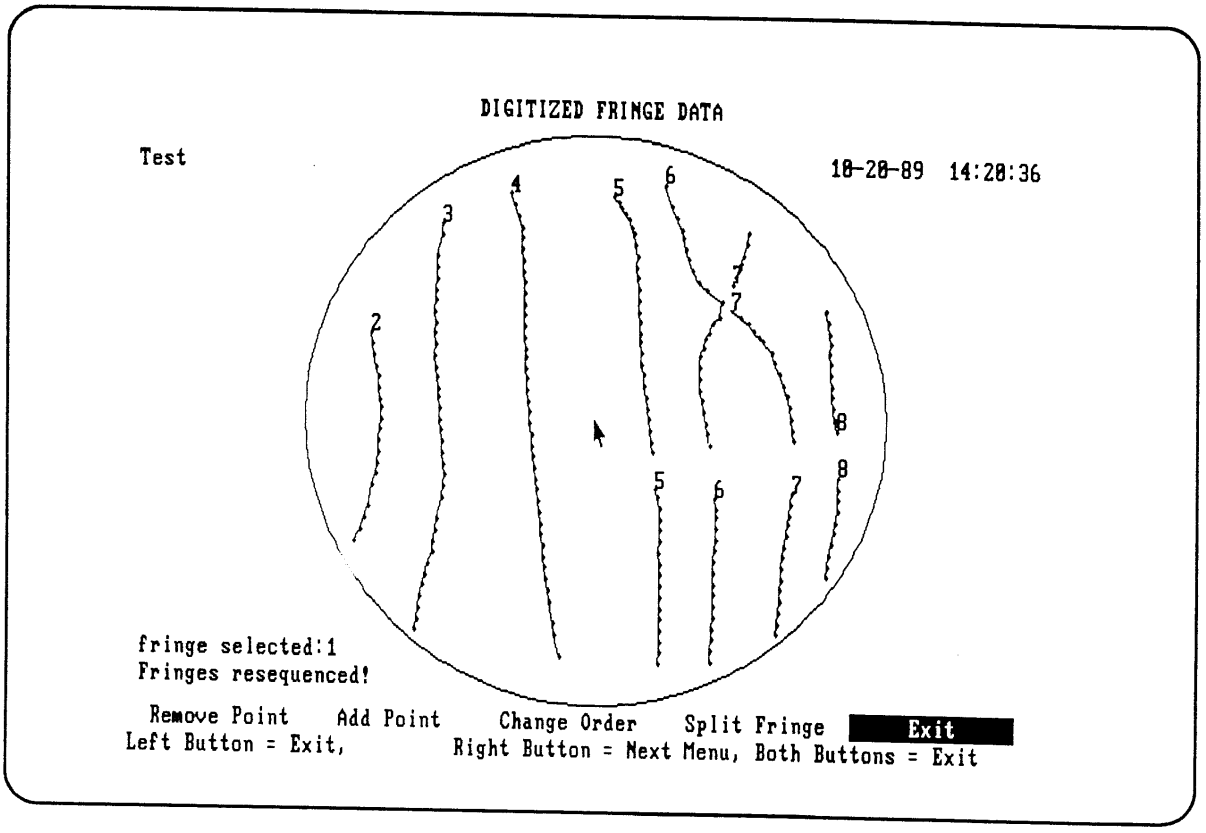
Be certain that the default order value within the prompt corresponds to order of the fringe to be changed, as this is a check for selected fringe. Enter the new order value of three followed by <Enter>. Respond negatively (N) to the resequencing prompt which follows. The fringes within the quadrant are now ordered self-consistently. The final task will be to resequence the fringe orders in the quadrant so that they are consistent with the remainder of the interferogram.



The resequencing of the quadrant fringes may be accomplished by changing the order of the first fringe followed by an affirmative response to the resequencing prompt. While still in the **Change Order** function, place the arrow cursor on the first fringe and depress the left mouse button. After taking the same precautions described earlier, change the fringe order to five. Now the resequencing prompt will appear. Respond affirmatively (**Y**) to resequence the fringe orders within the quadrant. Note that in every case the resequencing only applies to the pupil segment containing the selected fringe.



The corrected verification map appears as follows:



After the fringe editing has been completed, continue processing by exiting the verification map by pressing both mouse keys or by using the **Exit** function.

Introduction

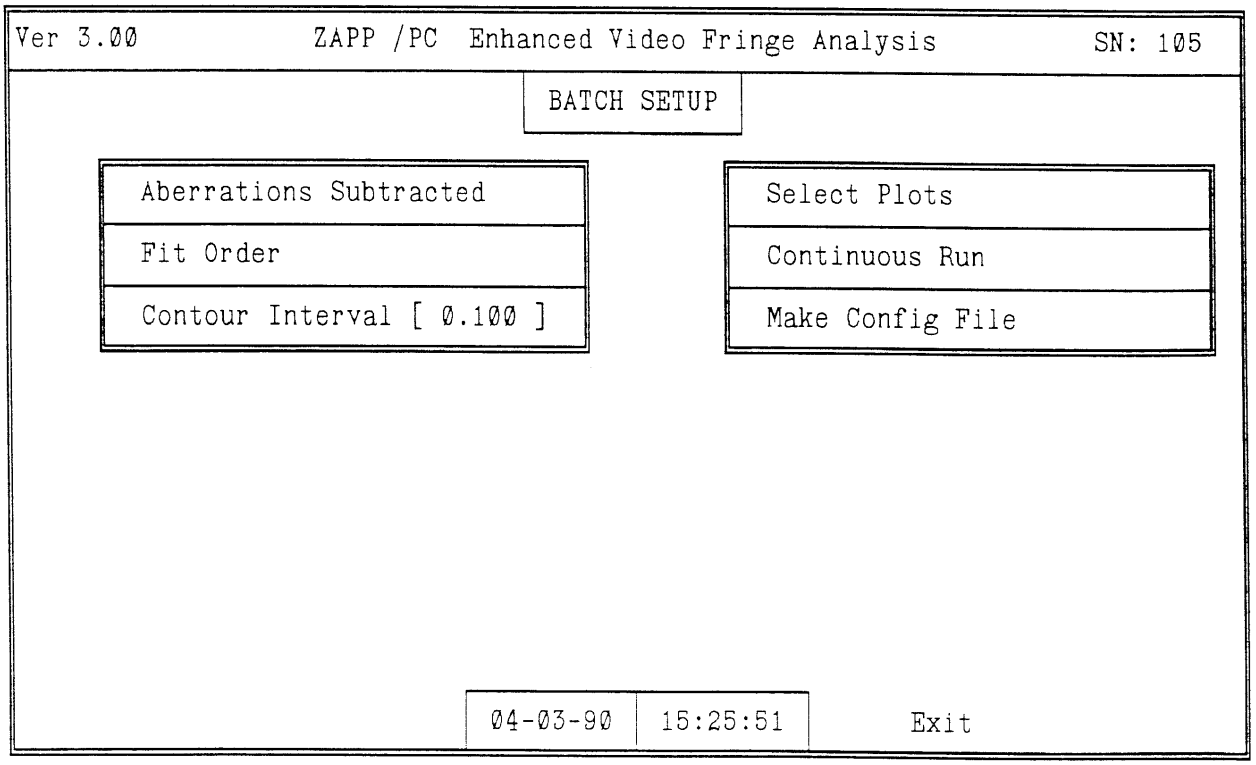
The **Batch Processing** mode is designed for repetitive data analysis which can be performed without operator intervention. In this mode of operation, all the analysis and data manipulation options are selected by the user before any data is actually processed. This is accomplished using the **BATCH SETUP** menu which will configure the system for the batch processing mode. Once all the options have been selected, they can be saved in a configuration file so that the setup procedure does not have to be repeated every time *ZAPP /PC* it is executed. Usually in batch mode a hardcopy device is selected to report the results. After batch processing has begun, all the selected operations will be performed consecutively and can only be terminated by pressing **E** on the keyboard to interrupt the processing.

Batch Processing will operate from any of the available data sources, be it graphics tablet, a stored data file, or Zernike data.

Batch Setup

The **BATCH SETUP** menu selects the operations that are to be performed during **Batch Processing**. The batch processing is initiated from the **Main** menu after all the options have been configured. If **Continous Run** has been enabled there will be no pause between the batch mode operations selected.

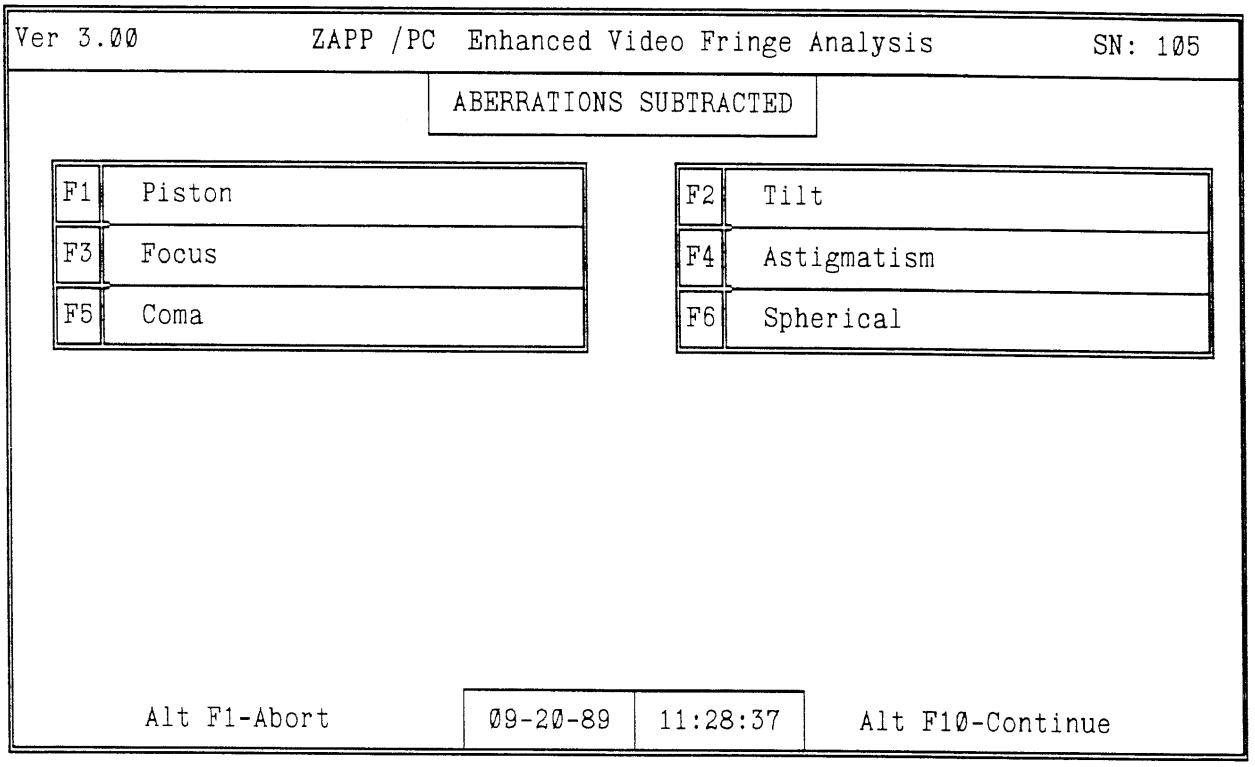
BATCH SETUP MENU



Aberrations Subtracted

This will define which low order aberrations will be subtracted from the data after the low order polynomials have been fitted. Refer to the ***Subtracting Aberrations*** section in Chapter 14 for further information on removing aberrations from the data. Note that modifications to this menu made during **Interactive Processing** will not affect those defined here.

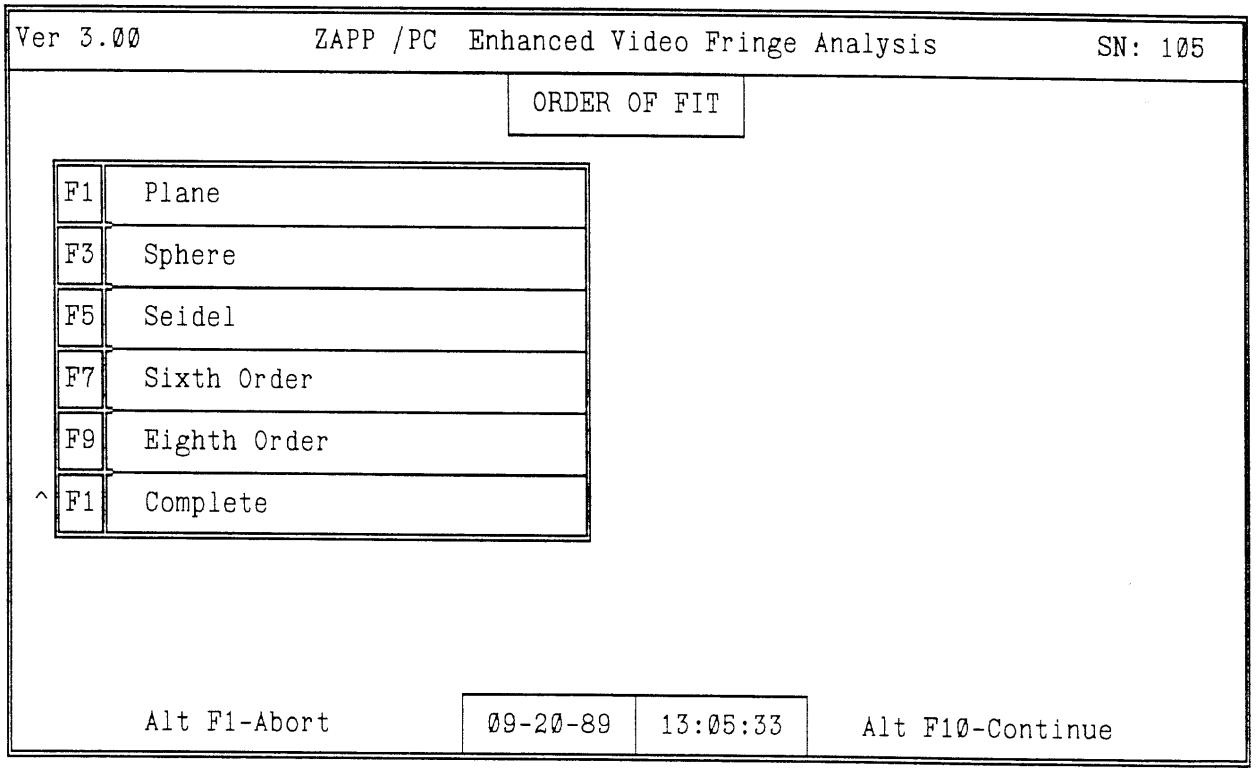
SELECT ABERRATIONS SUBTRACTED MENU



Fit Order

The user can select the order of fit, defining the number of coefficient terms to the polynomial fit. During batch mode processing this fit order will automatically be used when fitting the data. Refer to the ***Generating Aberrated Wavefronts*** section in Chapter 13 for further information. Note that modifications to this menu made during **Interactive Processing** will not affect those defined here.

ORDER OF FIT MENU



Continuous Run

If this is enabled, there will be no pause between the selected operations and options during **Batch Processing**. The program will automatically sequence through the analysis and plots that have been selected without pause. The plots will literally flash by if only the CRT is selected as an output device. The **Continuous Run** is specifically used for unattended printer output during a batch process of data.

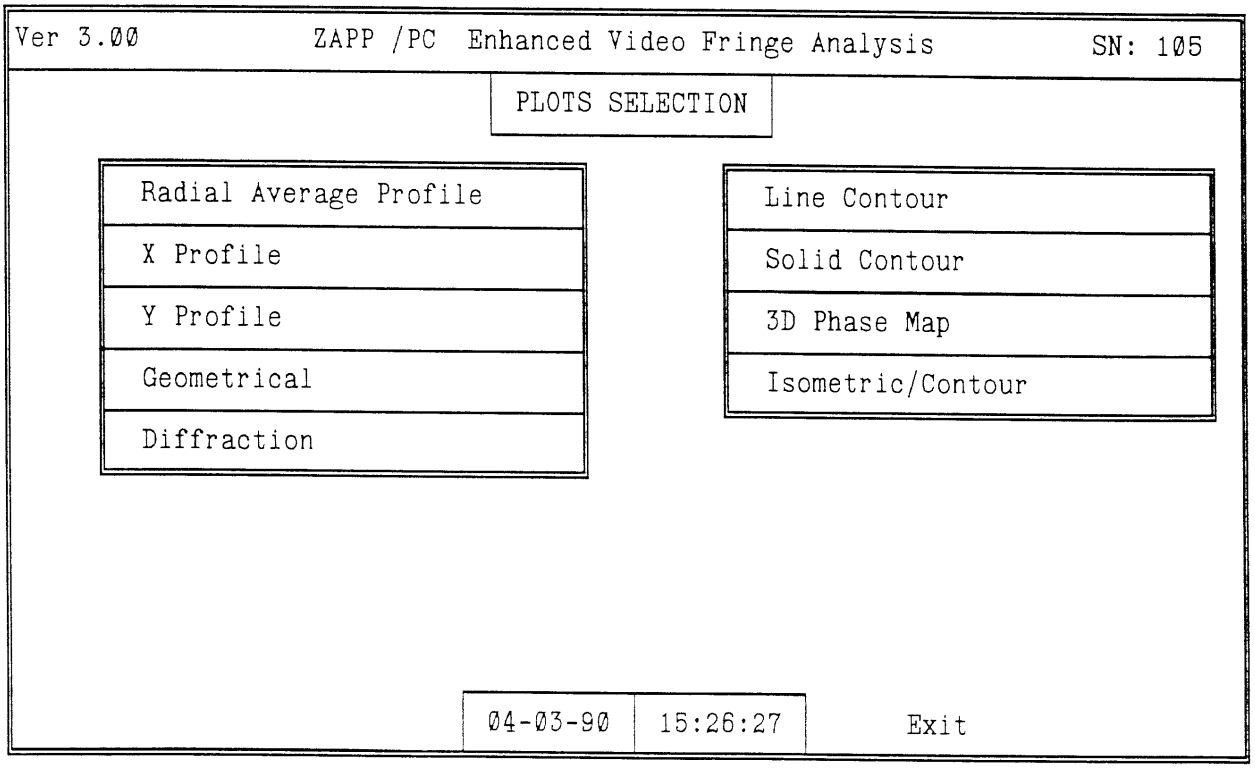
Once in a continuous run mode, the user can exit by pressing **E** on the keyboard.

Select Plots

After the data is fitted, the program will automatically sequence through the plotting mode and the user can define which plots should be automatically performed. If an output device such as a printer is selected, the plot will also be printed.

If **Geometrical** is selected from the **PLOTS SELECTION** menu, then all the graphic output from the **Geometrical Ray Analysis** will be generated and sent to the current output device. Similarly, if the **Diffraction Analysis** is selected, all **Diffraction Analysis** plots are included.

