SCHMITT MEASUREMENT SYSTEMS, INC.
A DIVISION OF SCHMITT INDUSTRIES, INC.

µScan™ SCATTEROMETER

User’s Manual

085-923-101
Revision 3
Software Version E

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September 25, 2000

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Contents

Introduction

Congratulations on your purchase of the Schmitt Measurement Systems, Inc. (SMS) µScan™ System. SMS, the leader in light scatter measurement technology, has developed this portable surface measurement instrument that allows the operator to rapidly take measurements at the sample—where you need them—in seconds.

The µScan System offers several features that provide for easier operation and require minimal operator training.

Features

- Microprocessor controlled
- Interchangeable measurement heads
- RS 232 serial port
- Rechargeable battery or external power
- PC compatible software

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This instrument has been thoroughly inspected and carefully packed prior to shipment. If the packing container is damaged upon receipt, please notify Schmitt Measurement Systems, Inc. immediately.
Upon receipt and prior to removing the instrument from its shipping container, please verify that the shipping invoice compares with the original purchase order. When removing the instrument from the ship-ping container, compare the items received with
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To order additional copies of this manual, contact Schmitt Measurement Systems, Inc. and request the µ*Scan System User's Manual*, Part Number **085-923-101.**

About This Manual

The purpose of the SMS µScan Manual is to provide information for installing and operating the instrument and managing data resulting from measurements you make.

The Tutorial contains general information about light scatter, its measurement, analysis, data curves, noise, samples, coordinate systems and other topics important to the understanding of the operation and use of SMS Scatterometers. Experienced users may need only to review this chapter for reference purposes. Others may find this information important as they begin to work with light measurement equipment.

Other sections contain information specific to the µScan instrument. Information is presented with the point of view that you are going to unpack, set up, install software, make measurements and analyze data.

It is important that you thoroughly understand the information presented in order to obtain the maximum utilization of this instrument.

Other References

Technical references on light scatter and measurements are listed in the Tutorial bibliography. It is suggested that you review the Microsoft ™ MS-DOS User's Guide and User's Reference if you are not experienced with the computer operating system.

This manual is designed to enable you to proceed step-by-step through system setup and operation of the SMS µScan System. To help you find specific information, the manual has been divided into five parts:

	Introduction
⇒ **Part 1**	Tutorial
⇒ **Part 2**	Control Unit
⇒ **Part 3**	Measurement Head
⇒ **Part 4**	PC Operation and Software

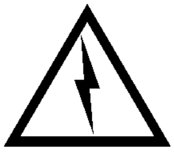
Carefully following the procedures outlined in this manual should answer most questions on how to set up and operate the system. If there are any questions regarding operation, do not hesitate to contact your sales representative or SMS directly.

Hardware Safety Precautions

Before operating any portion of this instrument, it is important to become familiar with the procedures outlined below.

It is important to understand the dangers of using the Surface Roughness and Scatter Measurement Instrumentation improperly. Every effort has been made to ensure user safety and the safety of bystanders. The procedures presented here must be followed to obtain the safest possible environment for both the operators and the instrument itself.

Electrical Shock Hazards



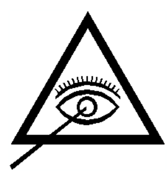
WARNING

The voltages and currents used in this equipment are potentially dangerous and normal precautions should be exercised when operating this equipment.

Before using any portion of this equipment, complete these tasks:

- ⇒ Make sure that none of the components are placed in standing water.
- ⇒ Ensure that the power supply cord is connected to an AC source of the correct voltage and frequency. Equipment is supplied with a three-wire, grounding-type power cord. Connect only to a properly grounded three-wire receptacle.
- ⇒ To prevent damage, ensure that any extension cord is sized properly for its load and length.
- ⇒ Locate power cords and bus cables where they will not become damaged.
- ⇒ Turn the system power off at the Power Supply to prevent damage to system components before connecting or disconnecting any individual items.
- ⇒ When operating, do not place the Measurement Head, Control Unit, Charging stand, and cables on or near sources of heat.
- ⇒ Always disconnect primary AC power from the equipment before performing any service or maintenance work.

Optical Injury Hazards



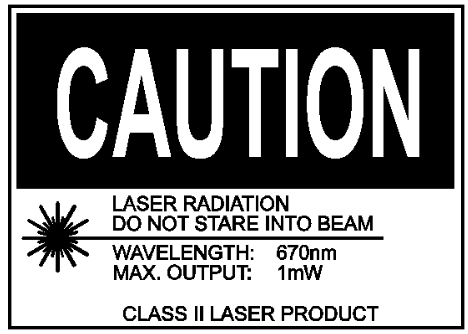
WARNING

The laser power source is enclosed in a specially designed housing to provide protection from inadvertent exposure to laser radiation. **DO NOT** attempt to perform any maintenance or disassembly of this optical assembly.

To avoid the risk of any possible exposure to harmful radiation, DO NOT stare or look directly into the laser beam and exit aperture on the bottom of the Measurement Head.

Use of control or adjustments, or performance of procedures other than those specified herein may result in hazardous radiation exposure.

Activate the laser only when the Measurement Head is placed on the sample. An audible warning is given from the Control Unit when the laser is **ON** and radiating energy.



- ⇒ All lasers are classified by the Center for Devices and Radiological Health, (CDRH) of the U.S. Food and Drug Administration and by ANSI Z-136. The classification philosophy is based upon human access and potential hazards.

- ⇒ Class I lasers are low-powered and do not emit hazardous radiation under normal operating conditions. Equipment, such as laser printers and bar code scanners, are examples of this class.

- ⇒ Class I laser operation does not require any special devices for eye protection.

- ⇒ Some Measurement Head models contain a Class II laser. Class II lasers do not have enough output power to accidentally injure a person, unless the viewer continuously stares into the laser beam.

- ⇒ Class II laser operation does not require any special devices for eye protection.

- ⇒ This instrument is specifically designed to reduce concerns of using a Class II laser device. The laser source is enclosed in the laser optical assembly to reduce the possibility of stray laser radiation. The exit aperture is clearly marked.

- ⇒ Maintenance beyond normal operating procedures should be performed only by factory authorized personnel.

Safety Considerations: Complies with all applicable laws for the manufacture of laser devices. This system is classified by the Center for Devices and Radiological Health (CDRH) as a class II laser device. Class II systems: do not stare directly into the laser source or point the laser at another's eye.

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Part 1: TUTORIAL

INTRODUCTION

This chapter provides the background information about light scatter, which you may find helpful for operating the SMS Scatterometer instruments. Users not acquainted with optical scatter are encouraged to study this chapter before using SMS instrumentation. Those with a background in this technology may prefer to skip this chapter or to refer to it only occasionally.

For more information on the subject, see the technical papers listed in the bibliography, or refer to the book *Optical Scattering: Measurement and Analysis* by John C. Stover (McGraw-Hill, 1990) upon which this chapter is based.

WHAT IS LIGHT SCATTER?

Anyone who has played pool is acquainted with the basic law of reflection - “the angle of incidence equals the angle of reflection.” A beam of light reflected from a mirror follows this rule - almost. Actually, all of the light is absorbed by the reflector and then radiated as the reflected beam. If the reflector is perfectly smooth and formed of a perfectly uniform material, all of the reflected light will be contained in a “mirror image” of the incident beam (Figure 1). This beam of light is often referred to as the specular beam. However, if the surface is rough (even on an atomic level) some of the light will be reflected (or scattered) out of the specular beam into the hemisphere in front of the reflector (Figure 2).

Rougher surfaces completely diffuse the incident light so that the specular reflection completely disappears (Figure 3). The resulting patterns may be observed by placing a white piece of paper in the specular direction as shown in Figure 2 by the dotted line.

Different surfaces scatter light differently. For example, periodic tool marks on a surface will cause a periodic structure in the scatter pattern (Figure 4), while a polished or ground surface will scatter light more uniformly (Figure 5).

Even small inclusions or bubbles in a transparent solid will scatter light. Emulsified liquids such as dairy products and machine coolants scatter light in a way that depends on droplet concentration and

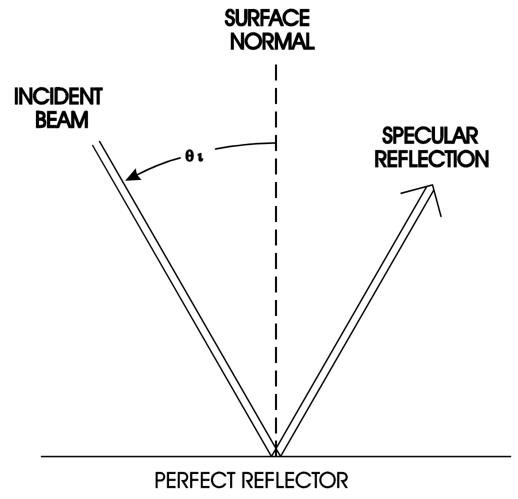

FIGURE 1
REFLECTION FROM A PERFECTLY SMOOTH SURFACE

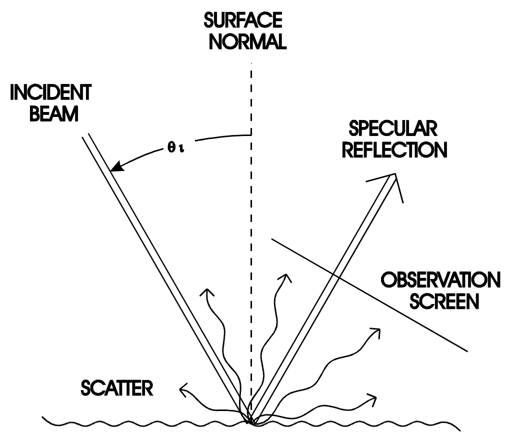

FIGURE 2
REFLECTION FROM A SLIGHTLY IMPERFECT SURFACE

size. In short, virtually everything scatters light. You see this page and the words on it because they scatter light.

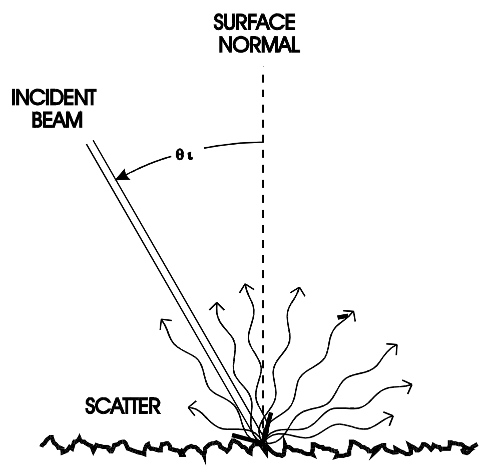

FIGURE 3
REFLECTION FROM A VERY ROUGH SURFACE

WHY MEASURE SCATTERED LIGHT?

Although measurement of scattered light is a fast, sensitive quality check for a variety of industrial applications, hundreds of quality and process control inspections are still done by visually inspecting surfaces. We won't argue speed and cost issues here; however, two other important contributions to quality control are made by light scatter measurements.

The obvious one is that computerized instrumentation provides a record keeping process that is becoming increasingly important. This information is needed to apply Statistical Process Control (SPC) techniques to product quality verification. The second, however, is equally important. Not only can the eye be tricked, or distracted, into missing critical defects, it also does not quantify the result. Pass/fail decisions are subjective, not objective. On the other hand, scatter measurements can be quantified, and collected data can be used to improve manufacturing processes.
The optics industry, for example, has used scatter measurement techniques for a number of years to ensure that scatter does not reduce product quality. However, even greater potential awaits industries outside of optics. By documenting defects or process characteristics, industries as diverse as paint, paper, machining and automotive manufacturers have the opportunity to improve their products and decrease overall manufacturing costs.

MEASUREMENT TECHNIQUES AND TERMINOLOGY

Several techniques have been developed for measuring scatter, from full capability laboratory Scatterometer to application-specific devices designed to bring speed and repeatability to one measurement requirement. But to understand how these instruments work, you must also be familiar with light scatter terminology.