BATCH MODE PLOTS SELECTION MENU



Contour Interval

Here the user can select the interval to be used in either of the contour options within the **PLOTS SELECTION** menu. The interval must be given in the units specifed by the **Select Units** option of the **CONFIGURATION** menu. These units are shown within the interval prompt:

```
Input contour interval (nm) [30.00]:
```

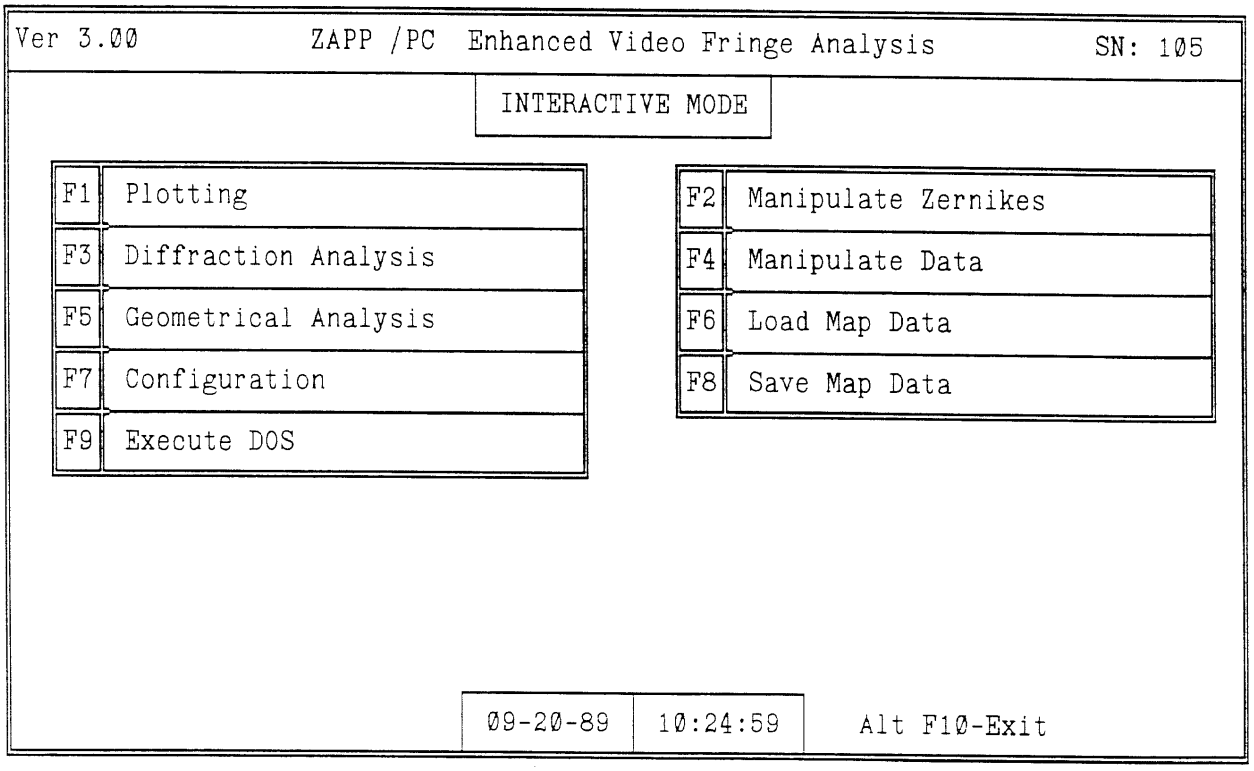
Note that a subsequent change in the unit type will adjust the interval value so that the effective interval is maintained.

Introduction

The **Interactive Processing** mode will input the data and then allow the user to pick and choose the operations to be performed on this data from a series of menus. These operations are performed immediately once chosen, giving the user a powerful tool to manipulate the data interactively. The data can be displayed in various formats such as **X-** and **Y-Profile** slices, **Contour** plots, or **3D** displays. The user might also select to perform analysis such as a point spread function or geometrical spot diagrams. The data can be fitted to Zernike polynomials which can then be edited, rotated, subtracted, averaged, or used to generate a new data map. Other data manipulations include adding or subtracting data sets, inverting the wavefront, or flipping the data about the X or Y axis. This **Interactive** mode of operation does not confine the user to a preselected set of operations but offers the user the flexibility to quickly manipulate the data as desired. It is also a great learning aid for new users allowing them to perform any operation and then inspect the data to see the results.

As with **Batch Processing**, **Interactive Processing** will operate from any data source selected, be it graphics tablet, a stored data file, or Zernike data. When **Interactive Processing** is selected from the **Main** menu, data is acquired from the selected data source and then the **INTERACTIVE MODE** menu is displayed after any processing and editing. This is the main menu for interactive analysis of the data.

INTERACTIVE PROCESSING MENU



Load Map Data

While in **Interactive Mode**, a data set that has been stored on disk can be loaded and then analyzed or plotted. This data set must be **.MAP** format which represents a data set over a uniform sample grid. Note that this will replace any current phase map data.

Save Map Data

The current uniform grid data set can be stored to a disk file for later use. This data could be generated from Seidel or Zernike coefficients, or fitted fringe data. The default extension of the uniform grid data files is **.MAP**.

Changing the Configuration

The **CONFIGURATION** menu is available from the **INTERACTIVE MODE** menu as well as from the **MAIN** menu. This allows various parameters such as units, wavelength, wedge factor, etc., and the operational functionality of *ZAPP /PC* to be changed. Refer to the *Setting up a Configuration* section for more details.

Executing DOS Commands from *ZAPP /PC*

The **EXECUTE DOS** option allows the user to temporarily suspend the *ZAPP /PC* program and execute any valid DOS command. After the desired commands have been issued, just type **exit** at the DOS prompt to return to *ZAPP /PC*. Thus, if sufficient memory is available, a text editor can be executed, notes entered, leave the editor, and type **exit** to return to *ZAPP /PC*. Files can be deleted or a specific data file can be looked for on the hard disk. Any command can be executed.

One limitation of this powerful feature is that programs which stay resident must not be executed at this point.

Other Options

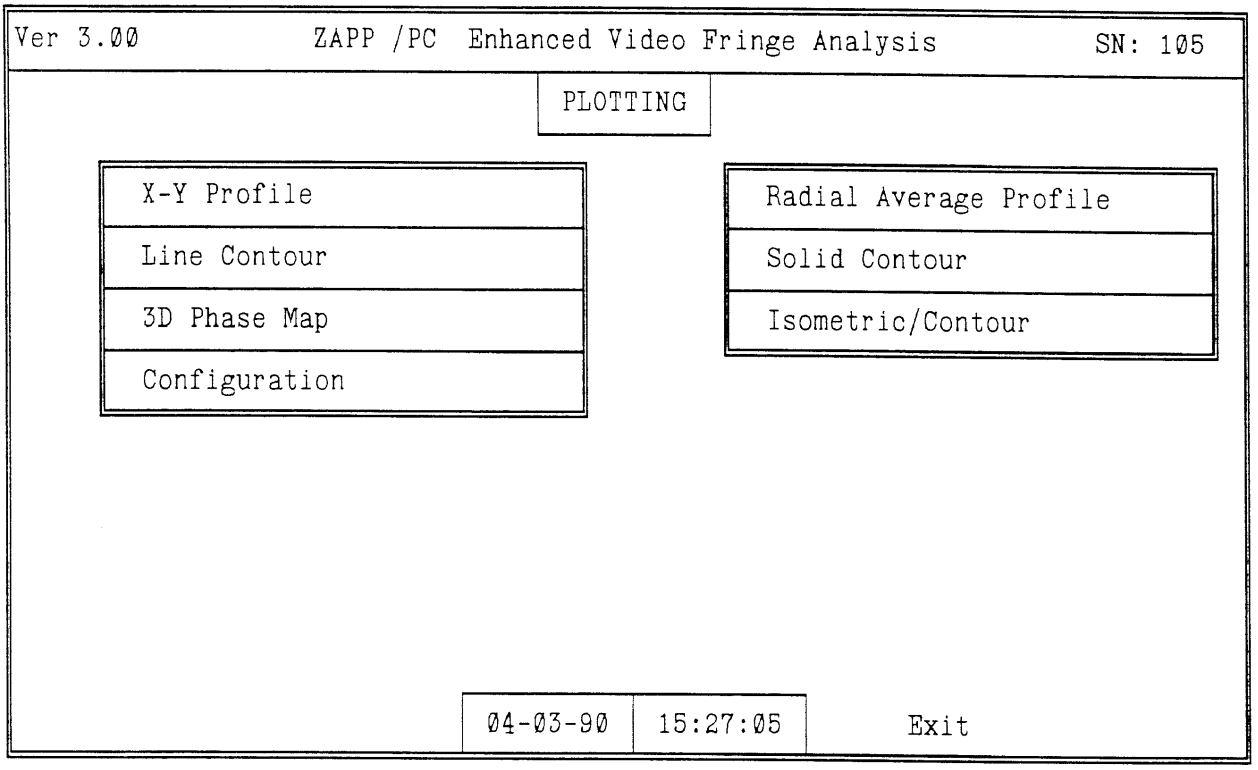
The options *Plotting, Diffraction Analysis, Geometrical Analysis, Manipulate Zernikes,* and *Manipulate Data* in the **INTERACTIVE MODE** menu are discussed in the following chapters.

Graphic Displays

The **PLOTTING** menu within the **INTERACTIVE MODE** menu allows the user to interactively select various methods to display the phase map data. Any of the plot selections can be requested in any sequence once in the **PLOTTING** menu.

During **BATCH MODE** operation, the selected plots are displayed in sequence. If **Continuous Run** is disabled, then the user will have control of the interactive features of the plot if available.

PLOTTING MODE MENU



Using the Mouse

When profile maps are displayed, a vertical line cursor appears within the plot. This line can be moved from left to right by moving the mouse left to right. As the line cursor is moved, the height of the wavefront at the cursor position is displayed in the upper left corner of the display giving the user quantitative information of any point on the wavefront map.

The cursor is enabled when a single profile is displayed. By pressing the left key on the mouse, this line cursor disappears and other profile plots can be shown in real time as the mouse is moved. Moving the mouse causes different profile sections of the wavefront map to be displayed. Refer to the specific profile descriptions for more information. Once the desired profile plot is displayed, pressing the leftmost button on the mouse causes the vertical line cursor to re-appear. One can toggle from the real-time profile plotting mode to cursor mode with the left most button on the mouse.

Using Cursor Keys

If a mouse is not available then the keyboard cursor (arrow) keys can be used for user manipulation of most graphics. During the **RADIAL** and **X-Y PROFILE** plots, the cursor keys can be used for two functions. If the plot is displayed with the vertical line cursor indicating the phase height at that location, then the left and right cursor keys can be used to move the vertical line cursor along the plot. The speed of the motion can be changed by pressing **1** through **9** on the keyboard. The profile plot can be switched to the "real-time" mode by using the the upper and lower cursor keys which can be used to scan through different profiles. If **X-Y PROFILE** has been selected, then pressing **T** will toggle between the X-Profile and the Y-Profile. This is true only if the profile plot is in the vertical line cursor mode.

The perspective of the 3-D plots can be changed by rotating the "house" on the plots using the cursor keys. The four cursor keys can rotate the "house" about two axes. When a new plot is desired, choose the orientation, and the plot will be generate by pressing **<Enter>**.

Wavefront Profile Plots

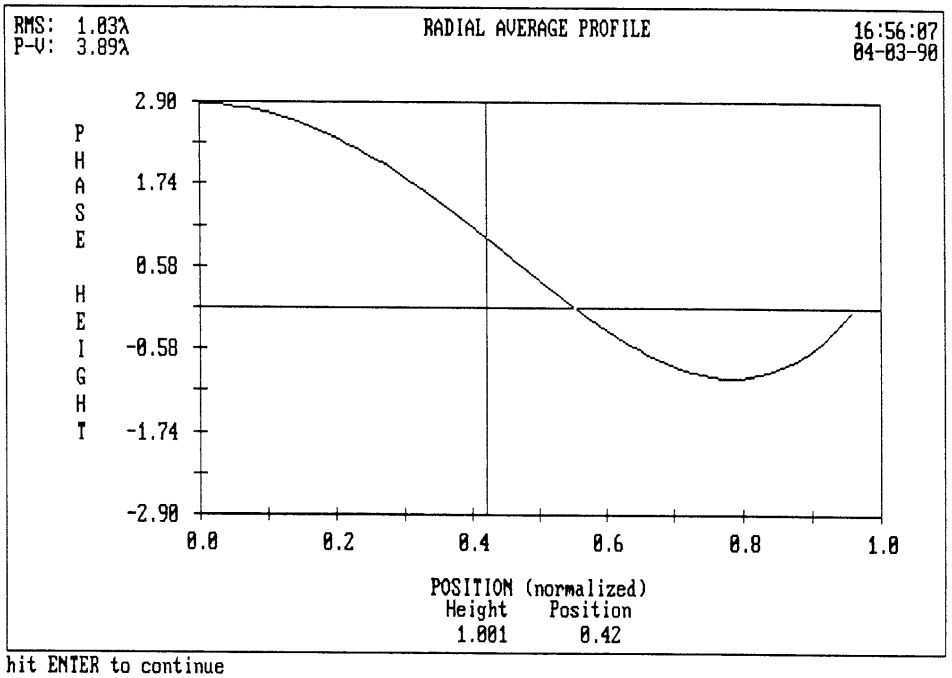
Radial, horizontal and vertical profiles can be displayed with rapid selection of any profile of the wavefront map. The responsive display capabilities of *ZAPP /PC* gives the user the ability to interactively scan the wavefront map to gain an understanding of how the map is changing along selected directions.

Radial Average Profile

This profile shows the average wavefront height of each radial band. That is, for any circular band about the center of the wavefront, the average height along that band is displayed. To the left of the profile, the radius of the band begins at zero. To the right, the band radius is increasing to meet the outside edge of the pupil. If any regions of wavefront data are missing (e.g., masked off), the averaging does not include that region. If an entire band of data is missing (such as a circular mask, a mask at the center, or a clipped pupil radius), there is no average shown in the profile for that radius. The resulting profile is a static representation of the whole wavefront at once, useful for comparing characteristic differences between different data sets.

The mouse or arrow keys may be used to move a line back and forth on the profile, to examine heights at certain radii or discover the radius of certain features of the profile. Either mouse button, the **E** or the **<Enter>** keys, will leave the plot.

RADIAL AVERAGE PROFILE PLOT



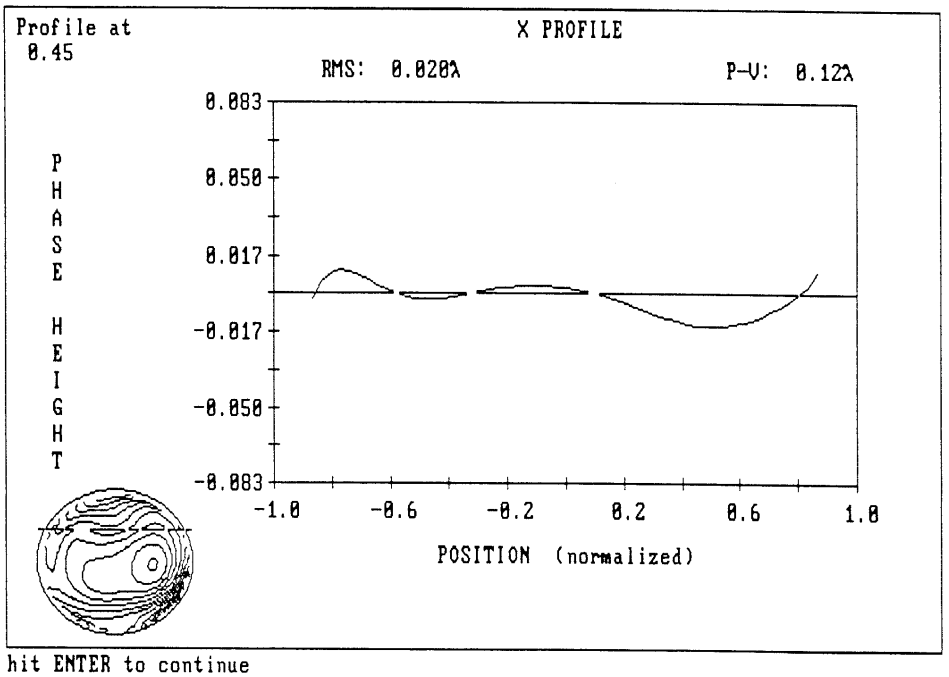
X-Y Profiles

Horizontal and vertical profiles can be displayed along any horizontal or vertical line through the wavefront map. In real-time mode (pressing the left mouse button or using the up and down cursor keys), motion of the mouse or cursor keys will display different profile slices through the data.

In the lower left corner of the screen a small line contour representation of the wavefront is shown which is used to indicate where on the data the profile is plotted. In real-time mode, a line, either in the X or Y directions, is drawn through the line contour plot to indicate where in the data the profile is plotted.

The X Profile plot below shows the display while in real-time mode, plotting a specific horizontal data line in the normalized coordinate system.

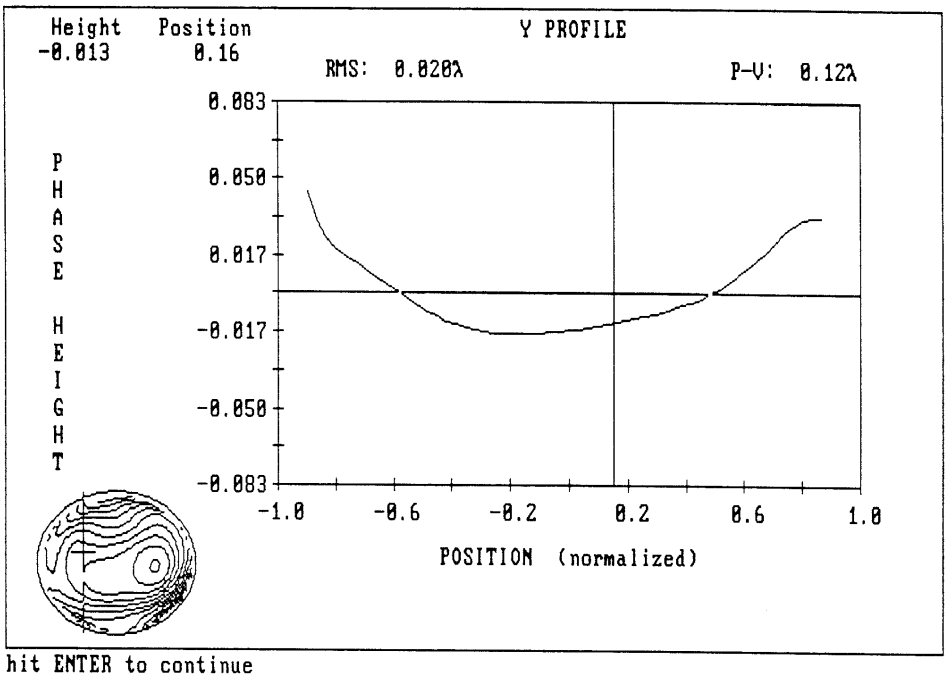
X PROFILE PLOT



X-Y Profiles

The Y Profile shown below is plotted while the vertical line cursor is active. As the cursor moves across the plot, the wavefront height at the cursor position is displayed in the selected units in the upper left corner.

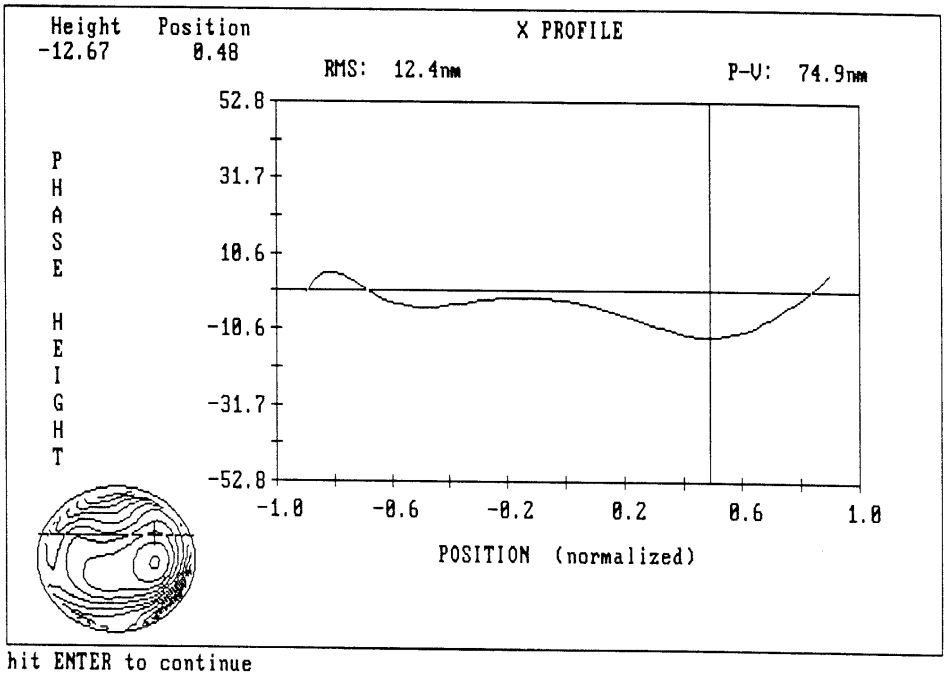
Y PROFILE PLOT



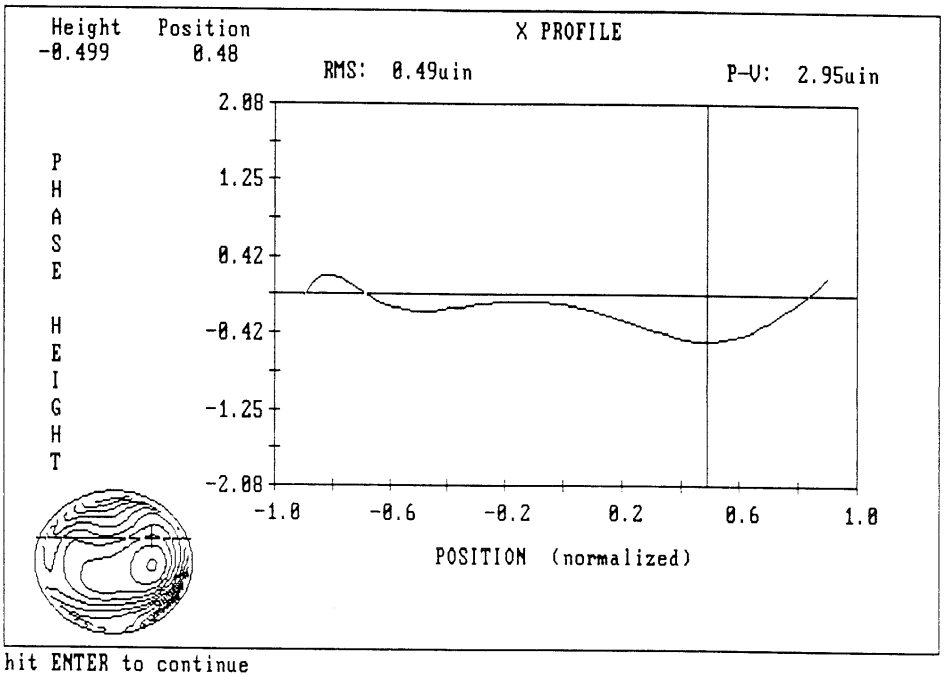
hit ENTER to continue

X-Y Profiles

To see the plot with different units, enter the **CONFIGURATION** menu and change the units, then go back and plot the profile to see the data presented with the new units. Below is an X Profile plot of a data set scaled in nanometers.

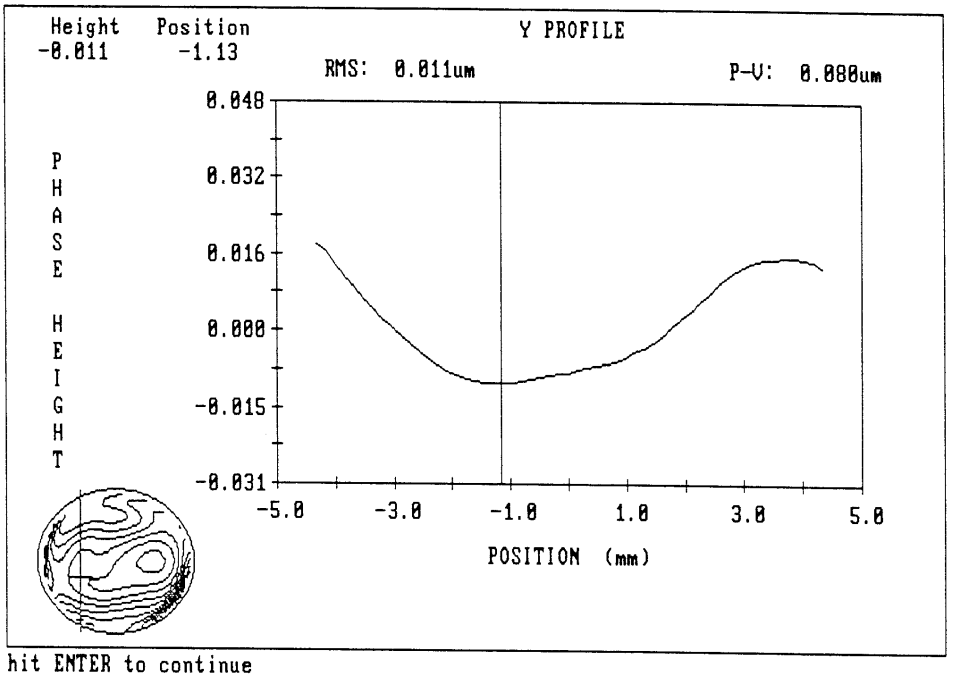


Or re-plot with the units in microinches. *ZAPP /PC* gives the user the capability to easily manipulate the data interactively.



X-Y Profiles

Also available from the **CONFIGURATION** menu are the **Profile Options**, which change the type of scale of the profile plot. The standard profile plot uses a **Zero Center** scale which is symmetrical about a zero line through the center of the plot, based on the extremes of the peak and valley. However, certain data sets may require the **Auto Scale** or **User Scale**. If it is necessary to compare several different data sets, then the **User Scale** is desirable since it will show all the profiles of the different data at the same scale. Below is a sample plot using the **Auto Scale** which is simply from peak to valley.



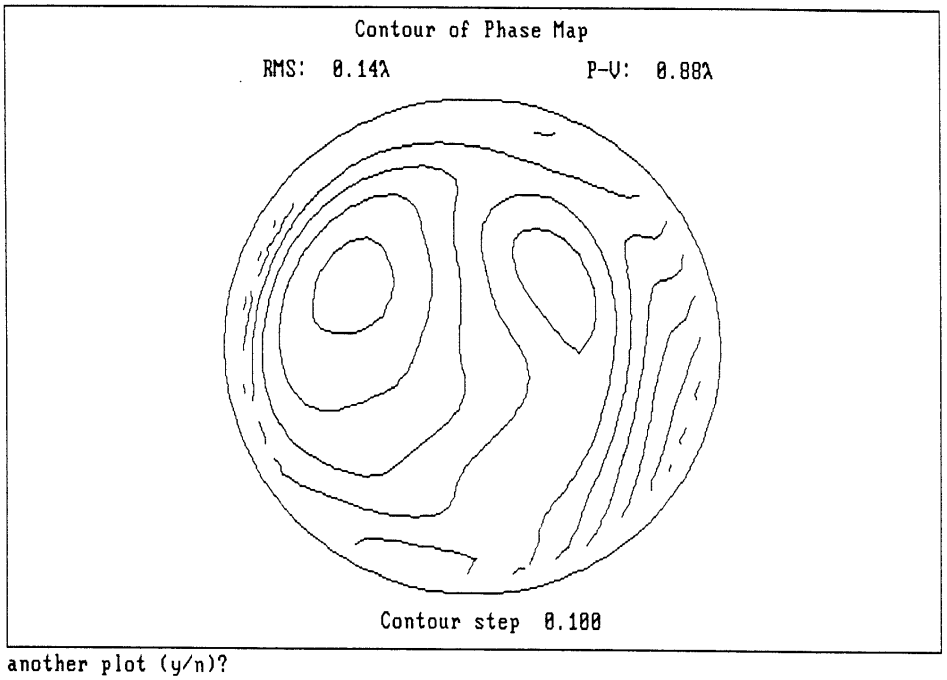
Contour Plot of Phase Map

A line contour map can be quickly drawn by selecting **Line Contour** in the **PLOTTING** menu. The contour interval can be selected within a defined range. Contour lines close together indicated high slope areas on the wavefront map.

A line-printer style contour map is also output which uses letters of the alphabet to indicate contour intervals. Capital letters indicate high areas and lower case letters indicate low areas.

The aspect ratio of this plot is set for the printer, thus a distorted pupil will appear on the CRT for the line-printer contour plot.

CONTOUR PLOT



another plot (y/n)?

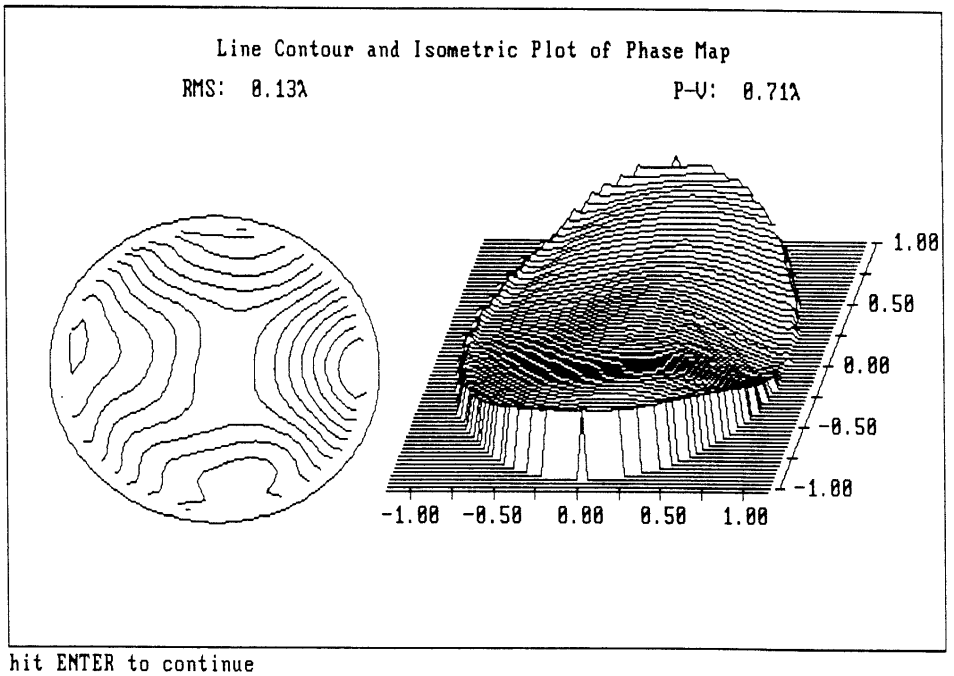
Solid Contour Plot of Phase Map

A solid contour map can be drawn by selecting **Solid Contour** in the **PLOTTING** menu. The contour interval can be selected by the user. Instead of drawing lines for each contour interval, each interval is filled with a different color producing a very colorful solid contour. Contour intervals close together indicated high slope areas on the wavefront map. This plot requires use of a color graphics display and therefore is disabled on monochrome graphics displays. Small contour intervals may cause colors to repeat due to the limited number of distinct colors used by the display controller.

Contour with Isometric Plot

This plot will show the wavefront map in a contour plot and an isometric plot side by side on the same display. The contour plot is drawn with a fixed number of intervals and if a color display is used, each interval will be displayed in a different color. The isometric 3D plot is drawn at a fixed orientation and will also use color, if it is available, to show different heights of the surface.

CONTOUR AND ISOMETRIC PLOT



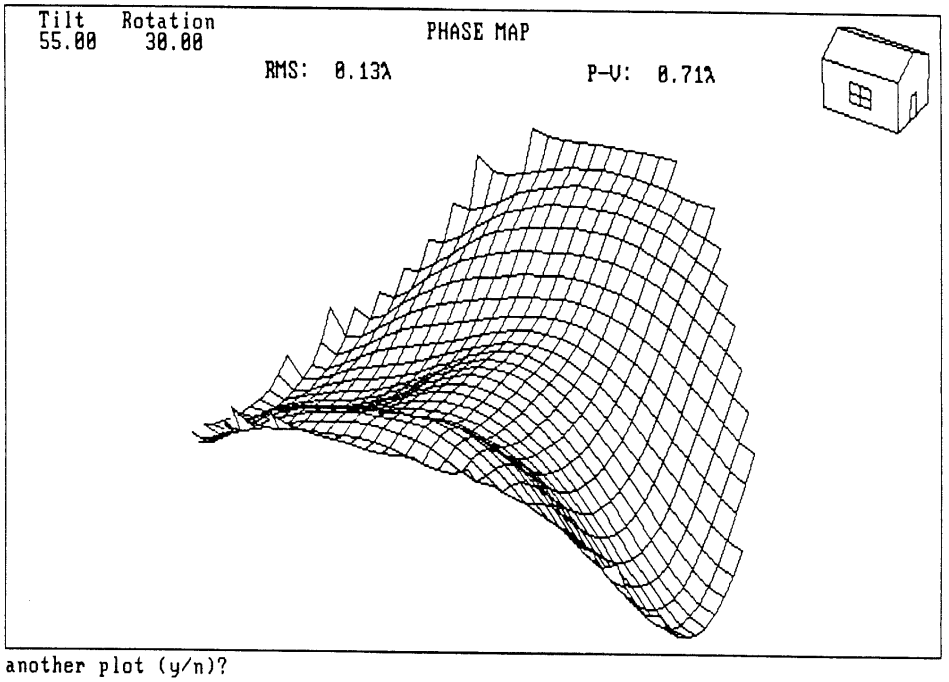
hit ENTER to continue

Three-Dimensional Plot of Phase Map

The wavefront map can be displayed as a true perspective three-dimensional plot with accurate cross-hatching. This plot can be rotated, allowing the user to view the map from another perspective. To clarify the desired perspective, a small "house" is displayed in 3-D in the lower right-hand corner of the screen which rotates as the mouse is moved. The perspective of the house represents that of the data map, where looking down the top of the house would also be looking down on the data showing just a grid with no relief. The house has a "side window" and a "front door" to indicate left-right and front-back orientations. The roof and floor of the house indicate the top and bottom orientations.

Responding affirmatively (**Y**) to the query for another plot allows one to rotate the house along the two axes to produce another orientation. Pressing the left button on the mouse will re-draw the plot at the new perspective. The plot can even be flipped up-side-down or viewed from another direction to observe features on the map. If a mouse is not available, the cursor positioning (arrow) keys on the keyboard perform the same function in rotating the house in orientation. When the desired perspective is reached, press **<ENTER>** to plot.

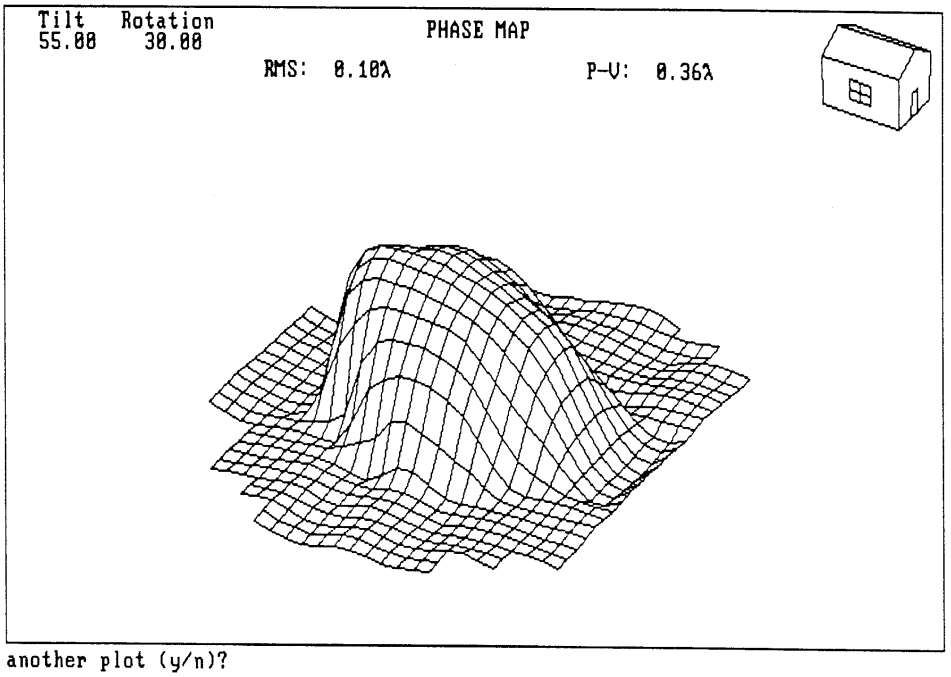
THREE-DIMENSIONAL PHASE MAP



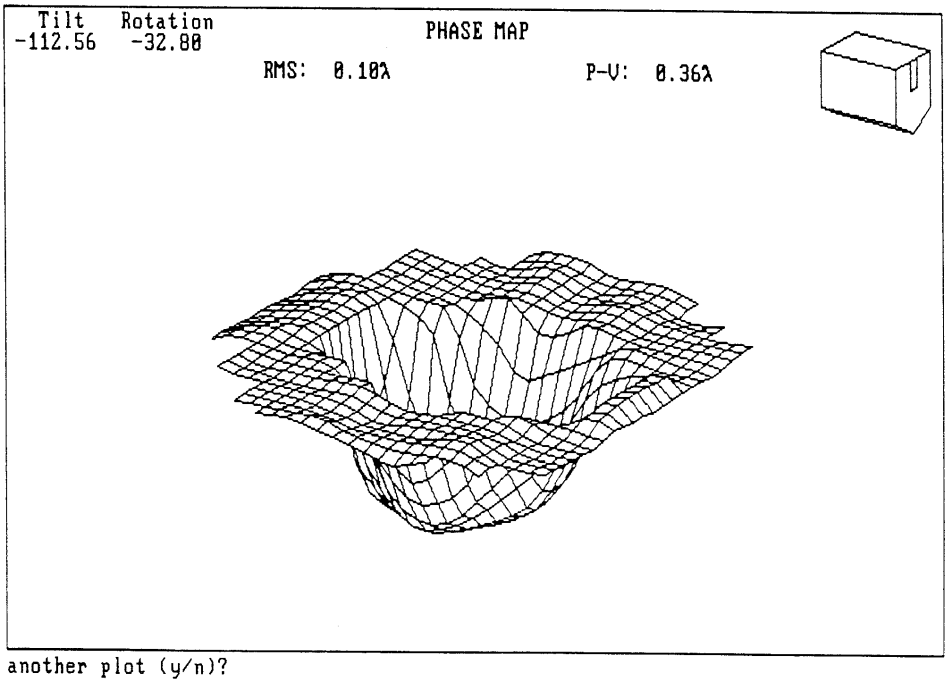
another plot (y/n)?

Rotation of Three-Dimensional Plot

The following plots are examples of 3D rotation of a phase map showing the data map right side up and then flipped upside down. Note that the house shows the perspective of the three-dimensional plot. The units displayed can be changed using the **CONFIGURATION** menu.