TOTAL INTEGRATED SCATTER
One of the first places to start with scattered light measurement is with the collection of as much scattered light as possible. This measurement, **Total Integrated Scatter** (TIS), is especially useful for fast measurement of non-uniform scatter patterns, such as for machined parts (see Figure 4). The reason is that TIS measurement is independent of sample (and pattern) rotations.

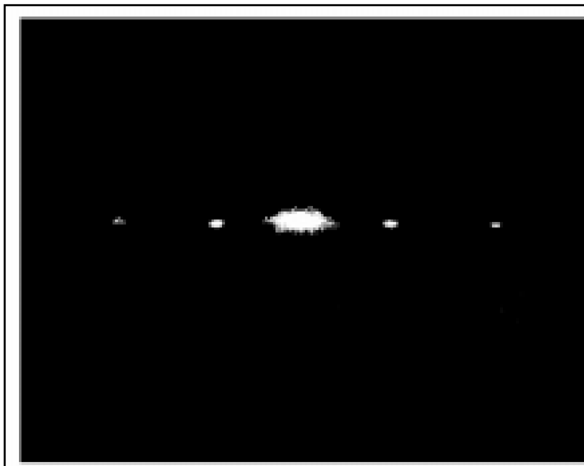

FIGURE 4
SCATTER FROM PERIODIC TOOL MARKS

Several techniques are available. The one shown in Figure 6 traps the scattered light in a diffuse, white integrating sphere. Typically, a beam of light is reflected off the surface and back into a sphere where as much of the scattered light as possible is measured. A single detector then samples the resulting uniform illumination of the interior, which is proportional to the total scatter.

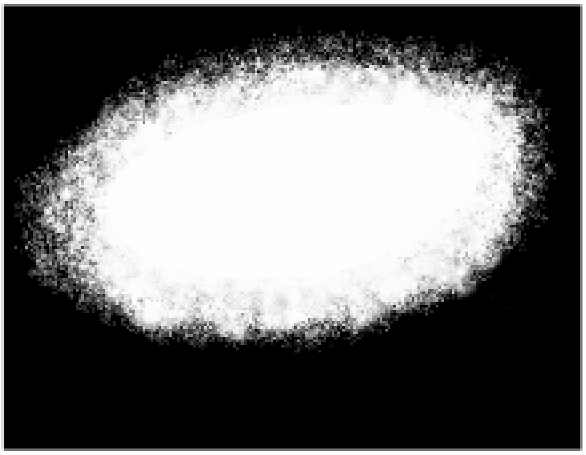

FIGURE 5
SCATTER FROM A POLISHED SURFACE

TIS equals the ratio formed by the scattered power divided by the specular reflection (which is also measured). When TIS measurements from different instruments are compared, care must be taken to ensure that the same band of collection angles is used. If the sample is relatively smooth, then the surface Root Mean Square (RMS) Roughness, may be found from the TIS as indicated in Figure 6.

One limitation of this type of measurement needs to be pointed out. TIS measurements are not really “total” because some light is lost at the entrance/exit aperture and at the waist of the hemispherical mirror. In addition, the instrument is less sensitive to high angle scatter than near specular scatter because detector response is lower for light incident at higher angles. Sometimes instrumentation is designed to specifically block angular segments of scatter from being collected (or integrated).

With these caveats in mind, many industrial surfaces could value from this type of measurement. For example, the roughness of aluminum soft drink can stock could be measured in this way, as could high gloss painted surfaces and smooth machined surfaces. TIS measurements have historically been made with table top instruments for inspection; however, SMS is now producing hand-held (or robot-held) heads for process control as part of our µScan line of instrumentation.

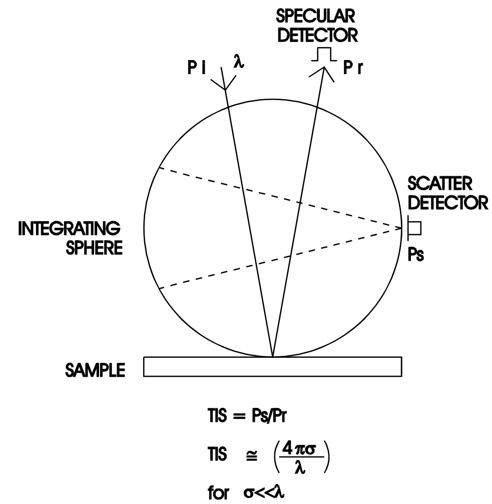

FIGURE 6
AN INTEGRATING SPHERE
USED TO MEASURE TIS

BIDIRECTIONAL SCATTER DISTRIBUTION FUNCTION (BSDF)

Although extremely useful in some applications, TIS instrumentation is not always appropriate for scatter measurements, particularly when a more complete measurement of the scatter pattern is required. For this reason, researchers began measuring scattered light as a function of angle from the specular. This work resulted in Scatterometer instrumentation which measures the Bi-directional Scatter Distribution Function (BSDF), which is now the generic term commonly used to quantify scattered light patterns.

BSDF is defined in terms of the incident power, scattered power, and geometry of reflected scatter. It is equal to the scattered power per unit solid angle normalized by the incident power and cos (θ_S).

$$BSDF = \frac{P_S \,/\, \Omega}{P_i \; COS\,\theta_S}$$

Where: P_S = measured scattered power

Ω = A/R^2 solid angle given by receiver aperture (A) and sample to receiver radius (R)

θ_S = measurement position from surface
P_i = power incident on the sample

This equation works for all angles of incidence and all angles of scatter. The $\cos(\theta_S)$ factor adjusts the area illuminated to its apparent size when viewed from the direction of scatter.

NOTE

The generic term BSDF is used throughout the remaining chapters and on SMS Scatterometer software screens unless it is necessary to refer specifically to a reflective (BRDF), transmissive (BTDF), or volume scatter pattern (BVDF).
Figure 7 shows a log-log plot of the BRDF of a molybdenum mirror. The vertical axis has units of inverse steradians (one over the solid angle). Notice that it drops over several orders of magnitude from its peak. The lower curve in this plot is the instrument signature - or noise level of the instrument. In this figure the BRDF is plotted against log degrees from specular (θ_S - θ_i). Other common choices include the difference of the scatter and incident angles (θ_S - θ_i) and the difference of the sines of these angles ($\sin \theta_S - \sin \theta_i$).

SURFACE ROUGHNESS

Surface roughness is one of the most common causes of scatter in optical systems. Conversely, scatter measurement is an extremely sensitive measure of surface roughness. To see how this comes about, it helps to first understand the parameters commonly used to quantify surface roughness.

In the optical community surface height fluctuations from average are generally called out as root mean square (RMS) Roughness (denoted by □) where the name describes the mathematical calculation used. In more general manufacturing applications, height

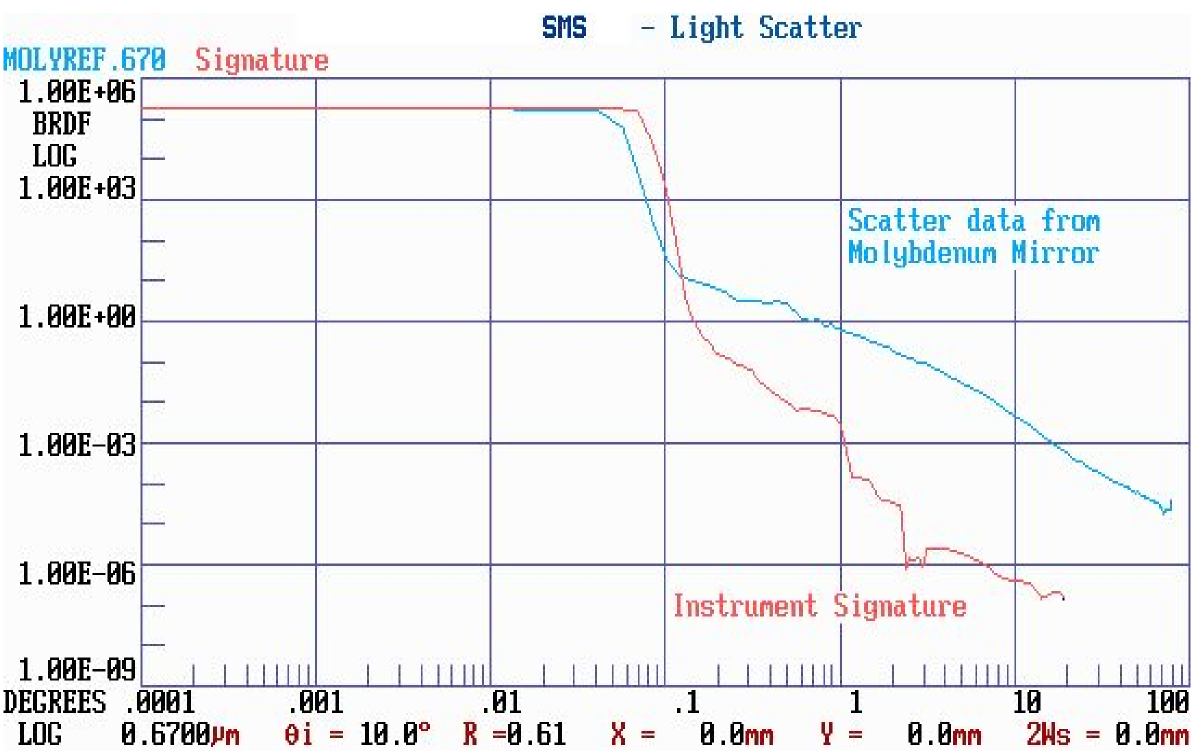

Figure 7
BRDF from a molybdenum mirror with instrument signature

roughness is given as an arithmetic average known as “a.a.” and denoted by R_a or □$_a$. For most surfaces these two numbers differ by only about 10%. The RMS descriptor has been used in optics because it arises naturally in theoretical calculations of scatter from rough surfaces. Conversely, electrical averaging of stylus profilometer signals produces a result proportional to the arithmetic average roughness, which has led to its use in most other industries. Either RMS Roughness or Arithmetic Average Roughness is generally given when the surface roughness is requested. However, surface structure is far more complicated than can be represented by just one number.

Another useful descriptor is a surface length parameter, such as the Average Surface Wavelength or the Correlation Length. Imagine two surfaces with textures that appear much like waves on the ocean. All the waves on both surfaces are the same height (they have the same RMS and the same a.a.), but on one surface the waves are spaced much farther apart. This surface will appear (and probably feel) smoother and the two will behave

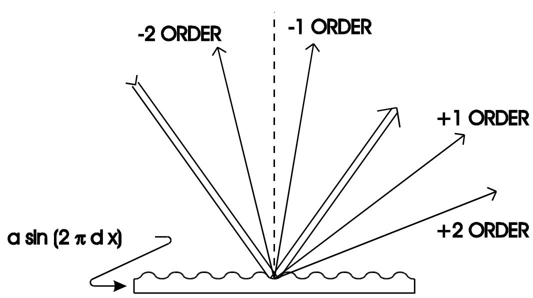

FIGURE 8

LIGHT DIFFRACTING FROM A SINUSOIDAL GRATING

quite differently in many applications.
If a laser beam is reflected off a surface that has smooth sinusoidal corrugations, the beam will be split into several segments, or diffraction orders, as shown in Figure 8. For optical surfaces (where surface heights are much smaller than a wavelength), only the plus and minus first orders are of any consequence. Diffraction theory allows the surface wavelength, d, to be found from the position of the first order diffraction (relative to the zero order) and the surface wave height, **a**, to be found from the first order power (relative to the first to zero order). Values of σ and/or σ_a are easily found from the peak value **a** as noted in Figure 8. Thus measurement of this simple scatter pattern allows characterization of the corresponding surface. More complex surfaces may be treated in a similar fashion through Fourier analysis. The surface is approximated by the summation of many sinusoidal components having different amplitudes, wavelengths and directions. In effect, each scatter measurement is treated as the first order diffraction from one sinusoidal component as outlined in Figure 9. Resulting data can be used

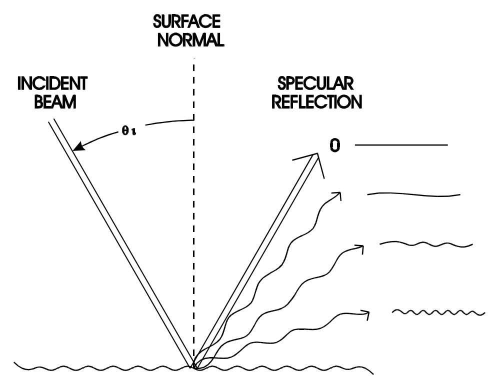

FIGURE 9

SCATTER FROM SURFACE ROUGHNESS MAY BE ANALYZED AS FIRST ORDER DIFFRACTION FROM MANY SINUSOIDAL COMPONENTS OF THE SURFACE

to find the corresponding surface statistics.
There are some distinct relationships between the surface and the resulting scatter pattern. Periodic surfaces (like the sinusoidal corrugations) have discrete scatter patterns. A surface composed of non-sinusoidal tool marks (and several parallel Fourier components) will have many discrete diffraction points. These “one dimensional” surfaces have another interesting property. The entire scatter is found in a single band across the reflective hemisphere in front of the sample. Surfaces made by extrusion and some types of grinding also exhibit a surface “lay,” or one-dimensional character. They scatter a virtually continuous streak of light indicating that many spatial wavelengths are present in the surface. Two-dimensional surfaces scatter into the full hemisphere. Thus a polished surface illuminated

at near normal incidence will have a scatter pattern much like that of Figure 5. Most nearly one-dimensional surfaces will also have a dim two-dimensional pattern in the background.