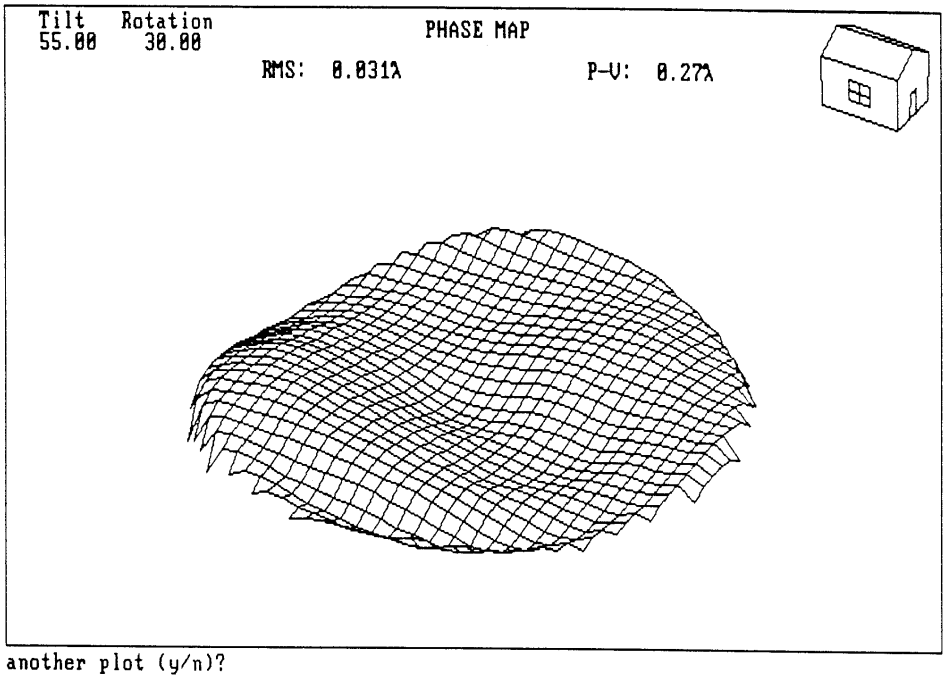
another plot (y/n)?



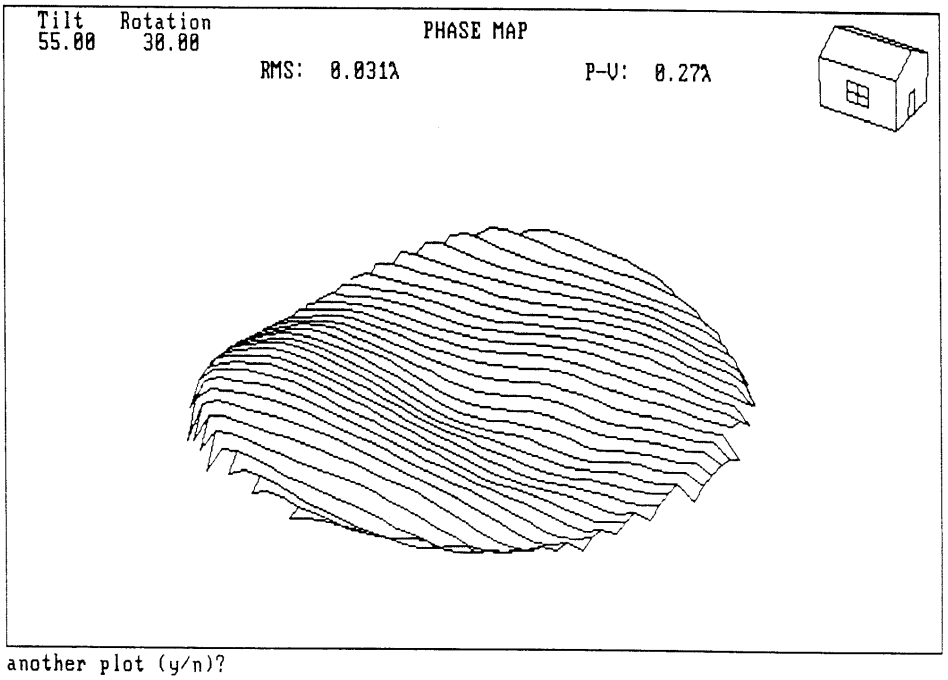
another plot (y/n)?

Cross Hatching

The 3D true perspective maps of the wavefront can be plotted with or without cross hatching. Selecting **Cross Hatching** from the **3D Options** in the **CONFIGURATION** will toggle between the two modes. The effect is seen the next time a phase map is plotted. Below is an example of the same phase data map plotted in the same perspective with and without cross-hatching. Certain orientations are better for data sets with high slopes. Use the interactive 3-D plot rotation capability to select the best orientation for display.



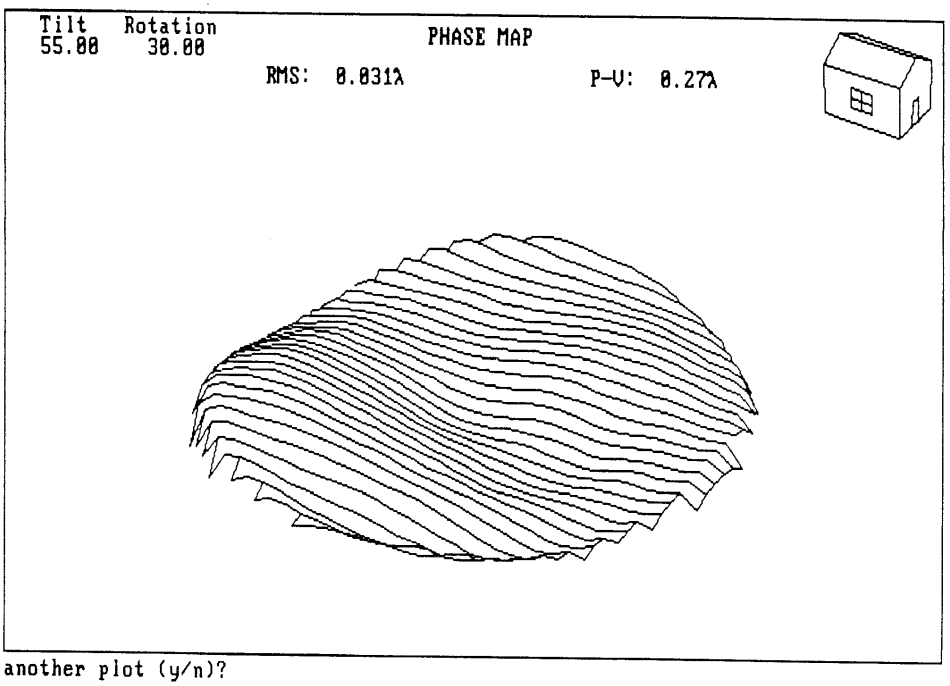
another plot (y/n)?



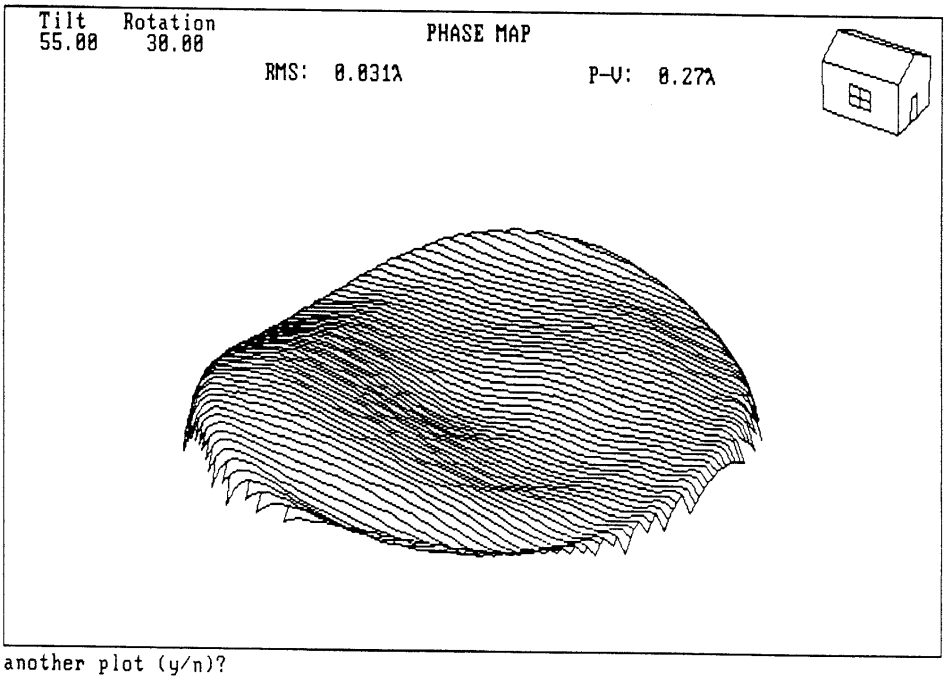
another plot (y/n)?

High Resolution 3D Plots

The 3D plot can be drawn at two resolutions which is useful for different aberrations and certain perspective views of the data. The low resolution is displayed faster since fewer points have to be processed. Selecting this option from the **3D OPTIONS** menu will toggle between the two resolutions. The effect is seen the next time the phase map is plotted. Below is an example of the same phase data map plotted in the same perspective at low and high resolutions.



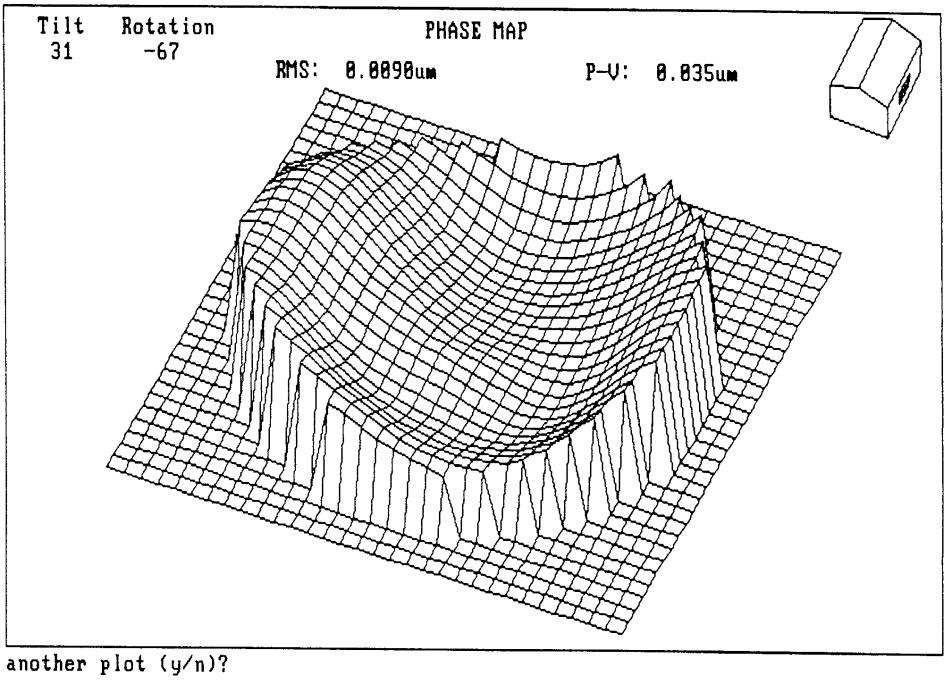
another plot (y/n)?



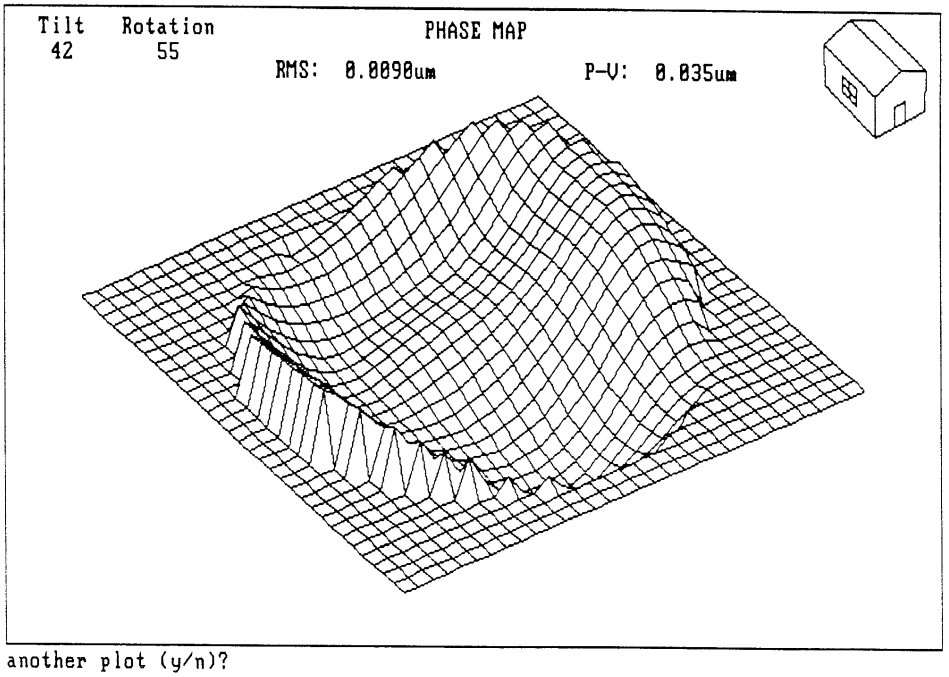
another plot (y/n)?

Backgrounds for 3D Plots

The 3D plots shown to this point, have all been drawn without a background. Two different backgrounds can be selected from the **3D OPTIONS** menu. The **Average Background** option draws a background reference at the average value computed from the data. The **Minimum Background** option draws a background reference at the minimum value computed from the data. The 3D plots below show the effect of using these backgrounds.



another plot (y/n)?



another plot (y/n)?

Introduction

Geometric ray analysis is most often used when wavefront slope errors are large. The geometric rays are based upon local wavefront slope information and are normal to the wavefront at any point on the wavefront. The rays intercept the ideal image plane. These transverse ray aberrations are calculated from the uniform grid of the wavefront map.

The functions provided within the geometric ray analysis are

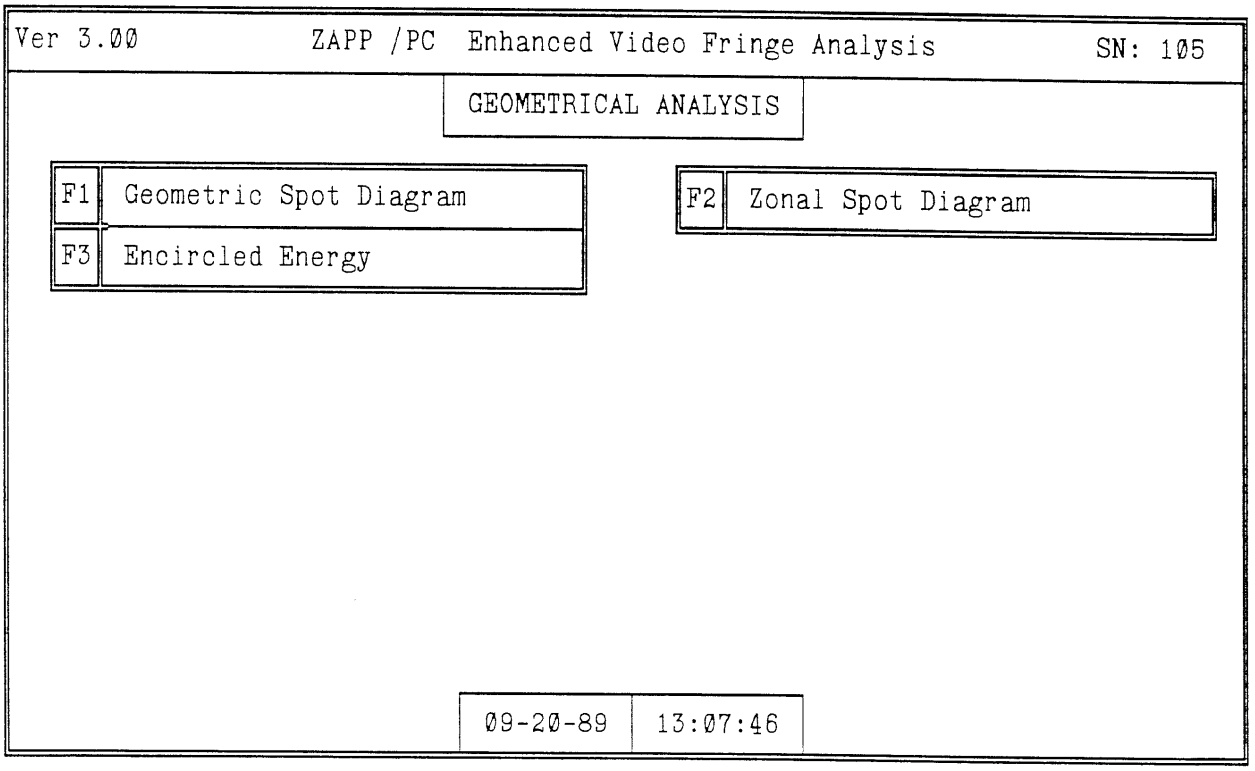
Geometric Spot Diagram

Zonal Spot Diagram

Geometric Encircled Energy

These functions are enabled by selecting **GEOMETRICAL ANALYSIS** in the **BATCH SETUP** or **INTERACTIVE MODE** menu.

GEOMETRIC ANALYSIS MENU

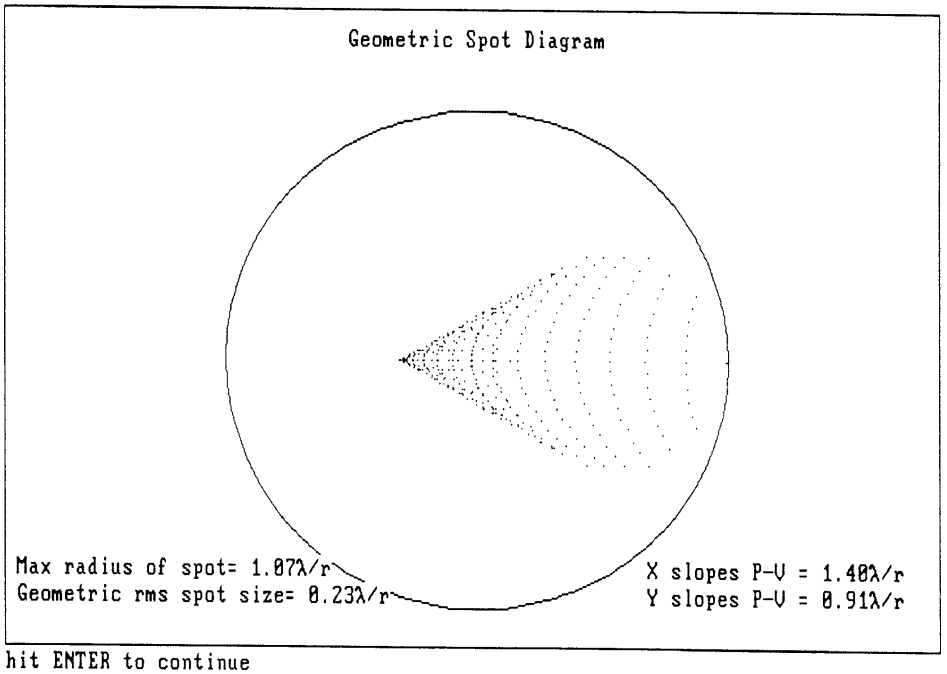


Geometric Spot Diagram

The ordinary geometric spot diagram shows the location of the ray intercepts that indicate the form of the transverse ray aberration due to the wavefront in the exit pupil.

The radius of the geometric spot diagram is determined by the maximum transverse ray intercept from the ideal image center position (location of an unaberrated wavefront with no tilt present). The numerical quantities presented:

Maximum radius of the geometric spot
RMS radius of the geometric spot
X width of the spot (X-slope P-V)
Y height of the spot (Y-slope P-V)



The units shown are normalized to waves per pupil radius. For example a tilt of 1λ at the edge of the pupil will produce a spot with radius of 1λ /r. To obtain a spot radius due to an optical system, use the following equation:

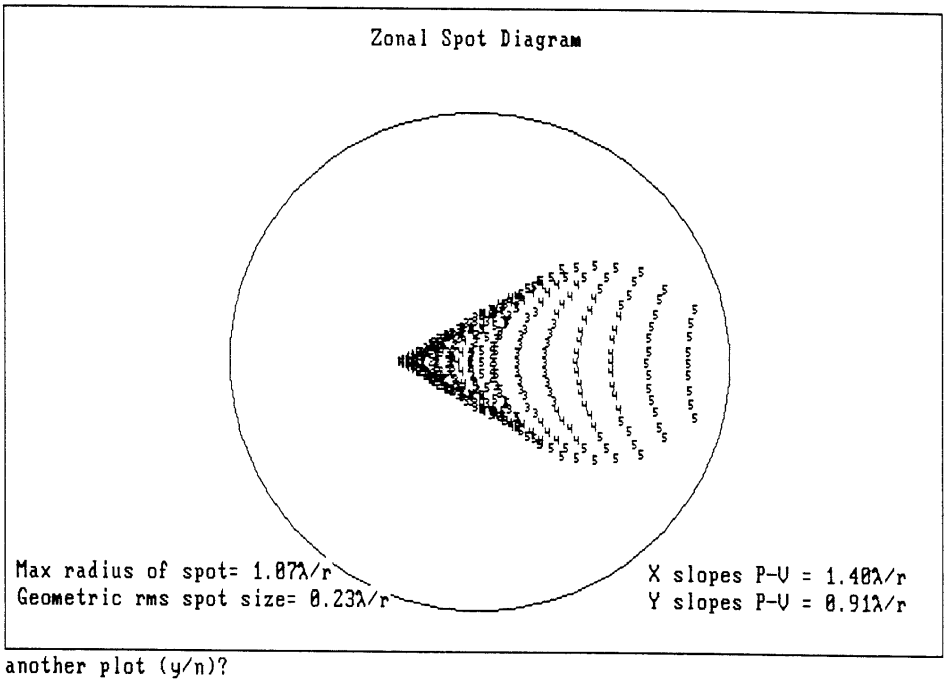
spot R = 2 (max radius of spot) λ (F-number).

Zonal Spot Diagram

The zonal spot diagram is of the same functional form as that of the geometric spot diagram except that the ray intercepts within five separate zones are tagged to indicate from which zone within the pupil the ray originates. The five zones for rays originating at radii are given by

Radius	Symbol
0.0 to 0.2	1
0.2 to 0.4	2
0.4 to 0.6	3
0.6 to 0.8	4
0.8 to 1.0	5

This diagram shows within which zone of the wavefront pupil high slope errors exist.

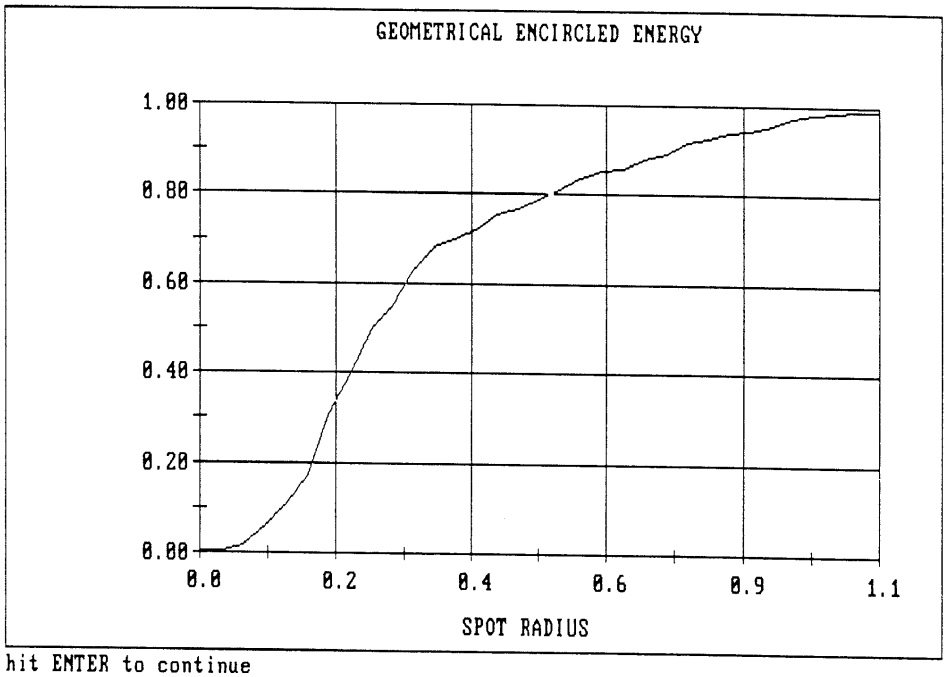


The geometric and zonal spot diagrams do not adjust for overall tilt within the exit pupil of the wavefront. To center the spot diagram, fit and remove tilt from the wavefront.

Geometric Encircled Energy

Geometric encircled energy computes the number of ray intercepts from the ideal image point to the maximum geometric spot radius as a function of the radius. The plot then indicates the percentage of ray intercepts within a given geometric spot radius. A spot diagram must be computed before this option can be activated.

The vertical axis is normalized to the total number of rays computed with the horizontal axis showing the range of radii of the geometric spot up to its maximum radius.



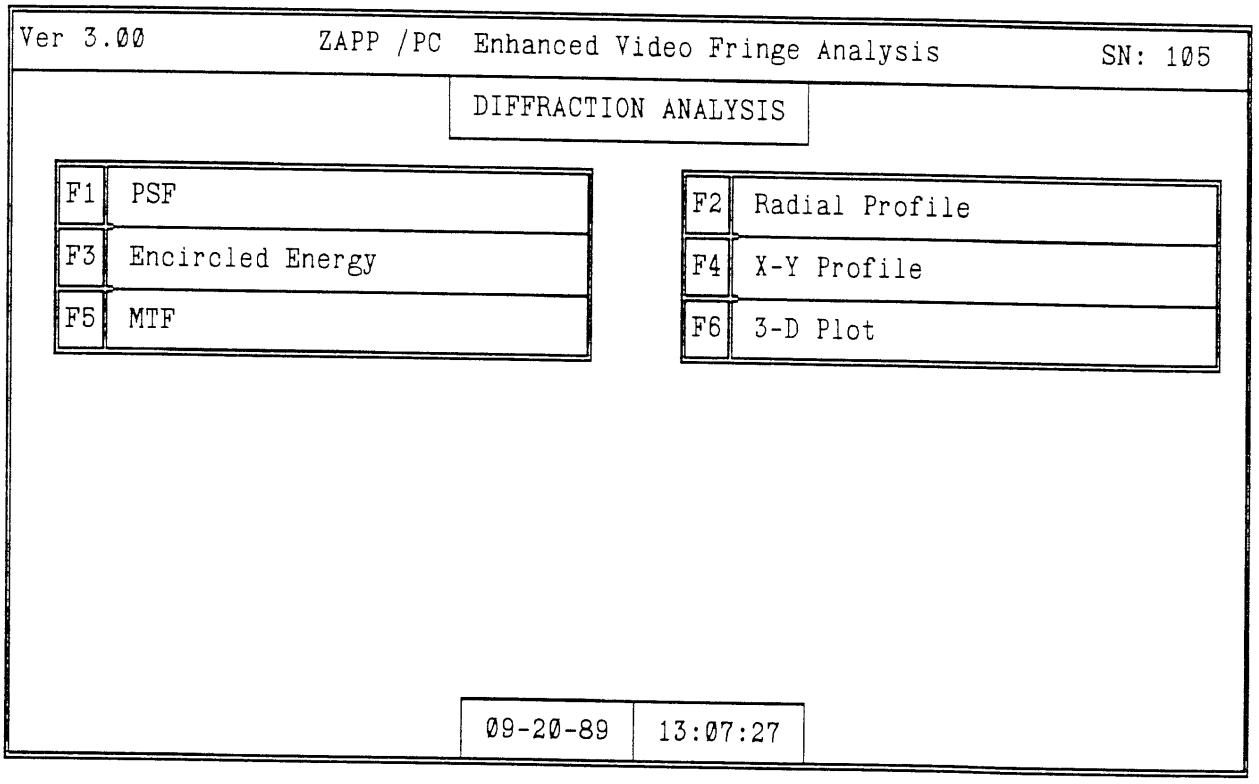
hit ENTER to continue

Introduction

Based upon Fourier optics theory, the diffraction analysis offers physical optics transformations of the wavefront map producing the Point Spread Function and the Modulation Transfer Function.

Since interferometric measurements of an optical system are far more accurate than image plane measurements, wavefront phase data must be used to obtain resultant image plane information. This can be computed by Fourier transforming the pupil function. In *ZAPP /PC*, the uniform grid of the wavefront phase values are used as the pupil phase with the modulus of the pupil function assumed to be uniform. Small variations in the modulus of the pupil function produce little effect in the image plane.

DIFFRACTION ANALYSIS MENU



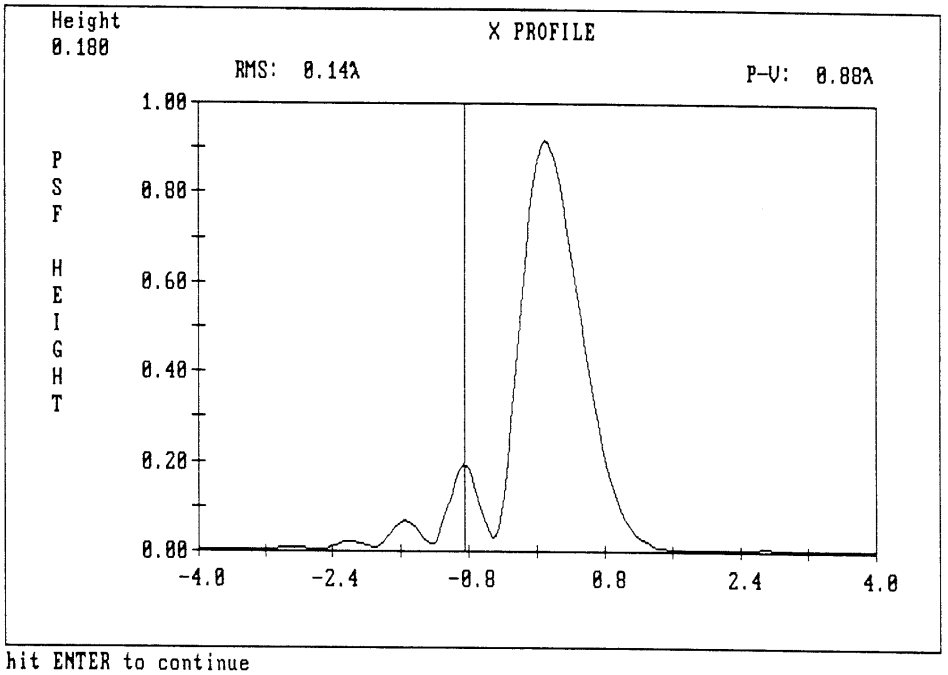
Point Spread Function

The impulse response of an optical system is the point spread function. In *ZAPP /PC*, the point spread function is computed by the Fast Fourier Transform over a 64 by 64 array. This will correctly sample a maximum of 4 waves per radius of slope error. For aberrations larger than this, aliasing may occur and thus a geometric analysis should be used.

Graphics display capability within the **DIFFRACTION ANALYSIS** menu can produce the same style plots as for the wavefront phase maps. Radial and X-Y profiles can be plotted with similar cursor and real-time slicing through the data. The true perspective 3-D plot also offers the user the ability to change the orientation of the data set.

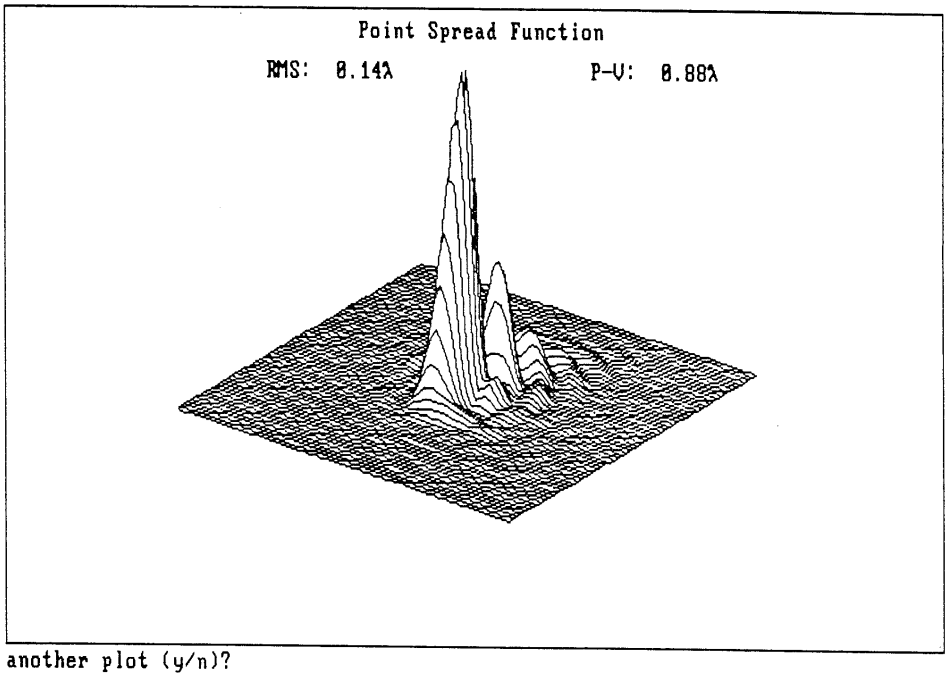
Profile plots through the Point Spread Function are smoothed by spline interpolation. This shows the fine structure realistically rather than simple linear line drawing to each point which shows jagged profiles due to under sampling. The vertical line cursor can be used to show the relative height of secondary peaks in the PSF.

POINT SPREAD FUNCTION X PROFILE

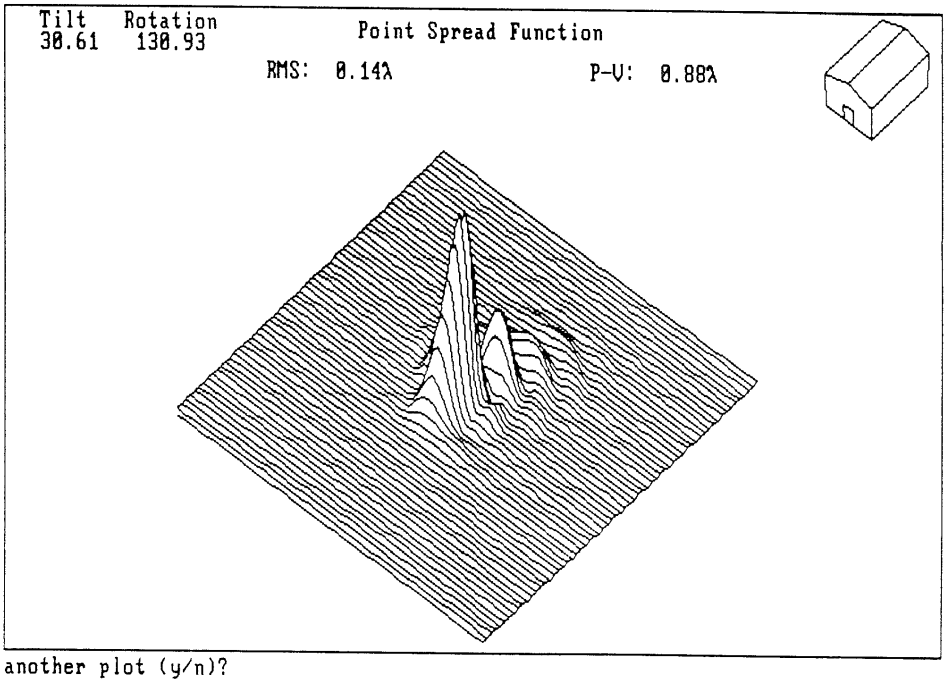


Point Spread Function 3-D Plot

The three-dimensional plot of the Point Spread Function (PSF) can also be rotated. Shown below are two perspective plots of the same PSF. The house in the lower right corner of the plots indicates the perspective, with the tilt and rotation values of the plot shown at the lower left of the plot.



another plot (y/n)?

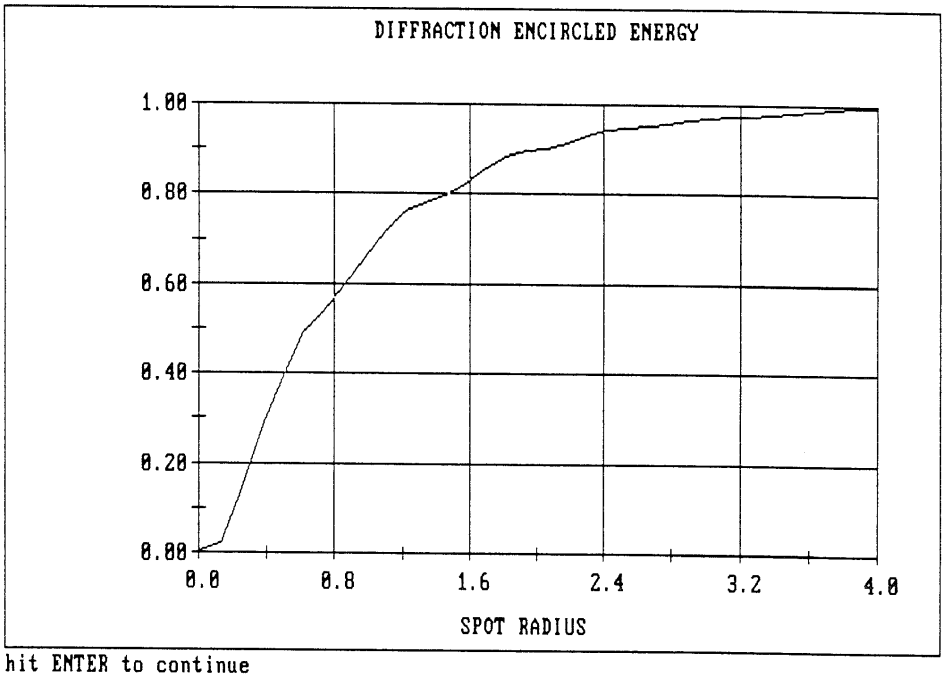


another plot (y/n)?

Encircled Energy

The diffraction encircled energy is a plot of the total energy encircled at a given radius from the center of the ***image plane***. The maximum spot radius is always that defined by the Fast Fourier Transform which computes the PSF and for this case is 4 waves per radius. Note that tilt within the pupil will shift the Point Spread Function away from the on-axis position. It is the user's responsibility to remove tilt from phase data before using **Diffraction Analysis**. Also since a focus term in the pupil can be compensated by a longitudinal shift of the image plane, at times it may be desirable to remove focus from the wavefront phase data.