There is still a lot more surface information in the scatter pattern than just averages of roughness and wavelength. The surface power spectral density function (PSD) is both useful and easy to calculate from the measured scatter. It is defined in terms of spatial frequency, f, which is just the inverse of spatial wavelength. The PSD may be thought of as roughness power (height squared) per unit spatial frequency (inverse length). For one-dimensional surfaces it has units of length cubed. For two-dimensional surfaces, it has units of length to the fourth power because frequencies running both in and out of the incident plane must be considered. It is generally plotted as a function of spatial frequency. Although this is not the place to develop the mathematics behind PSD calculations, a little thought about the sinusoidal surface examples should convince you that such a calculation is feasible.

Less obvious is the fact that the integral of (or the area under) the PSD is just the mean square roughness. Taking the square root yields the RMS. The average surface wavelength may be found by taking the second moment of the PSD - which is just the integral of frequency squared times the PSD. The example shown in Figure 10 is a log-log plot calculated from the BRDF values of Figure 7. The RMS Roughness is also found in this figure. Notice that both the PSD and the RMS are bandwidth limited quantities, that is they are not found from frequencies of zero to infinity. As implied by Figure 9, the

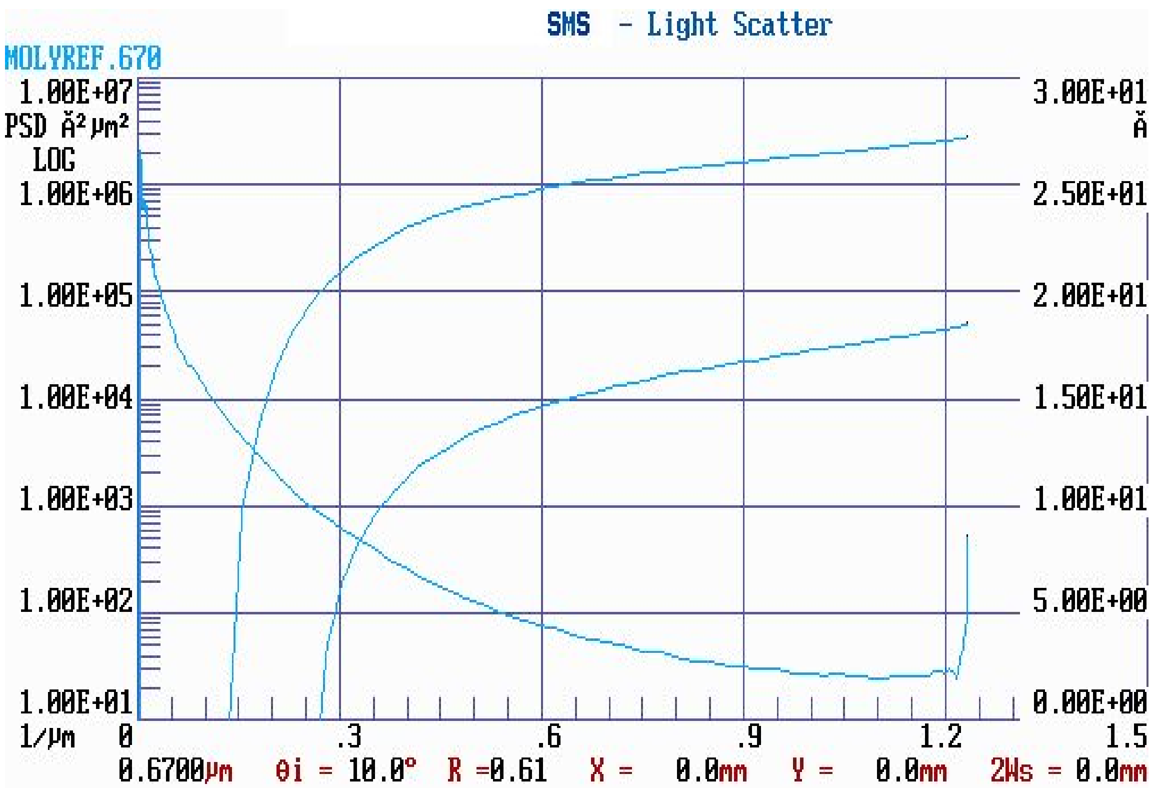

FIGURE 10
PSD PLOT OF MOLYBDENUM MIRROR
WITH RMS TOUGHNESS CURVE

low frequency limit is determined by the point at which the Scatterometer was able to separate near specular scatter from the specular reflection, and the high frequency value, which corresponds to the largest scatter angle measured, is eventually limited by scatter grazing the surface.

The PSD is nearly equal to the BRDF - off by a multiplier consisting of a constant times cos (θ_S). This is one of those properties that makes scatter measurement such a powerful surface analysis tool. A second function that is often suggested as an alternative to the PSD for surface characterization is the auto-correlation function. Its use in practical applications is severely limited and generally results in increased error.

The PSD looks a lot like the BRDF (compare Figures 7 and 10). This means that measurements sufficient to characterize the BRDF are enough to characterize the PSD. Another factor comes into play here. Many surfaces in nature are fractal like. Roughly stated, a defect with high peaks tends to have wide bases and vice versa. In terms of the math, it means the PSD is proportional to a constant divided by a power of the spatial frequency. “Power law” relationships of this sort plot as straight lines on log-log scales. As such they can be characterized by two points, or by one point and a slope. Slopes generally vary between -1 and -3. The PSD of Figure 10 is a good example of fractal behavior.

Fractal behavior has been exploited by SMS in some of its instrumentation. Typically only two scatter locations are measured. The PSD for a given sample set is assumed (or known) to be fractal, and the RMS is found over operator set limits from data provided by just two points.

INSTRUMENTATION AND MEASUREMENTS

INSTRUMENTATION

Instruments designed to obtain BSDF measurements must have either a single moving receiver or multiple receivers arrayed around the sample at scatter angles necessary for the desired measurement. Receivers have an aperture and a detector to measure the scattered power. Sometimes a lens, field stop, bandpass filter and polarizing elements are added.

A common laboratory practice is to first look at the sample and determine the measurements required. For example, the pattern in Figure 5 from a lightly polished surface could be characterized by one measurement sweep through the center at any angular orientation. Additional center sweeps will produce similar data with no gain in information. Matching the sample with the receiver in a fixed position can identify samples like this, which are termed “isotropic,”.

On the other hand, the pattern of Figure 4 from a machined surface requires both a horizontal and a vertical scan for characterization. An extruded surface scatters light much like the machined surface, except the line of discrete points is replaced by a streak of light. Accurate measurement of discrete scatter points in Figure 4 requires an almost con-

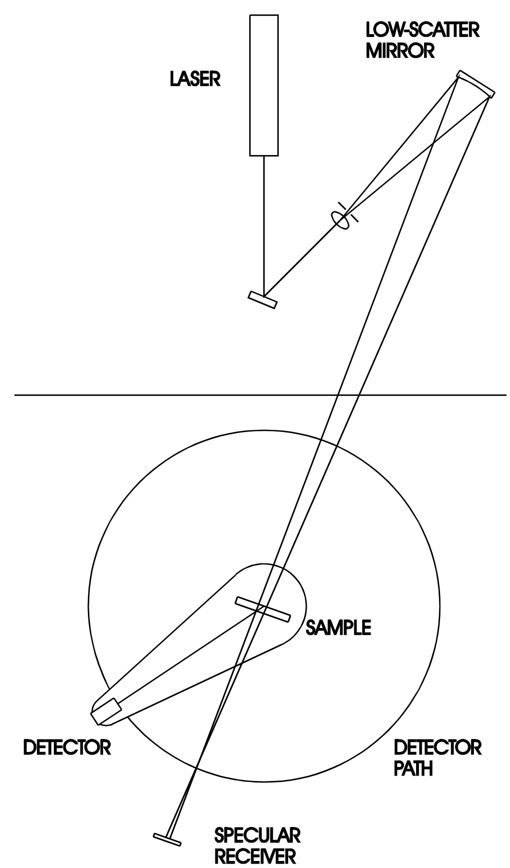

FIGURE 11
PLAN VIEW OF A COMPLETE
ANGLE SCAN INSTRUMENT

tinuous measurement scan in that initial scatter plane. Often surfaces that exhibit this type of scatter pattern also have an isotropic background and can be characterized by two scans.

Most cases can be characterized by measurements at a few discrete locations. This is because, for the vast majority of surfaces, scattered light tends to fall off in a simple power law form.

SMS engineers have designed both moving detector and multiple-fixed detector instruments which measure scatter both in and out of the plane of incidence (defined by the incident beam and the sample normal).

CASI™. The moving receiver instrument, SMS's CASI (Complete Angle Scan Instrument), has a receiver that moves 360° around the sample as shown in Figure 11. This instrument can measure all angles in the scatter plane with good resolution and has a variety of apertures (solid angles).

The single receiver in the CASI instrument can be moved in very small steps and measurements can be made very close to the specular reflection. Because many data points can be obtained, measurements with this type of instrument are thorough but time consuming (typically 1-5 minutes per scan) This instrument is best suited for research and development applications.

TASC™. Figure 12 is a drawing of the SMS TASC Full Hemispherical Polarimetric Scatterometer instrument. The source table (which is in a vertical plane) can be rotated about a horizontal axis through the sample to adjust the angle of incidence. Samples as large as six inches can be rotated or XY raster scanned in the horizontal plane. The receiver rides on a 186-degree arc centered on the sample. The TASC system is provided with programmable motorized sample X-Y translation stages. The use of this instrument facilitates analyzing scatter data in a variety of applications. Unique features include the ability to measure liquid samples, a small optical table devoted to customizing either laser or broad-

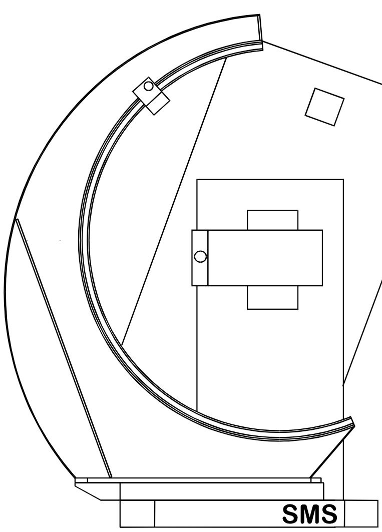

FIGURE 12
SMS TASC™ SCATTEROMETER

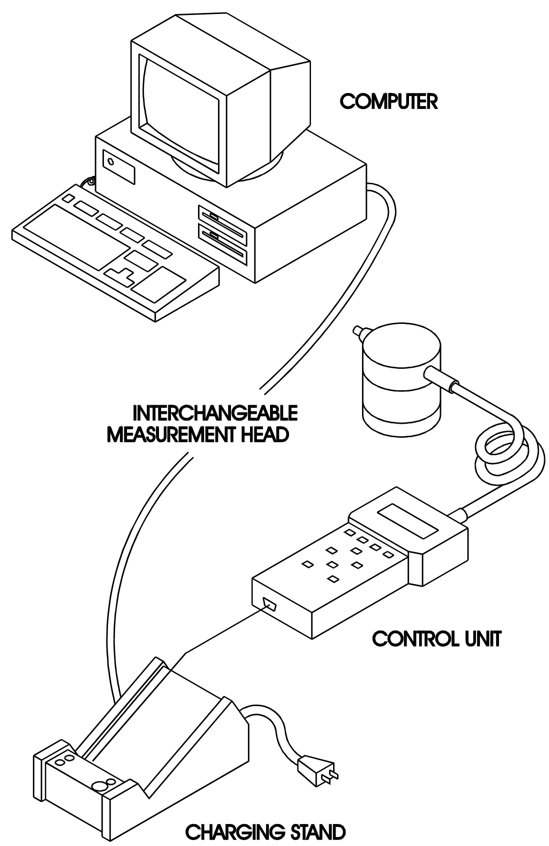

FIGURE 13
SMS µScan PORTABLE SCATTEROMETER
WITH INTERCHANGEABLE HEAD

band sources, software that allows complete automation, and the option for complete polarization control and analysis (Stokes Vectors and Mueller matrices, etc.) of laser sources and received signal.

µScan^{TM}. A third type of SMS Scatterometer is the portable, µScan instrument line. These units are controlled by a hand held Control Unit that is capable of data storage, some analysis and numerical display. Various interchangeable Measurement Heads can be used to make in plane and out-of-plane scatter measurements. The hand held head (shown in Figure 13) is intended for measurements where sample contact is permitted. A bench-top head is also available that does not require contact. A third head, which measures TIS, can be used for optics or to detect changes in finish of a variety of manufactured surfaces. Data from all three units can be
used to calculate RMS surface roughness. The Control Unit stores data in files, which can be, downloaded to a computer for further analysis, with the aid of plots, spreadsheets, or other software tools. Custom versions of µScan may be used to provide on line process control information to either an operator or a process computer.

MEASUREMENTS

BSDF data may be obtained from both reflective and transmissive optics that are either flat or curved. The type of sample and the scatter specification determine the measurement technique and the kind of analysis that can be performed with these data. For example, the BRDF of the front surface mirror of Figure 7 was plotted against log (θ_S-θ_i) to reveal the near specular scatter. Data this close to specular is important for optics that are to be used in imaging or surveillance applications where resolution is the dominant requirement. Figure 14 presents BRDF data from three reflective samples plotted as a function of linear degrees from specular. The scatter issues will be seen to be quite different for each of these samples.

Data from the Ring Laser Gyro (RLG) mirror (Figure 14) were taken starting at specular. Scatter from a precision-machined surface, also shown in Figure 14, consists of well defined, discrete peaks imposed on a low level background. The peaks are caused by diffraction from periodic tool marks left on the surface. The BRDF of clean front surface mirrors, such as this one, can be analyzed further to reveal surface statistics through a process that relies on the

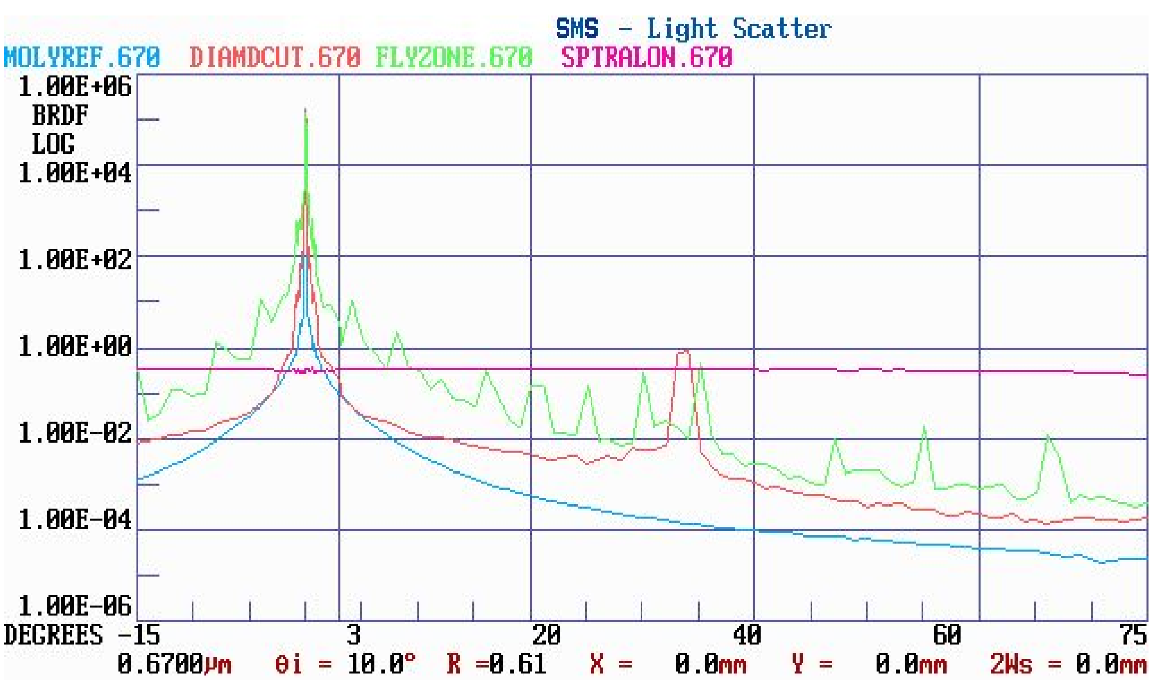

FIGURE 14
BRDF DATA FROM REFLECTORS

mathematical relationship between the BRDF and the surface Power Spectral Density function (PSD). The PSD, which can be thought of as a measure of roughness power per unit roughness frequency, can be used to study the machining process and even reveal machine tool characteristics. Surface statistics, such as RMS Roughness, RMS slope and average surface wavelength, may be obtained from the PSD. This type of analysis is not appropriate for dielectric mirrors, like those in RLG's, because they are not front surface reflectors. Although machined optics have a reputation for high scatter, it is clear from Figure 14 that they can be very low scatter in most directions and high scatter in just a few directions. Notice that the background scatter from this sample is actually lower than the scatter from the mirror of the ring laser gyro.

The scattered power density (watts/steradian) for the special case of a diffuse Lambertian sample is proportional to cos θ_S. If the sample has a total hemispherical reflectance of unity, then conservation of energy gives a constant BRDF value of $1/\pi$. The white diffuse sample of Figure 14, which approaches this special case is typical of the type of sample used as a system check or calibration standard. The measurement of scatter from black diffusers is another important area in the field of scatter measurements. Optical blacks are often used on baffles to limit background scatter due to stray radiation. The resulting reduction in stray light can be as important to modern imaging systems as is reducing scatter from transmissive and reflective optics.

Scatter measured from transmissive optics, plotted as BTDF, is more complicated because both reflective and transmissive scatter components are present. If a non-zero angle of incidence is used, then multiple reflection components will be present. These can drastically affect near specular measurements, even for very small angles of incidence. Small wedges, inherent in most windows, will also create complications.

Transmissive scatter is due, in general, to both volume and surface defects. Using special techniques, these two components can be separated. Volume scatter can be plotted in BSDF format by defining

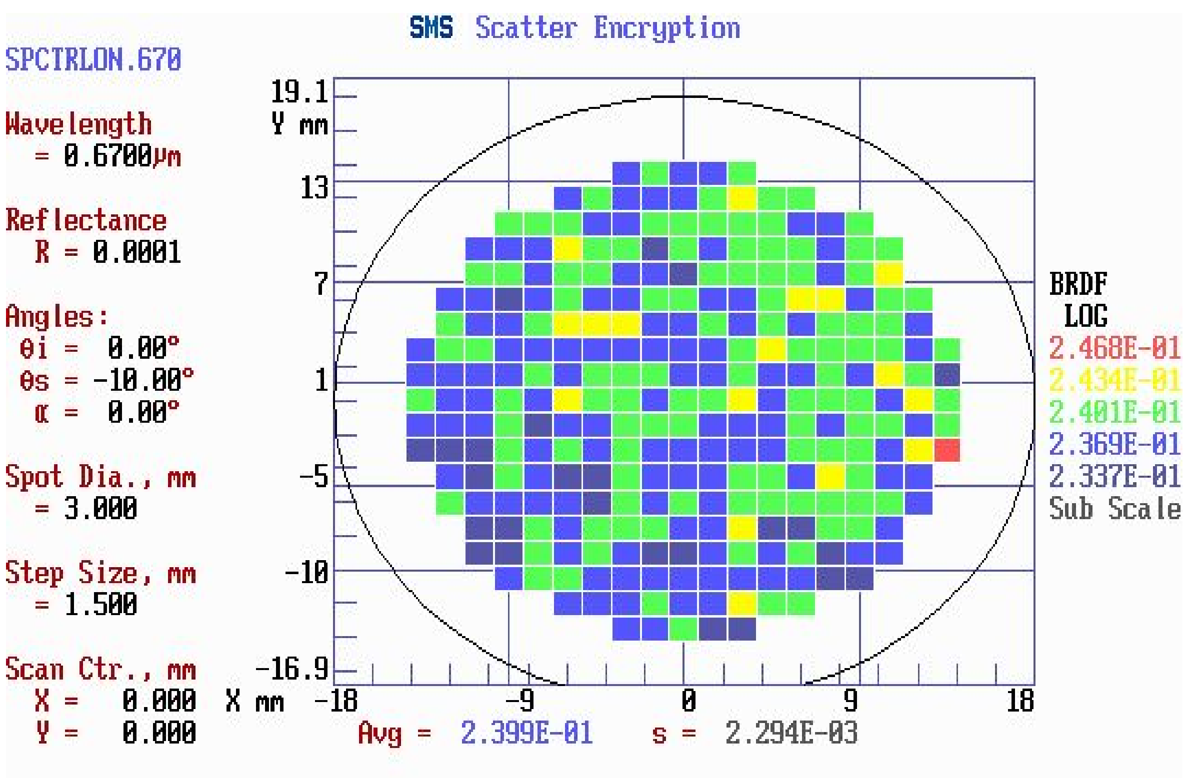

FIGURE 15
ANALYSIS OF RASTER SCANNED SAMPLE

the BVDF in terms of volume elements instead of area elements. This type of measurement is useful in material development programs where bulk affects, rather than surface affects, are of interest. Conversely, for optics whose eventual performance does not depend on volume scatter, such as transparent mirror substrates, surface scatter alone can be measured.

RASTER MEASUREMENTS

The TIS and BSDF measurements described above assume that the illuminated area of the sample is typical of the entire sample. This is often not the case. In fact, the most important issue may be locating, counting, or sizing isolated defects over an ex tended surface area. For these situations, a raster scan is used.

SMS's Raster Scan (available on CASI) moves the sample in its own plane while the source and receiver remain fixed. Each new sample position results in a measurement. When defects are moved into the source beam, the measured scatter signal increases. Results are plotted as three-dimensional (3D) BSDF profiles, or as color-coded maps of the sample, where each square (or pixel) represents a measurement. These different scatter levels are shown on the scale at the right in Figure 15.

Moving the sample at a rate of approximately one pixel per second is a time consuming process. Raster data can be taken very rapidly if the illuminated sample is imaged onto a Charged Coupled Device (CCD) array. Because the imaged pixels are not uniformly illuminated the value of incident power (P_i) for each pixel must be found. This process is shown in Figure 16 for the case of an incident beam with a Gaussian cross-section by means of color mapping to show light intensity. (Actual screen display of Figures 15 - 18 are in color, however, black and white are shown here.) Figure 16 is an intensity map of the incident beam. The spot is elliptical because the angle of incidence was not zero. In Figure 17 the image of the illuminated sample is shown. The computer divides Figure 16 into Figure 17 data, and computes the BRDF map of the sample shown in Figure 18. Notice that the prominent scratch across the width of the sample appears relatively uniform
in the BRDF plot even though its illumination in Figure 17 is uneven. Resolution on the sample is about 10 microns. The 150,000 pixels making up this image were obtained and displayed in just a few minutes. Changes in polarization, incident angle, and observation angle can be used to optimize defect signals over background scatter. Instrumentation to take raster scans at various wavelengths is finding its way into industries other than optics.