DIFFRACTION ENCIRCLED ENERGY PLOT



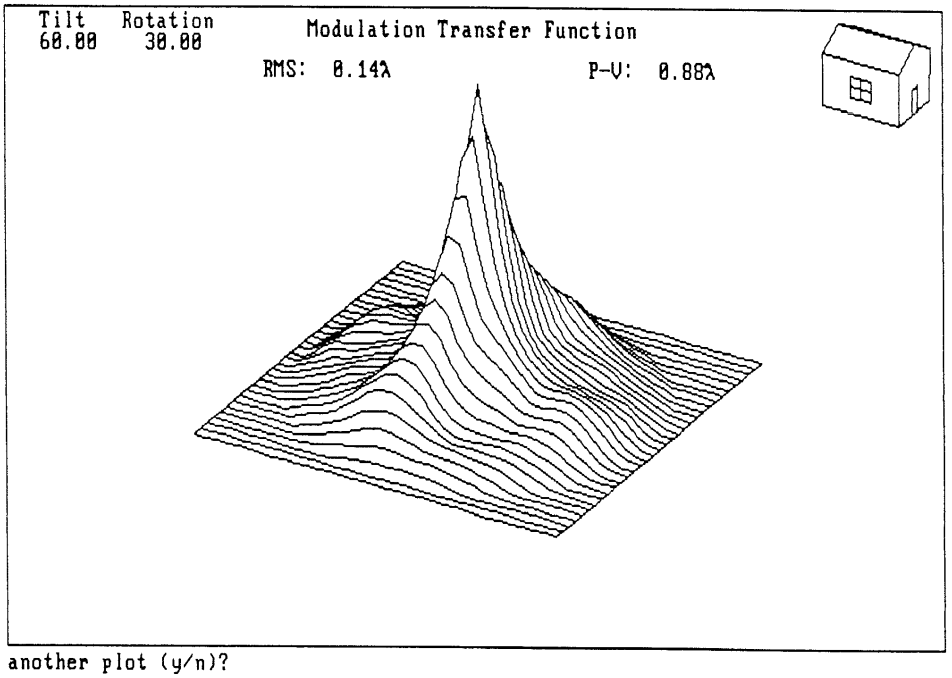
hit ENTER to continue

Modulation Transfer Function

The Modulation Transfer Function, MTF, for an incoherent optical system is the autocorrelation of the exit pupil. The exit pupil contains the aberrations of the optical system which is tested interferometrically. In *ZAPP /PC*, the MTF is calculated from the Fast Fourier Transform of the Point Spread Function. The value of the MTF at zero spatial frequency is normalized to unity.

The graphical display capability described for the PSF is also available for the MTF. Thus radial slices through the MTF at any angle can be plotted. Horizontal and vertical profiles with real-time slicing through the data can be performed using the MTF data. The true perspective 3-D plot of the Modulation Transfer Function can be displayed and rotated to any perspective.

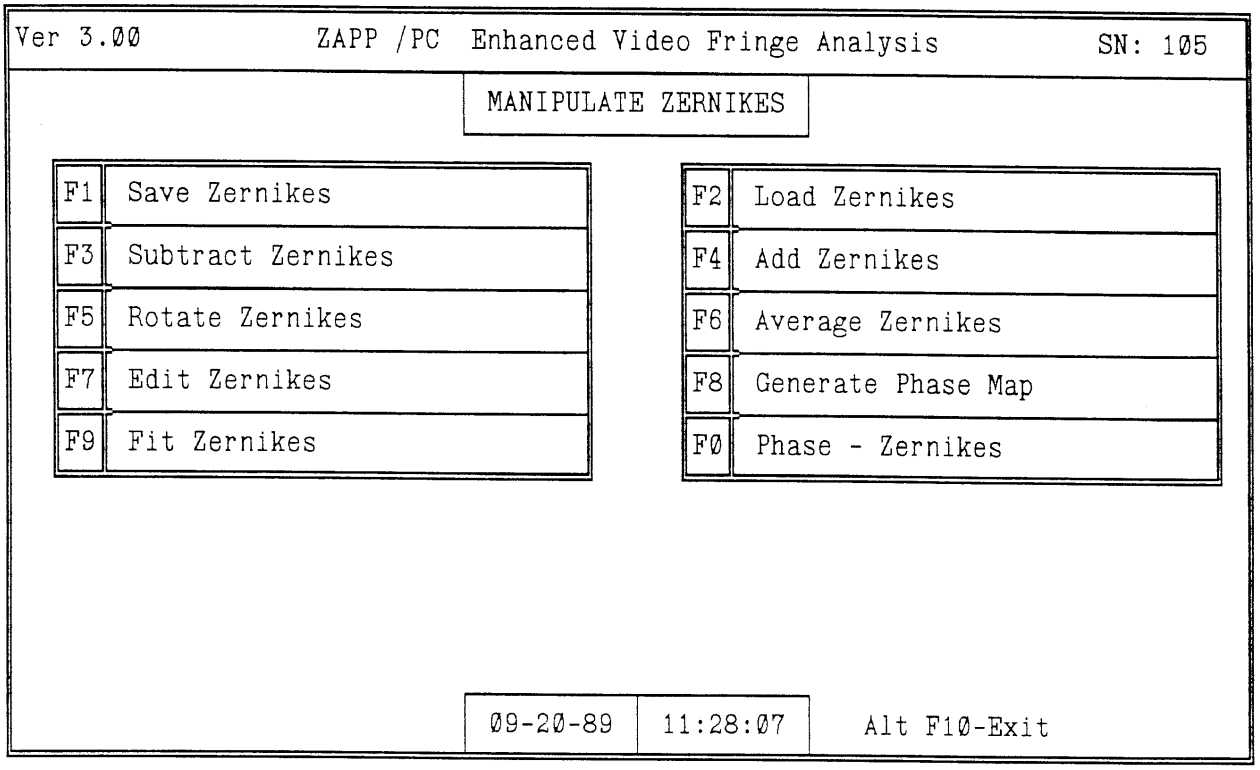
MODULATION TRANSFER FUNCTION 3-D PLOT



Introduction

Selected from the **INTERACTIVE MODE** menu, **Manipulate Zernikes** offers the user various operations concerning Zernike coefficients. Since *ZAPP /PC* uses 36 Zernike terms, these operations offer rapid, global manipulation of a wavefront which is specified by these coefficients. A uniform grid phase map can be generated from the Zernike coefficients that have been modified by the user.

MANIPULATE ZERNIKES MENU



Save Zernikes

The current set of Zernike coefficients are stored to a data file with this command. Only those coefficients up to the specified order are stored, with zero stored for any coefficients above the specified order. A title, time and date are stored with the data file containing the Zernike coefficients. The user can see the Zernike coefficients that will be stored by selecting the **Edit Zernikes** option which will display the complete set of Zernike coefficients.

Load Zernikes

A data set containing Zernike coefficients can be loaded from disk as the current set to be operated upon. These files typically will have the extension *filename*.**ZRN**. Only those coefficients up to the order specified when stored will be loaded, with zero values for coefficients above. The title for the data set is also loaded as well as the time and date the Zernike data file was created.

Add Zernikes

A stored data set of Zernike coefficients can be added to the current set of Zernike coefficients. The user must input the filename to be added when asked by the program. The title, time and date of the stored data set will replace the current title, time and date. Each current individual coefficient will be summed with its respective specified stored coefficients and the result will replace the current values. This can be used to add the wavefronts from multiple elements to obtain an overall system wavefront.

Subtract Zernikes

As with **Add Zernikes**, a stored data set of Zernike coefficients can be subtracted from the current set of Zernike coefficients with the result replacing the current set of coefficients. Each individual coefficient from the specified stored data set is subtracted from its respective coefficient that is currently loaded.

Average Zernikes

Multiple Zernike coefficient stored data sets can be averaged with the average becoming the current set of coefficients. The stored data sets must be of a "family" of generic filenames with the extension *filename*.**ZRN**. All the files to be averaged must have the same name except for a trailing number. For example, if a generic name of **TEST** is used, the files to be averaged would consist of **TEST1.ZRN, TEST2.ZRN, TEST3.ZRN**, ...etc.

Rotate Zernike

The aberrations in a wavefront which are asymmetric can be rotated by any specified angle with this option. The asymmetrical terms are rotated in a clockwise direction if a positive angle is specified. The current Zernike coefficients are operated upon. Thus if a stored data set is to be rotated, it must first be loaded using the **Load Zernikes** option, then rotated. It can then be saved or manipulated further. To see the effect of the rotation of the Zernike coefficients, one can use **Edit Zernikes** to verify that the asymmetrical Zernike coefficients truly have changed values. One can also use the **Generate Phase Map** option to create a uniform grid phase map and to observe how the aberrated phase map has rotated.

Generate Phase Map

Using the current set of Zernike coefficients, a phase map is generated over a circular pupil. This map can be processed as any other map.

Phase - Zernikes

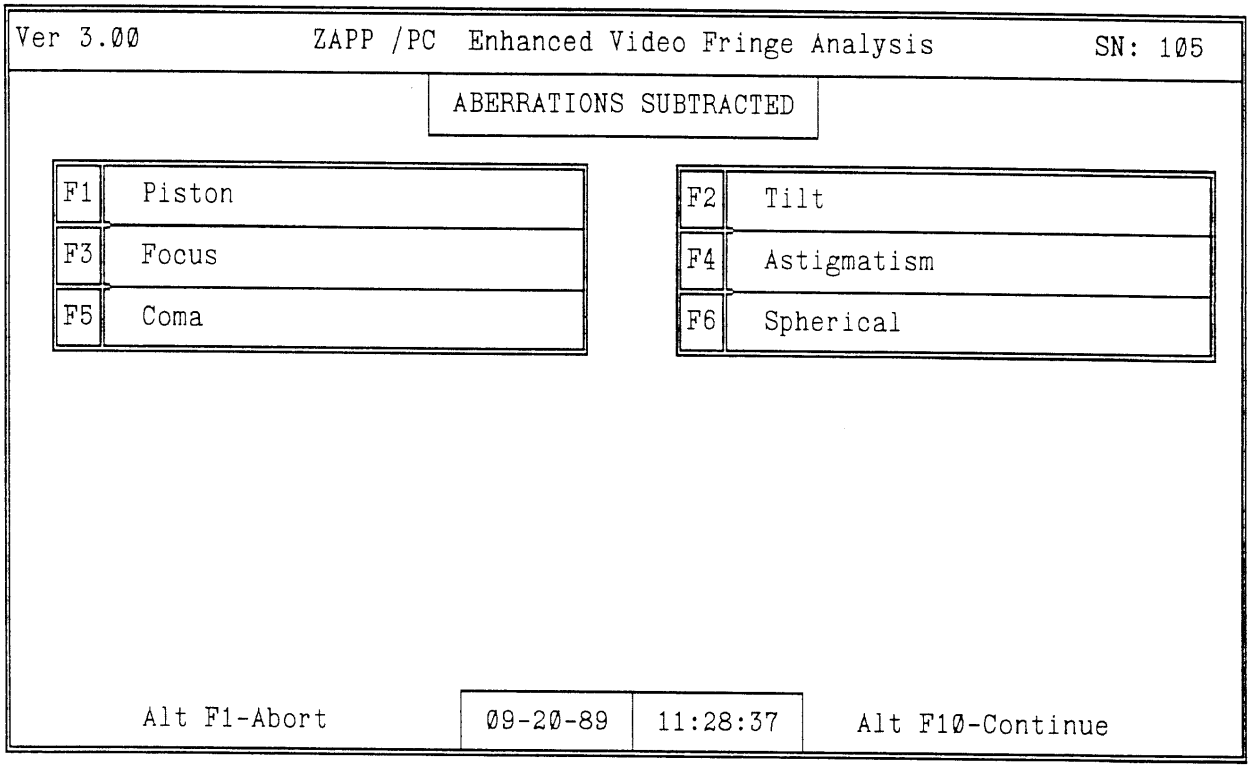
The current set of Zernike coefficients is subtracted from the current phase map. The Zernike coefficients can be loaded from a file, or specified by the user by selecting **Edit Zernikes**, or may even be the fitted Zernike coefficients from the current data map.

Using this function, any of the 36 Zernike terms (or any combination thereof) can be subtracted from a measured interferogram. Once a data set has been created as the current data, one can fit various orders of Zernike polynomials to this data. If **PHASE - ZERNIKES** is selected, then the relatively low order phase variations represented by the Zernike coefficients will be removed from the phase map. The resultant phase map can contain higher spatial frequency phase data if the **Interpolate Fringes** option was used to create the uniform data array. The user may also edit the fitted Zernike coefficients and subtract only the azimuthal terms or only the radial aberration terms.

Fit Zernike Polynomials

The user can select up to six orders of polynomial fitting of the data. The "complete" set of polynomials consists of 36 Zernike polynomial terms. The user can select the fit order to reduce processing time if higher order coefficients are not needed. First, the user is asked which low order aberrations are to be subtracted from the data. Usually piston, tilt and focus should be removed from the data since these aberrations are induced by the interferometer setup.

ABERRATIONS SUBTRACTED MENU

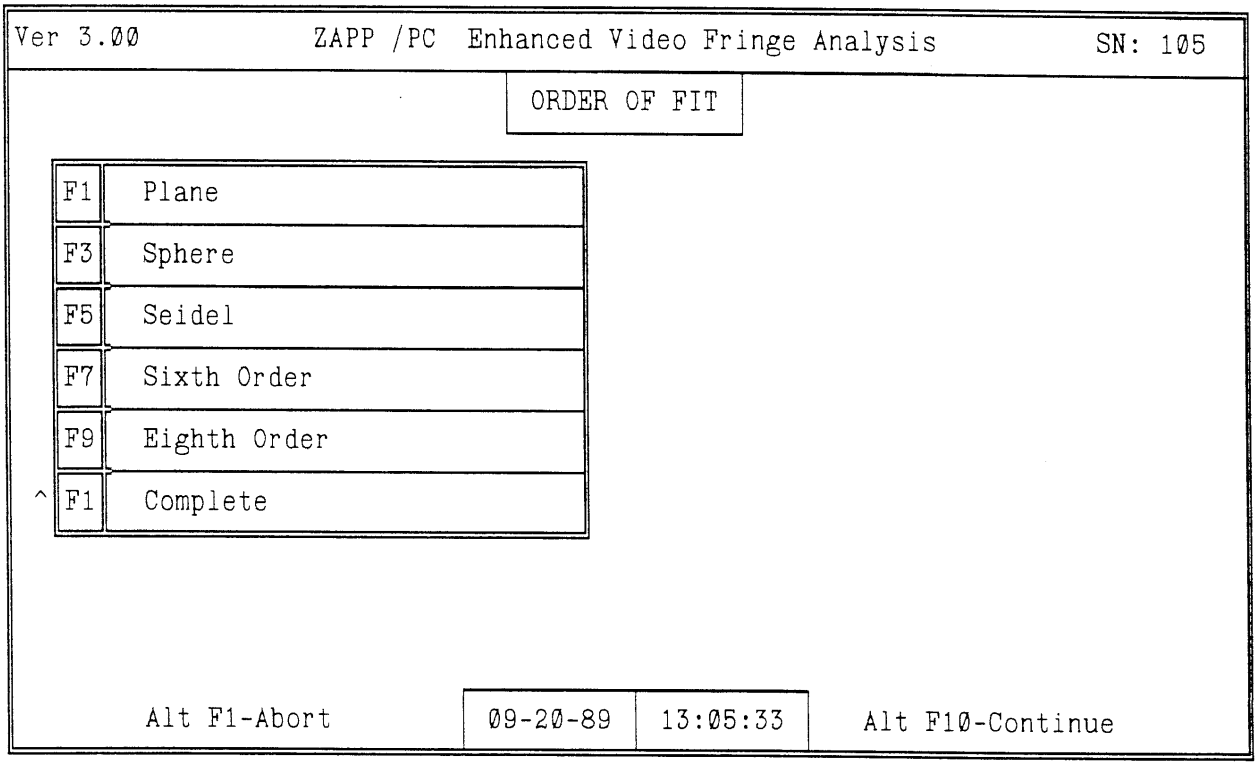


Next the user can enter the Fit Order.

Fitting to a plane consists of 3 terms — piston, tip/tilt.
Fitting to a sphere consists of 4 terms
Fitting to Seidels consists of 8 terms
Fitting to sixth order consists of 16 terms
Fitting to eighth order consists of 24 terms
Fitting to the complete set consists of 36 terms

See Chapter 2 for a list of the Zernike polynomials used by *ZAPP /PC*.

FIT ORDER MENU



After selection of the Fit Order, Zernike Polynomials will be fitted to the data up to the indicated order. The Zernike coefficients will be displayed along with the RMS fit error for each order of fit up to the selected order.

Quality of Fit of UNIFORM GRID for Different Polynomial Orders

Term	N	Rms fit	Zernike Polynomial Coefficients (in waves)					
Plane	2	Ø.948	Ø.2Ø4	Ø.147				
Sphere	3	Ø.927	Ø.2Ø4	Ø.147	Ø.192			
4th Order	8	Ø.485	Ø.Ø46	Ø.127	Ø.158	Ø.Ø27	-Ø.841	-Ø.799
			-Ø.1ØØ	-Ø.115				
6th Order	15	Ø.334	Ø.Ø97	Ø.114	Ø.1Ø8	Ø.Ø39	-Ø.676	-Ø.7Ø9
			-Ø.124	-Ø.185	-Ø.173	Ø.245	Ø.Ø42	Ø.536
			Ø.221	-Ø.Ø72	-Ø.144			
8th Order	24	Ø.154	Ø.Ø2Ø	Ø.Ø15	Ø.Ø71	Ø.Ø91	-Ø.838	-Ø.845
			-Ø.297	-Ø.237	-Ø.Ø58	Ø.2Ø4	Ø.114	Ø.312
			Ø.Ø58	-Ø.28Ø	-Ø.2ØØ	-Ø.ØØ5	-Ø.248	Ø.28Ø
			-Ø.Ø87	Ø.154	-Ø.433	-Ø.26Ø	-Ø.349	-Ø.Ø82
Complete	36	Ø.ØØ1	-Ø.ØØØ	Ø.ØØØ	Ø.Ø27	Ø.1Ø8	-Ø.914	-Ø.881
			-Ø.325	-Ø.3Ø1	Ø.Ø18	Ø.212	Ø.139	Ø.2Ø4
			Ø.Ø15	-Ø.313	-Ø.271	Ø.Ø92	-Ø.146	Ø.371
			-Ø.Ø77	Ø.181	-Ø.548	-Ø.3Ø1	-Ø.38Ø	-Ø.149
			-Ø.Ø37	Ø.151	Ø.193	Ø.2Ø8	Ø.152	Ø.Ø19
			Ø.Ø42	-Ø.157	-Ø.Ø46	-Ø.Ø31	-Ø.Ø27	-Ø.Ø85

Following this display will be the Seidel Coefficients and Fit Statistics.

SEIDEL ABERRATION COEFFICIENTS FROM UNIFORM GRID

Magnitude waves	Angle deg	Aberration
Ø.135	7Ø.3	TILT
Ø.317		FOCUS
1.683	-44.1	ASTIGMATISM
2.417	-172.9	COMA
-Ø.688		SPHERICAL

	Wedge	Wavelength
TEST:	Ø.5Ø	Ø.633
USER:	Ø.5Ø	Ø.633

Terms Subtracted From Data
Piston Coma

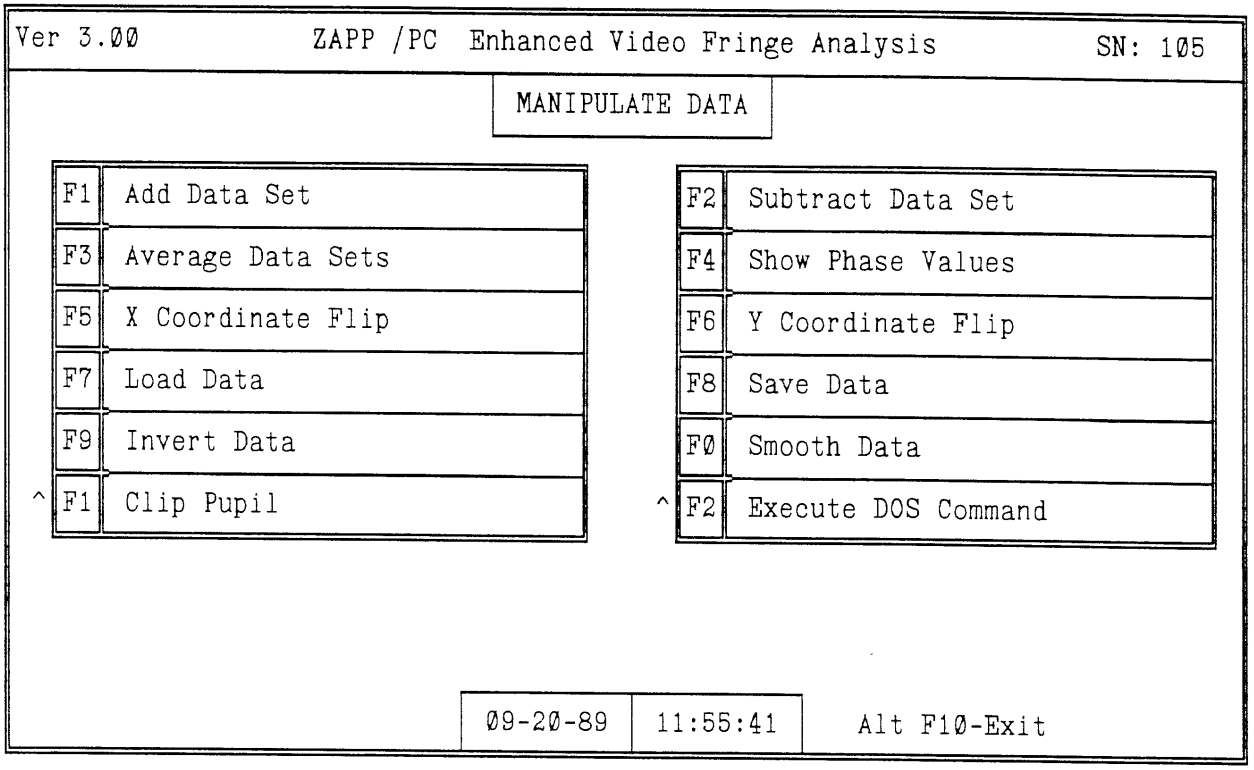
Residual Wavefront Variations Over Uniform Grid (in waves)

Number of pts	Peak	Valley	P-V	RMS	Strehl Ratio
27Ø1	Ø.934	-1.124	2.Ø58	Ø.412	Ø.ØØ1

Introduction

MANIPULATE DATA is another sub-menu in the **INTERACTIVE MODE** menu which offers various interactive manipulations of the data map. Any of these commands can be executed in any order or multiple times.