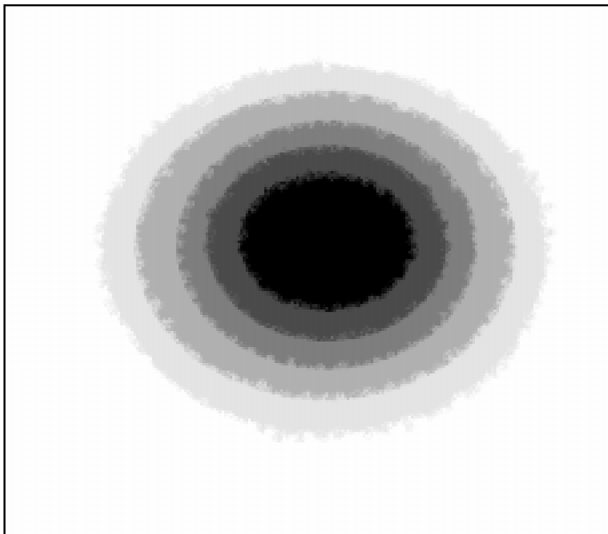

FIGURE 16
INTENSITY MAP OF A REFERENCE SAMPLE

NOISE AND ENVIRONMENT

It is difficult to measure light scatter at scatter angles very close to specular. The problem comes from scatter generated by the instrument optics, called instrument **Noise Signature** (or noise floor). The light scattered from the instrument (noise) mixes with near specular scatter thus making the measurement less accurate. In order to determine the amount of noise, the instrument signature may be measured without a sample in place and compared to (or subtracted from) scatter data taken with the sample in place. Signature scatter can usually be limited to a cone extending only a few degrees from specular. The boundary between near specular and large angle measurements is determined by whether or not the contribution from instrument signature is significant. Depending on the instrument, this usually occurs between 0.1° and 2° from specular. In general, measurements may be taken closer to specular, if the beam is focused onto the detector path and a small detector aperture is used.

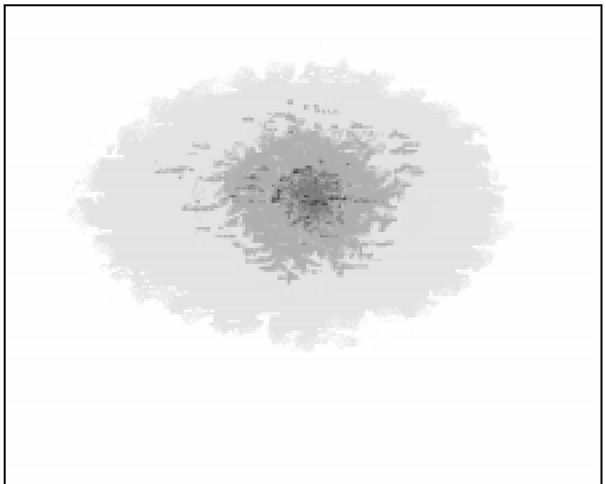

FIGURE 17
INTENSITY MAP OF AN ILLUMINATED SAMPLE

The second plot in Figure 7, labeled "Instrument Signature" is a BSDF measurement taken without the sample in place. The signature plot indicates the scatter produced by the instrument optics and represents the instrument noise floor as a function of angle. Signatures are a function of aperture size, diffraction limited spot size, system aberrations and system geometry as well as scatter. Signature plots help define measurement accuracy.

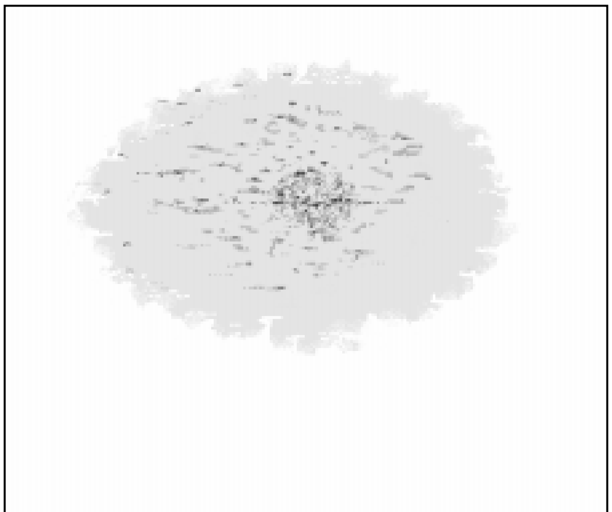

FIGURE 18
BRDF OF A SAMPLE AS A FUNCTION OF POSITION

The environment in which the instrument is located can also effect the accuracy of measurements. Dust, in particular, can have a detrimental effect on accuracy.

COORDINATES

Measurement of light requires an understanding of reference coordinates which make it possible to locate the sample, the beam and scattered light in a consistent way relative to each other. There are 4 sets of coordinates that are used in light measurements. These are **SAMPLE, SCATTER, BEAM** and **INSTRUMENT** coordinates. The first three systems are described below. Instrument coordinates are machine dependent and are described in documentation for that instrument.

TERMINOLOGY

It will be helpful to visualize the measurement of scattered light in terms of a sphere (or more specifically a hemisphere) as shown in Figure 19. Assume that the hemisphere is centered over the spot where the incident light beam strikes the horizontal surface of a sample. The specular reflected beam and scattered light can exit the hemisphere at any point. The need then, is to use consistent coordinates to describe the location of the sample, the position of the receiver (detector) to measure scatter, and the position of the source beam. We must deal with Sample, Scatter and Beam coordinates to do this. (Instrument coordinates are used to tell the instrument where to position machine axes.)

Coordinates are defined by cartesian (X,Y, Z) and polar (Radius and Angle) systems. The angles used are the azimuth and polar angles. Refer to Figure 19 to see how angles locate a point on the hemisphere. A shaded plane is drawn to include the vertical line through the center of the sphere and the point. This vertical plane intersects (projects) a line on the horizontal plane at the waist (equator) of the hemisphere. (Geographers call the intersection of the vertical plane on the surface of the sphere lines of longitude.) The **AZIMUTH** angle (phi) is measured from the positive X-axis (reference) and positive angles result from CCW rotation as viewed from the positive Z-axis. The azimuth angle is measured in the X-Y plane from the projection of the point on to the X-Y (horizontal) plane.

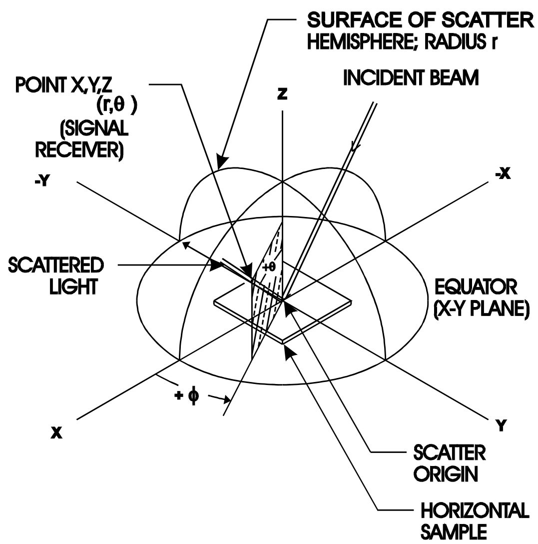

FIGURE 19
SCATTER HEMISPHERE SHOWING
SCATTER ANGLES

The **POLAR** angle (theta) is measured from the vertical line to the point in question. If the point were located at the very top of the sphere, the polar angle would be zero degrees. At the horizontal, (equator), the point would have a polar angle of 90°, and continuing around to the bottom pole of a full sphere, the polar angle would be 180°.

Each coordinate system has an **ORIGIN**. The origin for cartesian (X, Y, Z) coordinates is at the intersection of each axis with each other as shown in Figure 20. The origin for polar coordinates is at the intersection of the vertical line through the sphere and the horizontal plane (equator).

The **SAMPLE ORIGIN** can be anywhere on a sample and is selected by the user. It is often chosen by orienting the X and Y axes with the fiducial marks on the sample. (**Fiducial MARKS** are identifications that may be placed on the sample surface to maintain measurement orientation of the sample.)

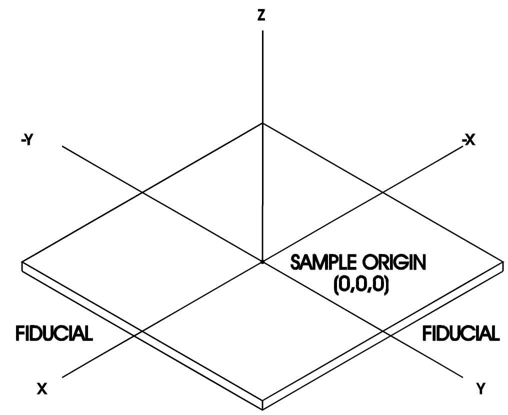

FIGURE 20
SAMPLE COORDINATES

The **SCATTER ORIGIN** is defined by the intersection of the central ray of the source beam and the sample surface. **The scatter origin becomes the center of the sphere where scatter measurements are made.**

SAMPLE COORDINATE SYSTEM

The Sample Coordinate System is arbitrarily placed on the sample as shown in Figure 20. (Fiducial marks are used to orient and position these coordinates with respect to the sample.) Since the X and Y axes are on the plane of the sample surface, the Z-axis is then collinear with the sample normal that exists at the origin of this flat sample. This coordinate system is only used to locate and orient points of interest on the sample. (It is not used for scatter location as measurement of scatter takes place on the surface of the hemisphere.)

The following axes are defined in the sample coordinate system. The positions of these axes are not critical, but must be repeatable from the fiducial marks on the same sample.

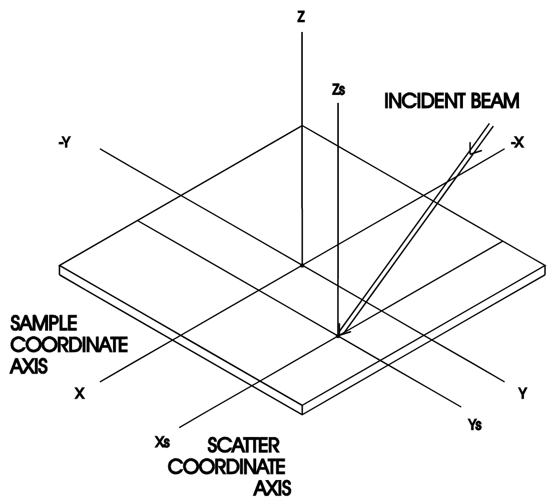

FIGURE 21
SCATTER COORDINATES

The Sample X, Y and Z-axes form a right hand coordinate system.

X: X-axis of the Sample Coordinate System. Aligned using a fiducial mark on the sample. For a flat sample, this axis would normally lie in the surface of interest.

Y: Y-axis of the Sample Coordinate System. Aligned using a fiducial mark on the sample and perpendicular to X. For a flat sample, this axis would normally lie in the surface of interest.

Z: Z-axis of the Sample Coordinate System. Z is perpendicular to the X-Y plane.

NOTE

Samples discussed here are assumed to be flat surfaces. Samples, however, can be curved (convex, concave or some other contour). Normals to a curved surface will not be collinear with the Z-axis. Thus, for curved sample surfaces, it is more difficult to relate a common point in all coordinate systems.

SCATTER COORDINATES

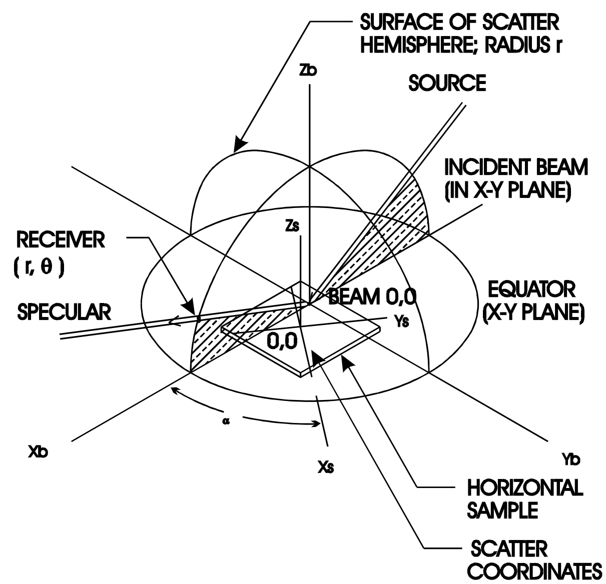

FIGURE 22
BEAM COORDINATES

The origin of the scatter coordinates is located at the illuminated spot where the incident beam strikes the sample surface as shown in Figure 21. The sample normal to the scatter origin on the sample surface becomes the vertical line through the top of the measurement sphere and is the reference for polar angles. The right hand (XS-YS-ZS) coordinates at the scatter origin are located at a position (X,Y, Z) measured with respect to the Sample Coordinate System. For a flat sample the Scatter axes are normally all parallel to the Sample axes, displaced only in the X-Y plane. (Additional rotation angles are required to define the Scatter Coordinate System orientation relative to the Sample Coordinate System if the sample is curved. See note above.)

The scatter coordinate system axes labels are denoted by upper case alphabetic characters with an 'S' extension. Azimuth and polar angles are identified with upper case Greek characters (ϕ and θ, respectively). These angles are subscripted by s (for scatter) or i (for incident) as well.

These labels are:

X_S: X-axis of the Scatter Coordinate System.

Y_S: Y-axis of the Scatter Coordinate System.

Z_S: Z-axis of the Scatter Coordinate System.

ϕ_S: The azimuthal angle (projection) of the scatter receiver onto the X_S-Y_S scatter plane. This angle is measured from the positive XS axis (0°) and positive rotation is CCW as viewed from the positive Z_S axis. ϕ_S has the internal limits $-180° \leq \phi_S \leq 180°$.

θ_S: Polar angle of the receiver as measured from the sample Z_S axis (sample normal). θ_S of 0° lies in the X_S-Z_S scatter plane along the positive Z_S axis and θ_S of 180° lies in the X_S-Z_S scatter plane along the negative Z_S axis. θ_S of 90° lies in the X_S-Y_S scatter plane. Limits on θ_S are $0° \leq \theta_S \leq 180°$.

ϕ_i: The azimuthal angle (projection) of the incident beam onto the X_S-Y_S scatter plane. This angle is measured from the positive X_S axis (0°) and positive rotation is CCW as viewed from the positive ZS axis. ϕ_i has the limits $-180° \leq \phi_i \leq 180°$.

θ_i: Polar angle of the incident beam as measured from the sample Z_S axis (sample normal). θ_i of 0° lies in the X_S-Z_S scatter plane along the positive Z_S axis and θ_i of 180° lies in the X_S-Z_S scatter plane along the negative Z_S axis. θ_i of 90° lies in the X_S-Y_S scatter plane. Limits on θ_i are $0° \leq \theta_i \leq 180°$.

BEAM COORDINATES

The Beam Coordinate System, designated (X_b,Y_b,Z_b), is defined to have the same origin and Z axis orientation as the Scatter Coordinate System as shown in Figure 22. The **Beam Origin** is at the illuminated spot on the sample and the Z_b axis is collinear with sample normal. **However, the beam coordinates are rotated about the Z_b axis until the plane of incidence lies in the X_b-Z_b plane and the incident light comes from the negative X_b direction.**

The beam coordinate system is valuable, as it is a commonly used system in optical literature. Equations found in literature, such as the grating equations, most often assume that beam coordinates are used.

The beam coordinate system coordinate labels are denoted by upper case alphabetic characters with a 'B' extension and lower case greek characters for azimuthal angles (ϕ's) and may be subscripted by s (for scatter) or i (for incident). These are:

X_b: X-axis of the Beam Coordinate System.

Y_b: Y-axis of the Beam Coordinate System.

Z_b: Z-axis of the Beam Coordinate System.

ϕ_S: The azimuthal angle (projection of the scatter receiver location onto the X_b-Y_b beam coordinate plane). This angle is measured from the positive X_b axis (0°) and positive rotation is CCW as viewed from the positive Z_b axis. ϕ_S has the limits $-180° \leq \phi_S \leq 180°$.

θ_S: Polar angle of the receiver as measured from the sample Z_b axis (sample normal). θ_S of 0° lies in the X_b-Z_b beam coordinate plane along the positive Z_b axis and θ_S of 180° lies in the X_b-Z_b beam coordinate plane along the negative Z_b axis. θ_S of 90° lies in the X_b -Y_b beam coordinate plane. Limits on θ_S are $0° \leq \theta_S \leq 180°$.

ϕ_i: The azimuthal angle (projection) of the incident beam onto the X_b-Y_b beam coordinate plane. This angle is measured from the positive X_b axis (0°) and positive rotation is CCW as viewed from the positive Z_b axis. **By definition, ϕ_i is always = 180 degrees.**

θ_i: Polar angle of the incident beam as measured from the Z_b axis (sample normal). θ_i of 0° lies in the X_b-Z_b beam coordinate plane along the positive Z_b axis and θ_i of 180° lies in the X_b-Z_b beam coordinate plane along the negative Zb axis. θ_i of 90° lies in the X_b-Y_b beam coordinate plane. Limits on θ_i are $0° \leq \theta_i \leq 180°$.

α: Rotation about the Z_b axis which measures the relative orientation between the Beam and Scatter Coordinate Systems. As viewed from the positive Z_b axis, α is the angle measured from the positive X_b Beam Coordinate axis and ending at the positive X_s Scatter Coordinate axis.

RELATIONSHIPS BETWEEN BEAM AND SCATTER COORDINATES

The following relationships can be shown between beam coordinates and scatter coordinates:

a) The incident theta angles (θ_i) are the same between the Beam Coordinates and the Scatter Coordinates and have the same nomenclature.
b) The receiver theta angles (θ_s) are the same between the Beam Coordinates and the Scatter Coordinates and have the same nomenclature.

c) The relationship between incident azimuthal angles in the beam coordinates and the scatter coordinates is:

$$\phi_i = \Phi_i + \alpha = 180°.$$

d) The relationship between the scatter (receiver) azimuthal angles in the beam coordinates and the scatter coordinates is:

$$\phi_s = \Phi_s + \alpha.$$

GLOSSARY

amplifier
An electronic circuit, which amplifies (increases) voltages or currents.

analog
A function or signal having a continuous set of values, such as analog currents or voltages.

A/D
Analog to Digital. A circuit which converts analog voltages or currents to digital values.

angle scan
Measurement of scatter patterns by obtaining values at various angles (i.e. "scanning").

anisotropic
Exhibiting properties with different values when measured along axes in different directions.

azimuth angle
The angle in the horizontal plane defined by the X axis and the projection of the vertical plane passing through the vertex (origin) and the point.

beam
A collection of parallel rays of light.

beam coordinates
The coordinate system defined by the incident plane and the sample face. The origin is at the point where the beam strikes the sample.

BRDF
Bi-directional Reflective Distribution Function is the term used to describe reflective scatter light patterns.

BSDF
Bi-directional Scatter Distribution Function is the generic term used to describe scattered light patterns. The scatter pattern is dependent upon both incident and scatter directions and hence is "bi-directional."

BTDF
Bi-directional Transmissive Distribution Function is the term used to describe transmissive scatter light patterns.

BVDF
Bi-directional Volume Distribution Function is the term
used to describe volume scatter light patterns.

bulk
Refers to sample volume as opposed to sample surface and plays a role in subsurface or volume scatter.

CASI™
Acronym for Complete Angle Scatter Instrument.

CCD
Charge Coupled Device. A type of array detector used in digital cameras.

clean
Implies that sample scatter is from the sample surface itself and not from contamination, or from subsurface defects (bulk).

collinear
The same line. Collinear axes are identical.

cosine corrected BSDF
The BRDF multiplied times cos θ_S.

diffraction
Failure of light to travel in exactly straight lines.

diffuse sample
A sample whose surface is rough enough that virtually all incident light is scattered. There is no specular reflection or specular reflection is very weak.

detector
A component which measures light power and converts it to an electrical value.

flux density
Light power per unit area.

fiducial
A standard or reference mark often used to orient samples.

Fourier analysis
The setting of terms of a Fourier serves to periodic data. It is used in the analysis of periodic functions such as found on some surfaces.

Gaussian
A mathematical expression that describes form or distribution. Laser beams have Gaussian intensity cross-sections.

goniometer
A device for controlling angles (positioning) of samples, sources and receivers.

incident angle
The angle at which the source beam of light strikes the sample plane as measured with respect to the normal line to the plane at that point.

Instrument signature
The BSDF measurement in which only the instrument itself causes the scatter (i.e. no sample is present).

irradiance
Radiant flux density on a given surface, in watts/area.

incident Beam
The light (laser beam) which strikes a surface.

inverse steradians
Reciprocal of steradians (sr^{-1}).

isotropic
Implies sameness in a statistical sense. An isotropic surface has the same roughness statistics regardless of the direction of a profile trace across the face. Polished surfaces tend to be isotropic; gratings and most mechanical surfaces are not.

lambertian sample
A diffuse sample from which the light density scattered per unit of observable illuminated spot is constant.

multiplexer
A component to send different signals on the same circuit.

noise floor
(See Instrument signature.)

normal
A line perpendicular to a surface (surface normal) or
another line.

pixel
Any of the small elements that together constitute an image as on a display screen or on an array detector.

polar angle
The angle measured from the surface normal to the surface itself.

polarization

The process of affecting light radiation so that the vibrations of the wave assume a definite form (linear, circular, elliptical).

profilometer
An instrument which measures surface roughness by

moving a stylus across the surface while recording stylus vertical motion.

PSD
Power Spectral Density function.

RASI™
Raster Angle Scatter Instrument.

raster scan
A pattern of sequentially and closely laid out parallel scanning rows used to measure sample area uniformity.

receiver
An assembly which is used to measure light scatter. It contains the detector as well as other parts (apertures, lens, filters, etc.).

RMS Roughness
Root Mean Square roughness. It can be found from either the surface profile or the PSD.

sample
The item for which light scatter characteristics are to be measured.

sample coordinates
Coordinates based on the sample itself and related to fiducial marks. The sample origin is an arbitrary point and can be set by orthogonal fiducial marks if present.

scatter
Light rays which are reflected (scattered) by the sample out of the specularly reflected and transmitted beams.

scatterometer
Instrument for measuring scattered light.

scatter coordinates
Coordinate system based on scattered light. The scatter origin is at the spot illuminated on the sample surface by the incident beam.

scatter sphere
The sphere whose center is on the scatter origin with
radius equal to the distance to measurement receivers. Measurements may be limited to smaller volumes such as the reflective hemisphere.

source beam
The beam of light from the source (laser) before it strikes the sample.

spatial filter
A lens pinhole combination used to eliminate stray light.

specular beam
Well defined incident, transmitted and reflected beams are referred to as specular.

specular zero
The position of the specular beam which defines the zero degree position for scatter measurements in the plane of incidence.

stage
The term given to physical axes of a goniometer (e.g. X-stage, Y-stage).

wedge
The result of two surfaces not being parallel.

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FIGURES

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Part 2: µScan™ CONTROL UNIT

INTRODUCTION

The SMS µScan Scatterometer is a lightweight, portable instrument, which provides quantitative light scatter measurements of a variety of samples and other applications. This instrument is designed for portable use and can make rapid and accurate readings in both indoor and outdoor applications. These readings can be expressed in three different data formats: BSDF, RMS Roughness and/or Reflectance. Several interchangeable Measurement Heads are available, thus allowing measurement of light scatter for a wide range of applications and environmental conditions.