MANIPULATE DATA MENU



Add Data Set

A user specified stored data map will be added to the current data map. The summed data map becomes the current data set and P-V and RMS values are re-calculated. If either data map has bad pixel locations, they will remain bad pixels. Data maps are added directly (with no manipulation) if the current data map contains less than three test optic fiducials. Otherwise, if the number of fiducials on each map is the same, the fiducials will be used to manipulate (scale, rotate, translate, or invert) the specified data map so that the addition of the phases at corresponding points is performed. If the fiducial sets cannot be manipulated to match (e.g. from unequal fiducial number or poor positioning), a warning message will appear and the original data map is preserved. It is also important to remember that with fiducials, in general, the data maps to be added may sample the test surface differently, and the individual maps with subtracted abberations can sum to a map where these abberations are present.

Subtract Data Set

Data maps may be subtracted from one another with the use of the test optic fiducials. The conditions and limitations of this process are identical to those described in **Add Data Set.**

Invert Data

The polarity of the current data map is flipped. Therefore what was a bump on the data map becomes a hole; what was a low region becomes a high region. Selecting this function two times in succession will result in no net change to the data map.

X Flip Data

Selecting this option will flip the complete data map about the Y axis, i.e. from left to right. The data map is flipped about the center of the user defined data area and not the centroid of the valid data.

Y Flip Data

This option will flip the complete data map about the X axis, ie from top to bottom. The data map is flipped about the center of the user defined data area using the height of this area to define the center line.

Show Phase Values

The numerical values of the data map can be displayed in a 13 by 20 array on the computer display. Points that are outside the valid data region or drop-out data are displayed as ***bad***. The integer values shown are the raw phase values.

to where 2048 equals one wave in phase. The user inputs the starting column and row numbers.

```
input starting column (Ø to exit) [1]:
input starting row [1]:
```

The user can enter an **E** to abort at any time and return to the menu.

Average Data

Data sets stored to disk with common "generic" filenames can be averaged.

```
Input generic map filename for average:
```

Enter the generic filename for the files to be averaged. A generic filename consists of a name with numbers appended, such as **SPHERE1.MAP, SPHERE2.MAP, SPHERE3.MAP**....etc. It is only necessary to enter the common name (**SPHERE** in this case), the program assumes the files are stored under the **.MAP** extension so it is not required. All the generic files will be averaged and resultant average will be the new data map. Missing data points, or *bad pixels*, will not propagate through the average. Therefore, at any given pixel location, if any one of the data maps has a valid pixel, that pixel will be valid.

Smooth Data

The current data is smoothed using this function with a 3 by 3 uniform weighted cell convolved over the whole data set. The average of the nine phase values within the cell becomes the center cell value. This function is useful for removing noise from the data set and can be applied a number of times to increase the smoothing. This function is most useful when used after interpolating to the uniform grid.

The results of this smoothing can be seen by first smoothing a stored phase map, then subtracting the original map from the smoothed data. The result is the information lost by smoothing.

Clip Pupil Diameter

A data set with a circular pupil can be reduced by some percentage with this command. This will allow the user to remove data greater than a specified pupil radius. The computer display will show

```
Enter clipped radius :
```

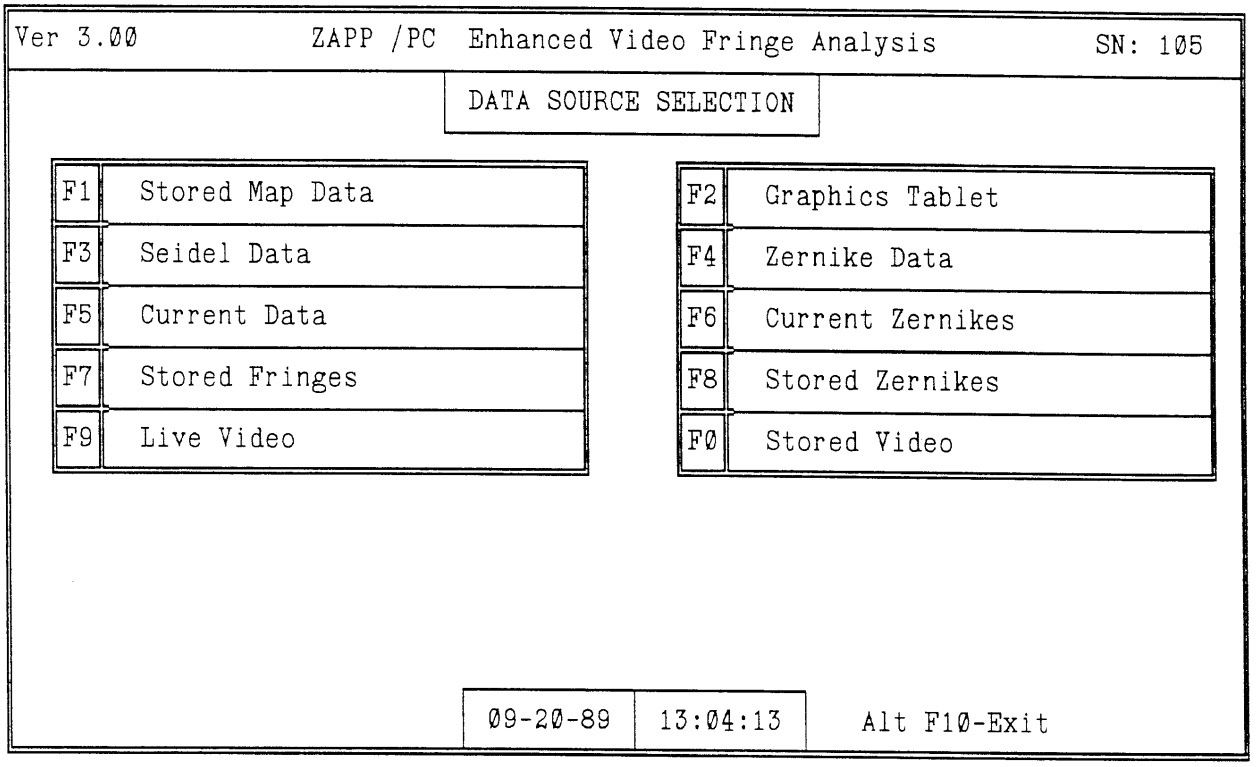
Entering a new radius less than unity (the normalized radius), will cause the data set to be clipped to the new radius. All data outside this radius will be lost. The new pupil will be analyzed for P-V and RMS and used as the current data set. Further processing, such as fitting will operate on this new data set with its pupil re-normalized to unity.

Creating Phase Maps from Polynomials

ZAPP /PC has the ability to generate a wavefront phase map from polynomial coefficients. This map is generated as a circular pupil function within a 63 by 63 grid. A wavefront map can be generated from either Seidel coefficients or Zernike coefficients, but not both at the same time.

A user created wavefront is generated by selecting the **Data Source** function from the **MAIN** menu. The **DATA SOURCE SELECTION** menu will be displayed and either **Seidel Data** or **Zernike Data** can be selected. **EXIT** will return back to the **MAIN** menu. To start creating the data, select one of the processing modes.

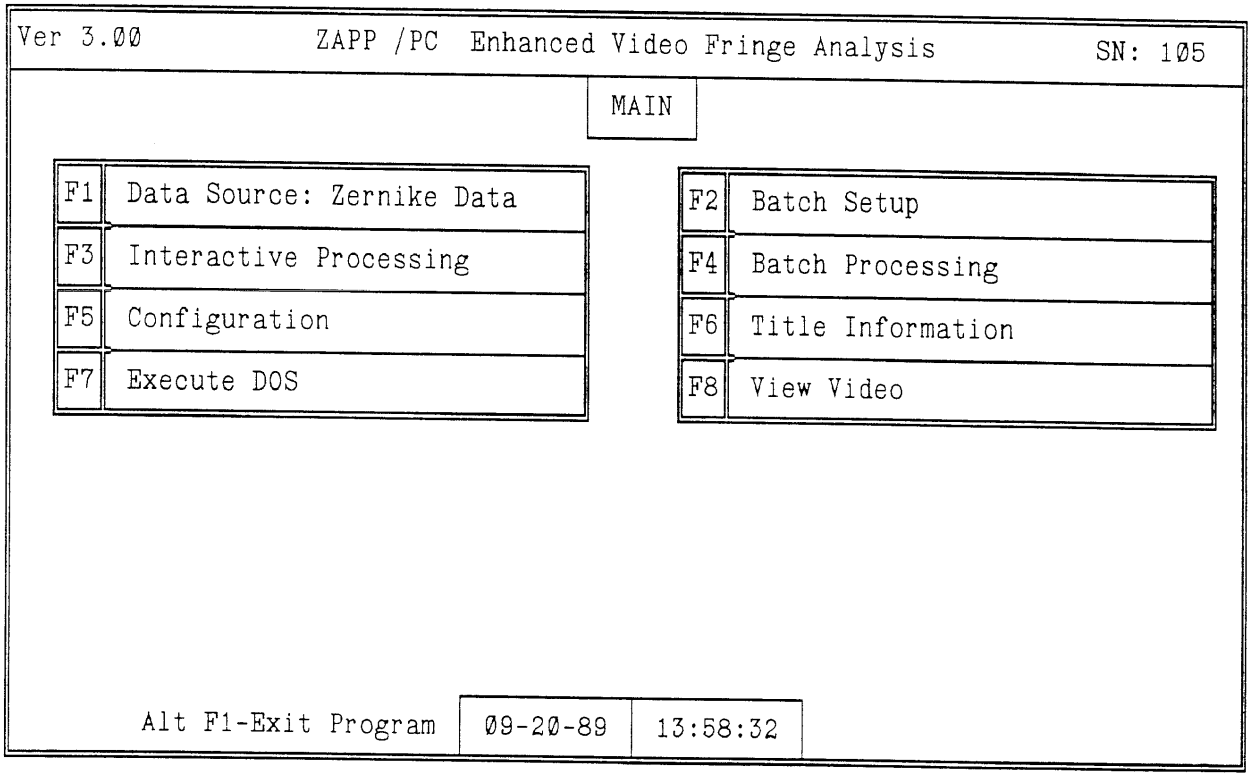
DATA SOURCE SELECTION MENU



Generating a Map from Zernike Coefficients

After a processing mode is selected from the **MAIN** menu with **Zernike Data** selected as the **DATA SOURCE**, a new menu is displayed showing all 36 Zernike coefficients. This grid of 36 Zernike coefficients allows the user to select any combination of coefficients to generate a data map. The coefficients must be entered in waves. Once the user is satisfied with the coefficients entered, **Continue** will generate the map. Once the map is completely generated, the **ORDER OF FIT** menu will request the fit order. If only low order terms were entered, then a low order fit can be used to analyze this particular wavefront map. Since the data was specified by the coefficients, the fitted terms should be equal to those specified if fitted to an order sufficient to specify the user input coefficients. Note that any terms selected to be subtracted will be subtracted from the map. Again, the user can operate on this map just like any other.

MAIN MENU WITH ZERNIKE DATA SELECTED



Zernike Polynomial Coefficient Input

With **Zernike Data** selected as **Data Source**, selecting a processing mode will display a set of 36 Zernike coefficients. Move the mouse or use the cursor keys to select any coefficient box with the screen cursor and press the left button on the mouse or press **<Enter>** on the keyboard to select that coefficient for entry. To enter a value, type in the numerical value in waves and complete by pressing **<Enter>**.

Shown below are three Zernike coefficients already entered in the table with a fourth coefficient being entered. These are then used to create the phase map.

Zernike Coefficients

Position cursor to coefficient using mouse or arrow keys
Press mouse button or ENTER to change coefficient under cursor
Press both buttons to zero coefficient under cursor

C1 = 0.000	C7 = 0.000	C13= 0.000	C19= 0.000	C25= 0.000	C31= 0.000
C2 = 0.000	C8 = 0.000	C14= 0.000	C20= 0.000	C26= 0.000	C32= 0.000
C3 = 0.000	C9 = 0.000	C15= 0.000	C21= 0.125	C27= 0.000	C33= 0.000
C4 = 0.400	C10= 0.000	C16=-0.200	C22= 0.000	C28= 0.000	C34= 0.000
C5 = 0.000	C11= 0.000	C17= 0.000	C23= 0.000	C29= 0.000	C35= 0.000
C6 = 0.000	C12= 0.000	C18= 0.000	C24= 0.000	C30= 0.000	C36= 0.000

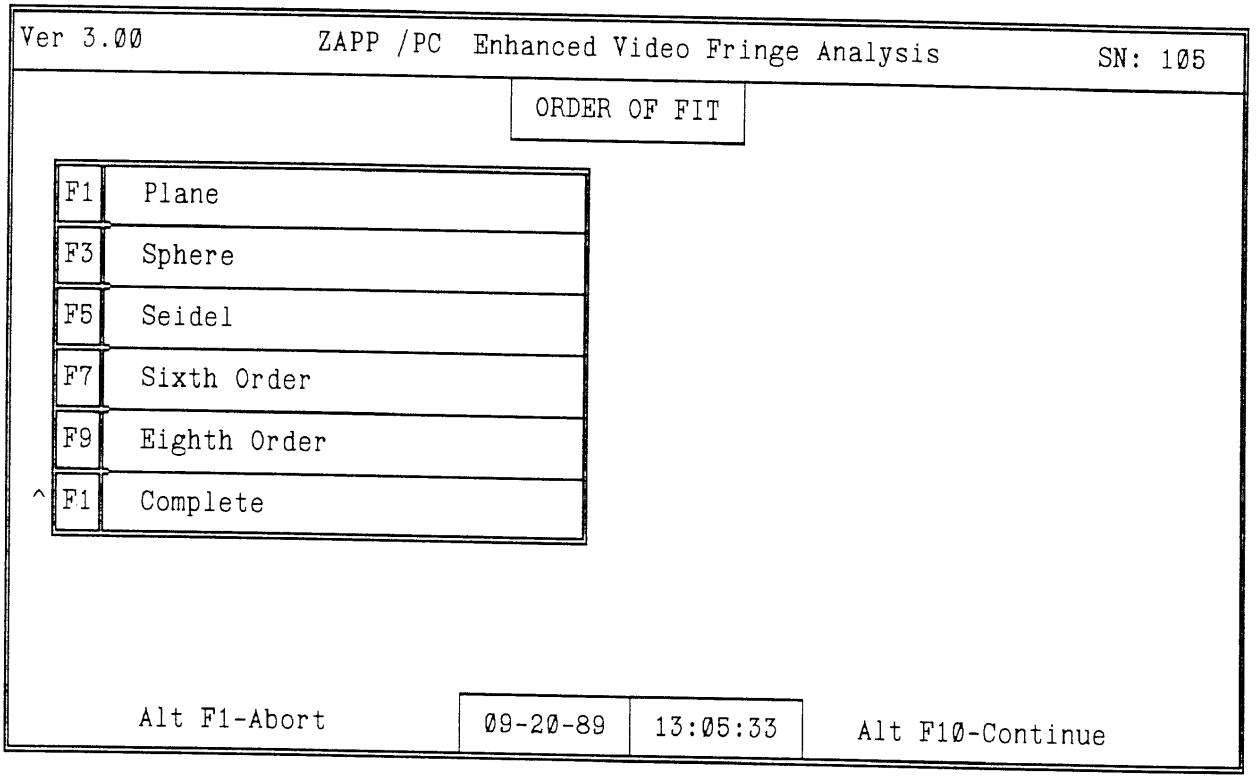
Input coefficient for Zernike #35: -0.05

Abort Continue

Wavefront Map Generated from Entered Zernike Coefficients

After the Zernike coefficients have been entered, select **Continue** at the lower right of the **ZERNIKE COEFFICIENTS** menu, and then if in **INTERACTIVE PROCESSING** the **SELECT ABERRATIONS SUBTRACTED** and the **ORDER OF FIT** menus will be displayed. These menus allow the user to select the aberrations to be subtracted from the data and how many terms of Zernike polynomials will be fit to the data. Make sure the order of fit is comparable to the order of the input coefficients. The phase map generated is analyzed for the wavefront statistics and Seidel coefficients. Note the selected aberrations will be subtracted from the generated wavefront map. If focus is entered as an aberration to be generated it makes no sense to subtract it from the newly fitted data set.

ORDER OF FIT MENU



Analysis of Generated Wavefront Map

The fitted Zernike coefficients are presented in increasing number. Coefficient C1 is the first term. C6 is at the start of the next rows.

Quality of Fit for Different Polynomial Orders

Term	N	Rms fit	Zernike Polynomial Coefficients (in waves)					
Plane	2	Ø.461	Ø.034	-Ø.ØØ8				
Sphere	3	Ø.461	Ø.033	-Ø.ØØ8	Ø.ØØ7			
4th Order	8	Ø.331	Ø.Ø2Ø	-Ø.Ø2Ø	Ø.ØØ9	Ø.4ØØ	Ø.Ø43	Ø.Ø41
			-Ø.Ø41	Ø.Ø15				
6th Order	15	Ø.324	Ø.Ø21	-Ø.Ø21	Ø.Ø14	Ø.4ØØ	Ø.Ø5Ø	Ø.Ø42
			-Ø.Ø42	Ø.Ø23	Ø.Ø21	Ø.Ø21	Ø.ØØØ	Ø.Ø73
			Ø.Ø61	-Ø.Ø61	Ø.Ø33			
8th Order	24	Ø.268	Ø.ØØ9	-Ø.ØØ9	Ø.Ø49	Ø.4ØØ	Ø.Ø72	Ø.Ø24
			-Ø.Ø24	Ø.Ø78	Ø.ØØ7	Ø.ØØ7	Ø.ØØØ	Ø.1Ø5
			Ø.Ø43	-Ø.Ø43	Ø.1ØØ	Ø.196	-Ø.ØØØ	Ø.Ø11
			Ø.Ø11	Ø.ØØØ	Ø.245	Ø.Ø6Ø	-Ø.Ø6Ø	Ø.113
Complete	36	Ø.ØØØ	Ø.ØØØ	Ø.ØØØ	Ø.ØØØ	Ø.4ØØ	-Ø.ØØØ	Ø.ØØØ
			Ø.ØØØ	Ø.ØØØ	-Ø.ØØØ	Ø.ØØØ	Ø.ØØØ	-Ø.ØØØ
			Ø.ØØØ	Ø.ØØØ	Ø.ØØØ	Ø.2ØØ	-Ø.ØØØ	Ø.ØØØ
			-Ø.ØØØ	Ø.ØØØ	Ø.125	-Ø.ØØØ	Ø.ØØØ	Ø.ØØØ
			-Ø.ØØØ	Ø.ØØØ	Ø.ØØØ	-Ø.ØØØ	Ø.ØØØ	-Ø.ØØØ
			-Ø.ØØØ	Ø.ØØØ	Ø.ØØØ	Ø.ØØØ	-Ø.5ØØ	Ø.ØØØ

Then the Seidel coefficients and statistics on the generated phase map are displayed. Note that fitting to eighth order was required to completely fit this data because a high order term, C35 was specified.