The SMS µScan™ consists of a hand held Control Unit, a cable connected interchangeable Measurement Head and a separate Charger Stand. This instrument is capable of recording and storing 700 measurements in 255 files for later analysis. A PC compatible software package is available for display and analysis of the measurement results on a standard IBM™ compatible computer. The software package allows current measurements to be compared to previous readings.

The portable, battery operated Control Unit controls all aspects of the system operation. When turned on, it automatically performs an internal test of the electronics and initializes the entire system for the particular Measurement Head that is attached. After power up, the operator selects the desired mode of operation. The operator is able to recall preprogrammed files or directly enter new file information into the Control Unit's memory. Upon taking a measurement, the results are presented on the Liquid Crystal Display (LCD) and can be stored in the system memory. A built-in real time clock tracks the date and time of each measurement taken.

An interchangeable Measurement Head contains a laser source and up to eight individual detectors. To perform a measurement, the operator simply places the head on the objective area and presses the key located either on the head or the Control Unit. The measurement operation and analysis takes approximately one second per detector. The Measurement Head is designed to allow measurements on either flat or curved surfaces. After a number of measurements are recorded and stored, the operator is able to download the measurement data into an optional PC software program for permanent storage and more detailed analysis.

This module of the µScan Scatterometer manual describes the installations and use of the Control Unit and Charging Stand. Examples of diagnostics and screen displays are typical of those found when the Model H-670-01, H-900-01 or H-1300-01 Measurement Head is connected.

WARNING

All laser equipment is labeled for operator and individual safety protection. Four levels or classifications have been established. Each classification has its own set of recommended safety precautions which should be followed for the protection of the operator as well as others near the laser system.

LASER SAFETY CLASSIFICATIONS

Lasers are classified by the Bureau of Radiological Health (BRH) of the US Food and Drug Administration and by ANSI Z-136. The classification philosophy is based upon human access and potential hazard. Class I levels of radiation are not considered to be hazards. Class II lasers are those visible lasers which do not have enough output power to accidentally injure a person but which may cause eye damage from chronic exposure. Class II lasers are often termed low-power or low-risk laser systems. They are hazardous only if the viewer overcomes his or her natural aversion response to bright light and continuously stares into the source. A Class II laser has an output power below 1 mW.

Class II laser products emit at levels at which biological damage to human tissue is possible from acute direct exposure. Class III, moderate risk or medium power lasers, are those that can cause injury within the natural aversion response time, i.e., faster than the blink reflex (0.25 s). Class III has been subdivided into IIIa and IIIb. Class IIIa are not hazardous when viewed with the unaided eye but may be hazardous when the energy is collected and directed into the eye, as with binoculars. These lasers are visible wavelength lasers in the 1 - 5 mW regime. Class IIIb lasers can produce a chance of accidental injury if viewed directly. The primary danger is exposure to the direct or specular reflected beam. Continuous wave lasers with an output between 1 mW and 0.5 W are classified as Class III.

Laser systems which are "High Power," present a "High Risk" of injury and can cause combustion of flammable materials and are designated as Class IV lasers. They may also cause diffuse reflections that are eye hazards and may also cause serious skin injury upon direct exposure. A more restrictive warning label is required and even more restrictive control measures are necessary.

CAUTION

Users are responsible for adhering to safety precautions for any lasers used with SMS Scatterometer Instruments. Lasers delivered with SMS Scatterometers are clearly labeled according to Title 21, CFR 1040.10 and 1040.11 specifications. It is the user's responsibility to follow the appropriate safety procedures. Contact the Center for Devices and Radiological Health, Food and Drug Administration, 2094 Gither Road, Rockville, MD 20850, (800) 532-4440 if you have specific safety concerns or questions. The following precautions are suggested for your safety.

SAFETY MAINTENANCE

It is important that this instrument be maintained such that it continues to meet all laser safety requirements. Periodically (at least monthly) examine the Measurement Head to see that the compliance labels are securely attached.

EYE PROTECTION

Operation of this instrument does not require special devices for eye protection. However, users of any SMS Scatterometer system are cautioned not to stare directly into the beam or into its reflections from shiny or diffuse surfaces.

SPECIFIC HAZARDS

The models H-900-01 and H-1300-01 Measurement Heads are Class I lasers of low power and do not emit hazardous radiation under normal operating conditions. The model H-670-01 instrument is designed to reduce concerns of using a Class II laser device. The laser source is enclosed in the optics assembly as are the other two Measurement Heads to reduce the possibility of stray laser radiation and the only exit aperture is clearly marked. Looking into the aperture should be avoided when the laser is turned on.

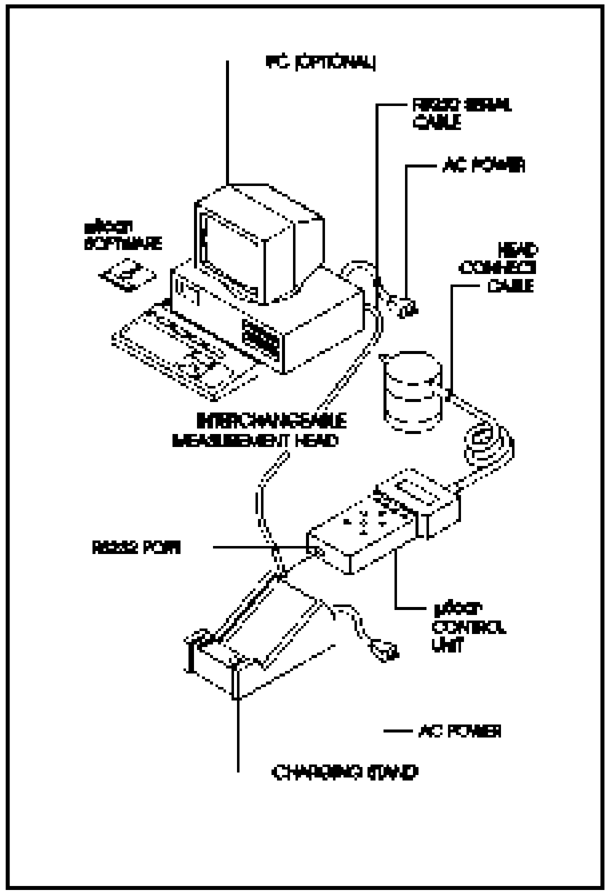


Figure 1
SMS µScan System

UNPACKING

The instrument is carefully packed before shipping. Any special unpacking instructions will be included with shipping documents. Upon unpacking the instrument, compare components received with shipping documents to see that your shipment is complete. It is recommended that this manual be read carefully prior to operating the µScan instrument.

GENERAL DESCRIPTION

There are 3 major components for the basic µScan Scatterometer. These are the hand held **Control Unit**, a **Charging Stand**, and an interchangeable **Measurement Head**. In addition, there is an optional **PC** Computer software program for use in storing and analyzing data (see Figure 1).

The Control Unit is a self-contained, handheld instrument designed to control the system (see Figure 2). At the top of the front panel is the Liquid Crystal Display (LCD). The LCD provides 4 lines of alphanumeric information such as commands, error diagnostics, and measurement data. Ten function keys are pressed (activated) to control the operation of the instrument. These keys are arranged in three groups. Commands to the unit are entered using four CONTROL keys. Functions are selected from the menu displayed on the LCD by use of four ARROW keys grouped in the center of the instrument. The unit is turned ON and OFF by the remaining two POWER keys.

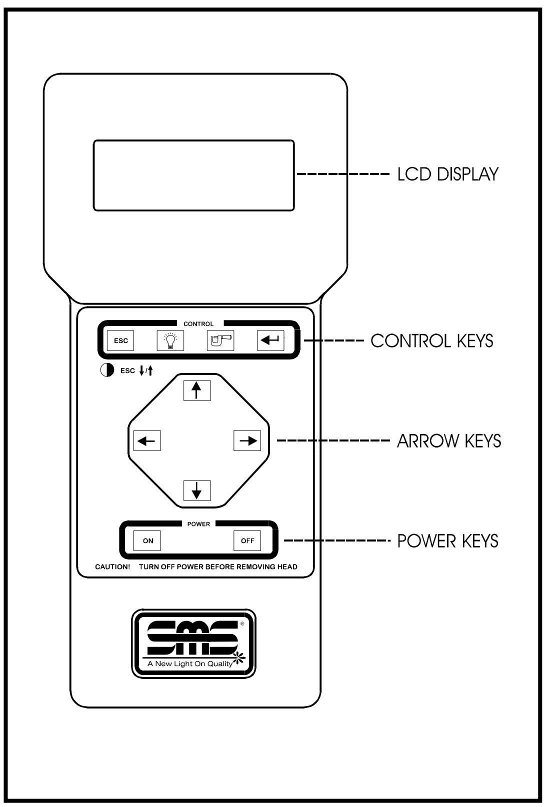


FIGURE 2
µScan Control Unit

The Charging Stand makes it possible to charge the Control Unit battery while operating on external power. It is also designed to hold the Control Unit so that the keyboard is accessible and the LCD easily read. The charging stand is connected to a standard 120 VAC, 50 Hz power source (240 VAC, 50/60 Hz also available). The Charging Stand is also used to transfer information to the optional PC computer via the connection port on the rear of the stand.

Light scatter measurements are taken with an interchangeable Measurement Head as shown in Figure 1. All heads include a light source and associated optics for producing the light beam that will be reflected from the sample surface. The head contains one or more detectors as shown in Figure 3. These detectors are installed at the factory at predetermined angles depending upon measurements to be made. Other heads can be substituted that contain different light sources and detectors. A cable is used to connect the Measurement Head to the Control Unit. Information specific to the Measurement Head you have selected is stored in that head.

An optional PC computer with the µScan Software Package provides the means to save and analyze data obtained by the basic µScan unit. The computer system consists of an IBM PC/AT™ or compatible. SMS µScan Scatterometer software provides menu/screen operator interface for ease of use. Refer to the software module of this manual for information about this option.

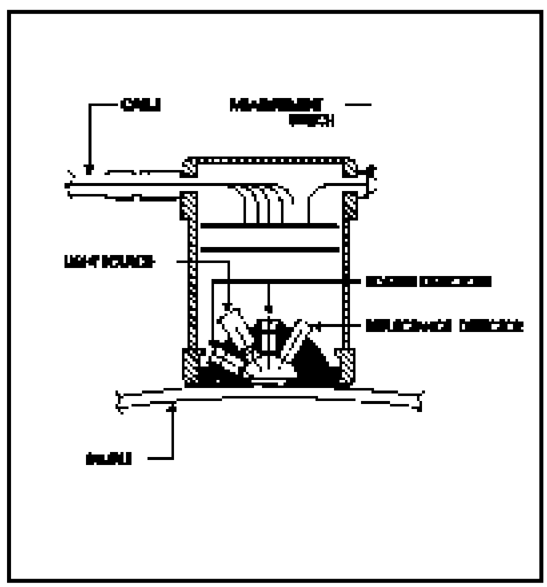


FIGURE 3
TYPICAL MEASUREMENT HEAD

Caution

Use of controls or adjustments or procedures other than those specified herein may result in hazardous radiation exposure.

INSTALLATION

Installation of the basic µScan unit is straightforward.

CHARGING STAND

Connect the Charging Stand to the AC outlet by inserting the power cord into the connector at the back of the stand. Turn on the Charging Stand using the ON/OFF power switch located above the power cord connection. The power indicator light (green) on the front panel of the Charging Stand will illuminate when the charger is turned on. Place the Control Unit in the charging stand. Make sure the connector at the bottom of the Control Unit mates properly with the plug in the stand. The trickle charge indicator (yellow) on the front panel will illuminate indicating proper seating of the Control Unit.

There are two charging modes available. The normal mode trickle charges the Control Unit battery. It requires about 14 hours to fully charge a completely discharged battery. Pressing the button in the lower right corner of the Charging Stand activates the TURBO Charge mode. The switch will light when this mode is activated and will require about 2-3 hours to fully charge the battery. The charger will automatically switch to the trickle charge mode when the battery has been fully charged.