SEIDEL ABERRATION COEFFICIENTS

Magnitude waves	Angle deg	Aberration
Ø.Ø29	-45.Ø	TILT
Ø.Ø19		FOCUS
Ø.8Ø5	3.1	ASTIGMATISM
Ø.175	-45.Ø	COMA
Ø.ØØ89		SPHERICAL

	Wedge	Wavelength
TEST:	Ø.5Ø	Ø.633
USER:	Ø.5Ø	Ø.633

Terms Subtracted From Data
Tilt Focus

Residual Wavefront Variations Over Uniform Grid (in waves)

Number of pts	Peak	Valley	P-V	RMS	Strehl Ratio
3ØØ1	Ø.711	-Ø.791	1.5Ø2	Ø.231	Ø.123

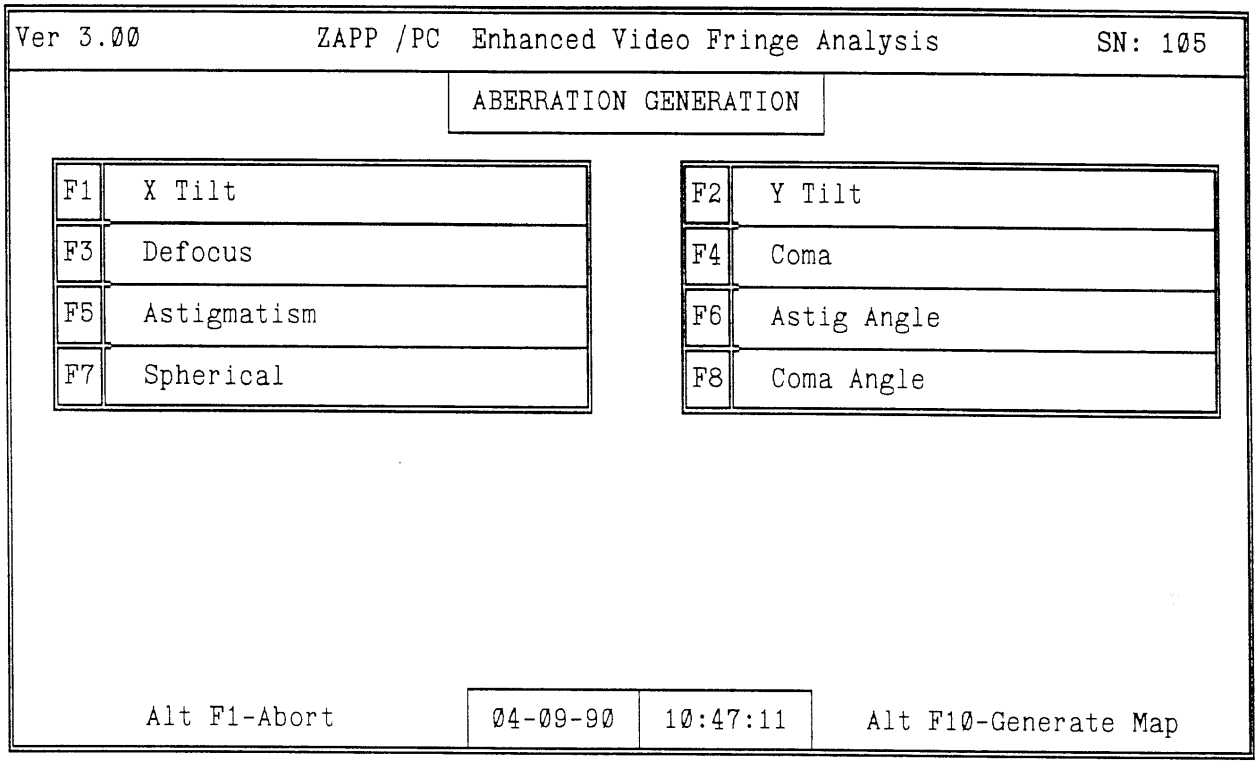
Generating a Map from Seidel Coefficients

As with creating a wavefront map from Zernike coefficients, selecting **Seidel** data in the **DATA SOURCE SELECTION** menu will allow Seidel coefficients to be entered when a processing mode is selected. The **ABERRATION GENERATION** menu allows the user to select any combination of Seidel aberrations. Upon selection of a specific aberration (for example **Coma**), the user can input the amount of aberration to be generated. This input must be in waves. The two options **Coma Angle** and **Astigmatism Angle** describe the orientation of any Coma or Astigmatism aberrations. They take a rotation in degrees, and calculate the necessary mixture of the X and Y component terms. If the user chooses **Coma Angle** before the **Coma**, then the software automatically asks for the magnitude of the coma in waves. The same is true for Astigmatism.

After specifying the complete wavefront, the user can either change his mind and **Abort** the processing or continue by selecting **Generate Map**. Once the wavefront map has been generated, if in **INTERACTIVE PROCESSING**, the **SELECT ABERRATIONS SUBTRACTED** menu and the **ORDER OF FIT** menu will be displayed as they were for the Zernike data, which allows the user to select what aberrations to subtract from the data and how many terms of Zernike polynomials will be fit to the data. For Seidel data, only up to 4th order or **Seidel** is needed. Then the generated map will be analyzed, the selected aberrations will be subtracted (see section on subtracting fitted aberrations), and the statistics such as peak-to-valley and RMS wavefront error will be presented. After the analysis of the fit has been displayed, the user can exit by pressing **E** or the processing will continue based on whether the **INTERACTIVE** or **BATCH PROCESSING** has been selected.

The user generated wavefront map can now be plotted and analyzed as any other data set. It can also be stored and then subtracted from a real data set.

SEIDEL COEFFICIENTS INPUT MENU



ANALYSIS OF GENERATED WAVEFRONT

Quality of Fit for Different Polynomial Orders

Term	N	Rms fit	Zernike Polynomial Coefficients (in waves)					
Plane	2	0.228	0.653	-0.013				
Sphere	3	0.228	0.653	-0.013	0.005			
4th Order	8	0.000	0.667	0.000	0.000	0.000	-0.000	0.333
			0.000	-0.000				

The Seidel coefficients and statistics on the generated phase map are displayed on the following screen.

SEIDEL ABERRATION COEFFICIENTS

Magnitude waves	Angle deg	Aberration
Ø.667	Ø.Ø	TILT
Ø.ØØØ		FOCUS
Ø.ØØØ	Ø.Ø	ASTIGMATISM
1.ØØØ	Ø.Ø	COMA
-Ø.ØØØ		SPHERICAL

	Wedge	Wavelength
TEST:	Ø.5Ø	Ø.633
USER:	Ø.5Ø	Ø.633

Terms Subtracted From Data
Tilt Focus

Residual Wavefront Variations Over Uniform Grid (in waves)

Number of pts	Peak	Valley	P-V	RMS	Strehl Ratio
3ØØ1	Ø.333	-Ø.333	Ø.667	Ø.117	Ø.583

Removing Aberrations from Phase Maps

To accurately reduce an interferogram to a uniform array of phase data, tilt should be introduced in the interference pattern so that twelve to fifteen fringes are visible. While *ZAPP /PC* can accept circular fringes, it is best to adjust the focus of the interference pattern to eliminate ***closed*** fringes when testing surfaces with optical power. It is common to remove **Tilt** and **Focus** from an interferogram. Also, depending upon the interferometric test configuration, coma may be introduced in the interferogram which is not representative of the optical figure alone.

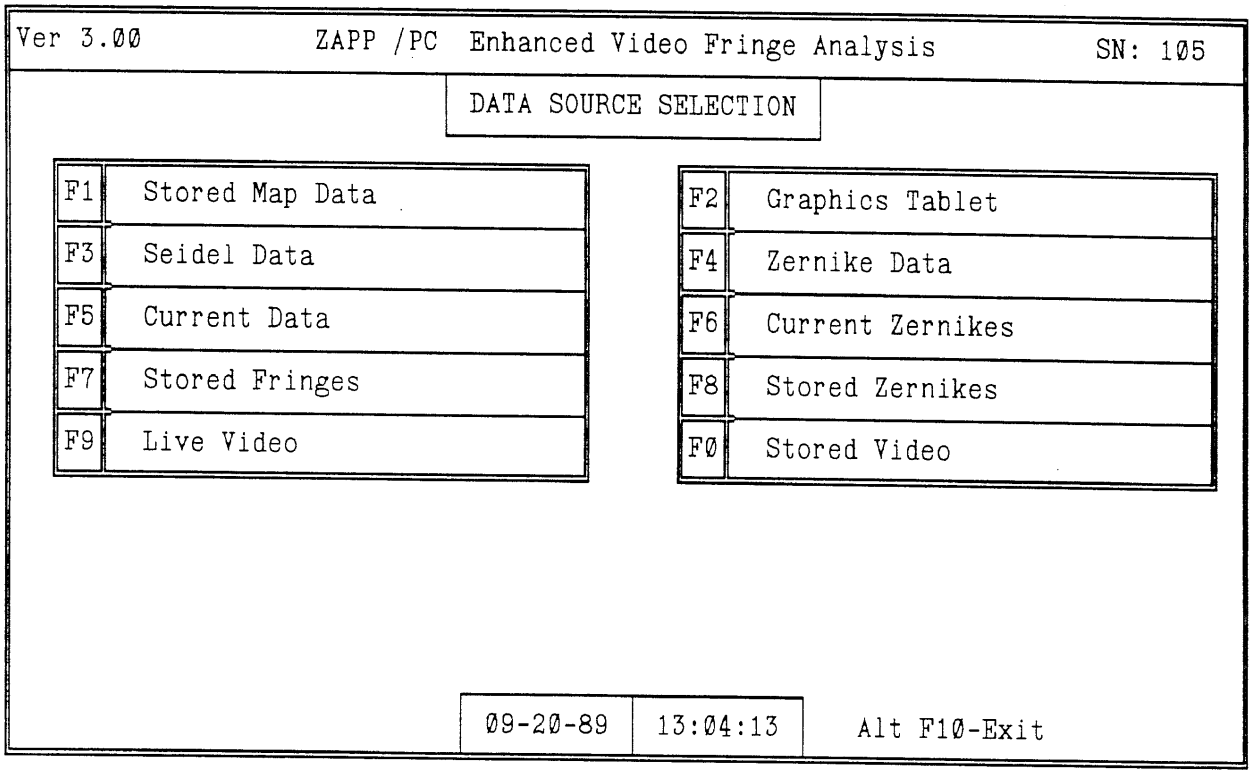
Removing Selected Zernike Coefficients

Using the Seidel coefficients to remove third-order aberrations from the phase data map may not be sufficient at times when one would like to further manipulate the data. For example, the contribution of radially symmetric terms to the wavefront map may be desired. Or perhaps one would like to remove the contribution of some of the higher spatial frequency Zernike terms to the wavefront map. Any Zernike coefficients can be set to zero and thereby remove its contribution to the phase data map.

Removing Selected Zernike Coefficients

This feature of modifying any of the Zernike polynomial coefficients is found in the **DATA SOURCE** menu. As shown under ***Generating Aberrated Wavefronts***, a phase map can be created from user input of coefficients. If the function **Current Zernike Data** is selected then the current Zernike polynomial coefficients from a fitted data set are displayed in the Zernike coefficients input menu. This is the basis from which a new phase map can be generated. If none of the coefficients are changed, then the same phase map will be created.

DATA SOURCE MENU



Removing Selected Zernike Coefficients

Any of the 36 Zernike coefficients can be edited from the **Zernike Coefficients** input menu. Coefficients can be set to zero or modified. Setting a coefficient to zero subtracts that particular Zernike polynomials from the phase map. Thus, any of the Zernike coefficients can be removed from the data. Note that data must have been fitted with the Zernike polynomials before this feature can be used. Also to edit the complete set of Zernike coefficients, all of the terms must have been used in the fit.

Below is an example of the **ZERNIKE COEFFICIENT** menu when using the **Current Zernike** data source. This menu shows the Zernike polynomial coefficients for the currently fitted data. Any of these coefficients can be edited by moving the screen cursor to the coefficient box (either with the mouse or using the keyboard cursor keys) and selecting that coefficient for entry by pressing the leftmost button on the mouse or pressing **<Enter>** on the keyboard. By selecting **Continue** at the lower left of the menu a new wavefront will be generated using the indicated set of Zernike coefficients.

ZERNIKE COEFFICIENT INPUT MENU WITH CURRENT ZERNIKES

Zernike Coefficients

Position cursor to coefficient using mouse or arrow keys
Press mouse button or ENTER to change coefficient under cursor
Press both buttons to zero coefficient under cursor

C1 =-0.000	C7 = 0.028	C13= 0.017	C19= 0.010	C25=-0.028	C31=-0.013
C2 = 0.000	C8 = 0.010	C14= 0.008	C20= 0.006	C26= 0.002	C32=-0.008
C3 =-0.000	C9 =-0.072	C15= 0.003	C21=-0.003	C27= 0.023	C33=-0.008
C4 =-0.310	C10=-0.036	C16=-0.030	C22=-0.011	C28=-0.009	C34=-0.000
C5 = 0.016	C11= 0.052	C17= 0.002	C23=-0.009	C29= 0.002	C35= 0.004
C6 =-0.020	C12=-0.008	C18= 0.024	C24= 0.028	C30=-0.001	C36= 0.001

Abort Continue

Phase Map Data Files

The **.MAP** file is the uniform array of phase data points. The file is a binary file containing different Pascal types. The phase data is stored as 4-byte integers. ASCII characters used in the title, time, and date are standard one byte ASCII characters. The 4-byte "long" integers used for the phase data have an implicit fixed point scaling used internal to the program. The phase data thus are scaled so that 2048 is equivalent to one wave.

Variables appear in the file in the following order:

ID	4000 decimal value (2 bytes)
number of columns	(2 bytes)
number of rows	(2 bytes)
size of title	(1 byte)
title	(1 byte ASCII values - 20 bytes max)
size of operator	(1 byte)
operator	(1 byte ASCII values - 20 bytes max)
size of customer	(1 byte)
customer	(1 byte ASCII values - 20 bytes max)
size part ID	(1 byte)
part ID	(1 byte ASCII values - 20 bytes max)
time	(8 bytes in the format hh:mm:ss)
date	(8 bytes in the format mm-dd-yy)
wedge	(4 byte real - IEEE 32-bit format)
wavelength	(4 byte real - IEEE format)
fwaves	(4 byte real - IEEE format)
x scale	(4 byte real - IEEE format)
y scale	(4 byte real - IEEE format)
length of units label	(1 byte)
lateral units label	(1 byte ASCII values - 15 bytes max)
number of int fids	(2 bytes - 0, 3 or 4)
(x,y) int fids coord	(4 byte real values - all x's then all y's)
number of test fids	(2 bytes - 0, 3 or 4)
(x,y) test fids coord	(4 byte real values - all x's then all y's)
data	(4 byte signed integers)

Fringe Center Data Files

Digitized fringe data files contain the X,Y coordinates along with the fringe order number (M). The file is a binary file containing different Pascal types. Variables appear in the file in the following order:

ID	3001 decimal value (2 bytes)
size of title	(1 byte)
title	(1 byte ASCII values - 20 bytes max)
size of operator	(1 byte)
operator	(1 byte ASCII values - 20 bytes max)
size of customer	(1 byte)
customer	(1 byte ASCII values - 20 bytes max)
size part ID	(1 byte)
part ID	(1 byte ASCII values - 20 bytes max)
time	(8 bytes in the format hh:mm:ss)
date	(8 bytes in the format mm-dd-yy)
wedge	(4 byte real - IEEE 32-bit format)
wavelength	(4 byte real - IEEE format)
fwaves	(4 byte real - IEEE format)
x scale	(4 byte real - IEEE format)
y scale	(4 byte real - IEEE format)
length of units label	(1 byte)
lateral units label	(1 byte ASCII values - 15 bytes max)
number of int fids	(2 bytes - 0, 3 or 4)
(x,y) int fids coord	(4 byte real values - all x's then all y's)
number of test fids	(2 bytes - 0, 3 or 4)
(x,y) test fids coord	(4 byte real values - all x's then all y's)
number of points	(2 byte integer)
X coordinate array	(4 byte reals)
Y coordinate array	(4 byte reals)
M coordinate array	(2 byte integers)

The data have no separators and the XY coordinates must be scaled to a range of -1.0 to +1.0 and M represents the order number.

Zernike Data Files

Zernike data files contain the coefficients of a fitted data set up to the number of terms that were fitted. The file is a binary file containing different Pascal types including ASCII, integer, and real. Variables appear in the file in the following order:

ID	2000 decimal value (2 bytes)
size of title	(1 byte)
title	(1 byte ASCII values - 20 bytes max)
size of operator	(1 byte)
operator	(1 byte ASCII values - 20 bytes max)
size of customer	(1 byte)
customer	(1 byte ASCII values - 20 bytes max)
size part ID	(1 byte)
part ID	(1 byte ASCII values - 20 bytes max)
time	(8 bytes in the format hh:mm:ss)
date	(8 bytes in the format mm-dd-yy)
wedge	(4 byte real - IEEE 32-bit format)
wavelength	(4 byte real - IEEE format)
fwaves	(4 byte real - IEEE format)
x scale	(4 byte real - IEEE format)
y scale	(4 byte real - IEEE format)
length of units label	(1 byte)
lateral units label	(1 byte ASCII values - 15 bytes max)
number of int fids	(2 bytes - 0, 3 or 4)
(x,y) int fids coord	(4 byte real values - all x's then all y's)
number of test fids	(2 bytes - 0, 3 or 4)
(x,y) test fids coord	(4 byte real values - all x's then all y's)
# of coefficients	(2 bytes)
Zernike coefficients	(4 bytes each, no <CR> or <LF> separaters)

Intensity Data Files

Intensity data files contain the 256 grey level values that compose the video image. The file is a binary file containing different Pascal types including ASCII, integer, byte, and real. Variables appear in the file in the following order:

ID	1002 decimal value (2 bytes)
number of columns	(2 bytes)
number of rows	(2 bytes)
least X image coord	(2 bytes)
least Y image coord	(2 bytes)
size of title	(1 byte)
title	(1 byte ASCII values - 20 bytes max)
size of operator	(1 byte)
operator	(1 byte ASCII values - 20 bytes max)
size of customer	(1 byte)
customer	(1 byte ASCII values - 20 bytes max)
size part ID	(1 byte)
part ID	(1 byte ASCII values - 20 bytes max)
time	(8 bytes in the format hh:mm:ss)
date	(8 bytes in the format mm-dd-yy)
wedge	(4 byte real - IEEE 32-bit format)
wavelength	(4 byte real - IEEE format)
fwaves	(4 byte real - IEEE format)
data	(1 byte video data is sequenced by rows)