Caution

TO PREVENT DAMAGE TO THE µScan SYSTEM ALWAYS TURN THE POWER OFF TO THE CONTRROL UNIT BEFORE CONNECTING OR REMOVING THE MEASUREMENT HEAD.

CONTROL UNIT

The Control Unit should be off. This can be determined by checking the LCD display as no characters are shown when the unit is off.

The next step is to connect the Measurement Head to the Control Unit with the cable provided. Do this by placing either end of the Measurement Head cable into the head and the other end into the connector at the top of the Control Unit. Make sure the red dots on the connector and the plug are aligned prior to inserting.

NOTE

At this time you may choose to install the optional PC Software program into the computer and connect the computer to the basic µScan instrument. However, it is not necessary to have the PC connected at this point in the installation. If you choose to install the computer software, follow installation instructions in the software documentation (supplied with the software).

OPERATION

CONTROL UNIT FUNCTION KEYS

Observe the keys on the Control Unit (or see Figure 2). Keys are grouped in 3 functional locations. These are (from the bottom up) POWER, ARROWS (untitled), and at the top, CONTROL. These keys have multiple functions and are enabled only as needed for the operation being performed.

NOTE

There will be references in the following sections to keystroke operations on the Control Unit and the optional computer. These instructions will be presented in a format with the keystroke as a header, and the resulting operation as text that follows. The word "Activate" will be used to ask you to perform a keyboard operation.

POWER KEYS

There are two power keys. One is labeled **ON**, the other **OFF**. The ON key turns the Control Unit on:

Press (Activate) ON

The LCD display will show the SMS banner followed by system diagnostics. After system diagnostics, the MAIN MENU will be displayed.

Press (Activate) OFF

The Control Unit turns off and the LCD display goes blank. A tone is sounded.

DIAGNOSTICS

There are several diagnostic displays that appear when the Control Unit is turned on. Messages which contain current information, such as battery voltage, appear each time power is turned on. Other messages appear only if a diagnostic test fails.

These messages automatically scroll quickly to minimize power up time. To display an individual message:

Press and hold ANY ARROW KEY
Press and hold any of the four arrow keys to stop diagnostics' scrolling. To resume scrolling simply release the arrow key.

MESSAGE DESCRIPTIONS, NORMAL SEQUENCE

The first message to appear is SMS followed by the company address and telephone number. The serial number of the Control Unit is also shown so that you can identify your unit should factory assistance be required:

SMS, Inc.
PORTLAND, OREGON
(503) 227-5178
S/N xxxxxx

The current time and date is the next normal display:

_ _ _ _ SYSTEM CHECK _ _ _ _

TIME 09:11:40
DATE 01/22/97

NOTE

The time and date is set at the factory. It can be changed with the use of the optional SMS µScan Software as described in the software documentation.

The next message provides the current battery voltage:

_ _ _ _ SYSTEM CHECK _ _ _ _
Battery Voltage
_ _ _ _ _
8 9 10

(NOTE: A fully charged unit should have a voltage between 9 and 10 volts DC.)

The last message in the normal power up sequence provides information on the Measurement Head. It provides the serial number of the head, and the wavelength of the light source (nm). The Measurement Head must have been attached during the previous power up for this message to be displayed:

_ _ _ _ SYSTEM CHECK _ _ _ _
Head Calibrated
S/N XXXX-XX
λ XXX nm

Any time a different head is connected to the Control Unit, the first power up sequence following installation will read information from the head into the Control Unit. The message during that information transfer is:

_ _ _ _ SYSTEM CHECK _ _ _ _
PLEASE WAIT !
Reading HEAD
information.

It is possible to operate the Control Unit without a Measurement Head connected. New measurements, of course, can not be taken. When the Control Unit is powered up without a Measurement Head attached, this message appears:

_ _ _ _ SYSTEM CHECK _ _ _ _
HEAD NOT INSTALLED
Measurements will
not be allowed!

NOTE

Be sure to turn the power off before connecting or disconnecting a Measurement Head.

The µScan Control Unit has a built-in power off feature that will automatically turn the power off if no activity has been detected for approximately 10 minutes. When that occurs, or if power is turned off for other reasons, this message will appear:

```
_ _ _ POWER SHUTDOWN _ _ _
Power shutdown
in progress...
```

No special operator requirements are needed in the event of an automatic shutdown. Simply turn the instrument back on to use it.

DIAGNOSTIC MESSAGES, ABNORMAL OPERATION

Messages that appear when the Control Unit has a problem or if the Measurement Head is not connected are described next. Each time the unit is powered up, the RAM memory used by the internal microprocessor is checked. If there is a problem, this message appears, and the unit will turn off: (Contact SMS for further assistance.)

```
_ _ _ _ SYSTEM CHECK _ _ _ _
CPU MEMORY ERROR
Call SMS at
(503) 227-5178
```

The system will not allow you to operate it if the battery voltage is too low. When that happens, this message appears, and after a few seconds, the unit turns off (previously stored measurements are not lost):

```
_ _ _ SYSTEM CHECK _ _ _
LOW BATTERY ! !
recharge unit
before using.
```

If an incompatible head is attached to the Control Unit, this message will appear:

```
_ _ _ INVALID HEAD TYPE _ _ _
The present head
will not work
this Control Unit!
```

The Control Unit maintains serial number information for a total of eight heads. Whenever a new head is connected whose serial number cannot be stored because the internal serial number file is full, this message will appear:

```
_ _ _ HEAD AREA FULL _ _ _
DELETE or CLEAR all
Measurements before
Using this head ! ! !
```

DELETE File is a Control Unit command to delete data files from the µScan Control Unit. It is described in DELETE File. CLEAR is a command in the optional PC computer software. It is described in the software documentation.

NOTE

When either DELETE or CLEAR is activated in response to this message, be sure to turn the Control Unit off and then on again. This initializes the instrument for proper operation.

ARROW KEYS

There are four keys in the center of the Control Unit, each with an arrow showing the direction of movement of the cursor. These keys have several functions. During the power up sequence, holding down any of these keys will stop diagnostic messages from scrolling.

The two vertical movement keys (up arrow, down arrow) are used to move the menu cursor (shown on the LCD as ▶) to the desired menu entry. In some menus they also function as **alphanumeric** keys. Successive pressing of these keys will allow you to enter <SPACE>, all alphabet characters, -, $, @ and numbers 0-9. The down arrow key scrolls in the opposite direction of the up arrow key. Continuous holding of these keys cause these characters to scroll rapidly. The alphanumeric function of these keys is enabled whenever information is entered into the Control Unit such as creating or editing file names.

The two horizontal arrow keys (left arrow, right arrow) are used to scroll between the various options within the selected menu entry.

CONTROL KEYS

Four control keys are located at the top of the keypad. They are described from left to right.

ESC

The escape <ESC> key makes it possible to return to the previous menu level. It can be selected at any time. Successive selections will return the cursor to the **MAIN MENU**.

The <ESC> key in conjunction with vertical arrow keys provides the means to change the contrast of the LCD. (The instruction for this is printed just below the <ESC> key as shown in Figure 2.) To change LCD contrast:

Select and hold **<ESC>** and press either **UP** or **DOWN ARROW**

Observe the contrast on the LCD display and set it to a comfortable level.

LCD DISPLAY ILLUMINATION

The second key from the left has a “light bulb” graphic. It is used to turn on the light, which illuminates the LCD display. Use this light only when necessary as it consumes more power. This light is automatically turned off during power down.

MEASURE KEY

The measure key has a graphic of a micrometer to illustrate measurement. This key is used to initiate a scan measurement. This key also serves as the down arrow key to select individual measurement scans stored in files as the main down arrow key is used to scroll through data within that measurement. (See menu selection SUMMARY below for an expanded discussion.)

ENTER KEY

The rightmost key with the bent arrow graphic is the <ENTER> key. This key is used whenever information is to be “entered” (read) by the Control Unit. This also serves as the up arrow key in conjunction with the special function of the measure key. (See menu selection SUMMARY below for an expanded discussion.)

µScan MENU FUNCTIONS

When the µScan instrument is powered up and completes its diagnostics, the **Main Menu** appears.

This menu contains four possible selections (only three of which can appear at any one time). To make menu selections simply move the cursor to the menu item desired (using either the up or down arrow key) and press <ENTER> (bent arrow key). You can easily determine which item is selected, since the cursor (▶) points to the item which is also displayed in capital letters.

Figures 4 - 7 show the menu tree structure. Beside each menu screen are listed keyboard commands needed for selections. Refer to these figures and try each of these selections. Comments about these menu entries are given below.

MAIN MENU

The Main Menu has four entries: **Measure, Setup, Summary** and **RS232 Access**.

MEASURE MENU

Measurements are made using the Measure commands. Move the cursor (▶) to MEASURE using the up and down Arrow keys. Press <ENTER> to activate the MEASURE menu. See Figure 4 (A) for the keystroke commands and to follow the menu selection process.

The Measure Menu has three selections. These are measurement TYPE, SAVE and FILE as shown in Figure 4 (B). If menu function TYPE is selected, then three measurement formats can be chosen. These are BSDF, RMS Roughness and Reflectance. Use the left or right arrow keys to scroll through these three measurement format choices. (BSDF, RMS Roughness and Reflectance are described in the Light Scatter Measurement Tutorial.) The Control Unit will display data for whichever measurement format is selected. The Control Unit will remember the last display format that was selected, even if the unit is shut off.

Selection and activation of the SAVE menu has the three options: ALWAYS, NEVER and VERIFY. You use the left/right arrow keys to make the choices. See Figure 4 (B).

Selection of FILE allows you entry into the FILE SETUP screen.

> **Caution**
>
> Review safety precautions (above) before making measurements. Be sure hand held scanning head is properly placed on the sample surface before initiating a scan. To prevent unintentional exposure from the laser beam use of the cover is recommended when head is moved away from a sample surface. Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure**.**

A measurement is first initiated by selecting one of the measurement choices. Ordinarily pressing either the measurement key on the Control Unit or the button on the Measurement Head will make the measurement. An LCD display as shown in Figure 4 (C) will appear and an audible tone will sound to indicate the laser source has been turned on. If the cursor is pointing to TYPE, pressing <ENTER> will also initiate a measurement scan. The display of data will depend on the format selected (either BSDF, RMS Roughness or Reflectance).

Once the measurement is initiated, the Control Unit LCD display shows a caution message and, when the measurement is complete, measured data will be displayed on the screen. All values can be examined using the up/down arrow keys.

Example values for each data format are presented below.

NOTE

These <u>numerical</u> values will be different than these obtained from your sample. YOU MUST MAKE A MEASEREMTN IN ORDER TO HAVE DATA TO DISPLAY!

TYPE

There can be as many as 10 lines of data when the BSDF display is shown depending upon how many detectors are installed in the Measurement Head that you are using for the number of detectors and their placement. As many as eight detectors can be installed in a given head, so up to eight detector entries may appear in the following format:

(15,0)°: 2.21E-01

In the above example, a detector located at (15,0)° has a BSDF of 2.21E-01 $sr^{-1.}$ Detectors in the Measurement Head are located using Beam Coordinates (see Light Scatter Measurement Tutorial documentation). Thus, $\theta_{s\ is}$ 15° and ϕ_s is 0° (indicating the detector is in the incident plane). The incident angle of the source is reported in the firs line of the BSDF display as θ_i, followed by the wavelength of the source(λ) in nm. Since these data are listed for each detector, you can determine the number of detectors located in the Measurement Head from this information.

If a threshold (limit) value has been set using the optional PC software, BSDF data will be presented with a plus (+) or a minus (-) sign before the angle coordinates [e.g. – (15,0)°]. The + or – indicates that the reading is higher (+) or lower (-) than a preset threshold value you establish using the PC software. (The software documentation provides more information about threshold values.)

Two other lines of data included in the BSDF display are the RMS Roughness shown in Angstroms and Reflectance displayed as a percentage:

σ(Ang) 695.3
REFL: 33.0%

RMS ROUGHNESS

The RMS Roughness value is calculated from BSDF and Reflectance data. It is important that the user realizes that the algorithm used for the RMS Roughness calculation assumes certain properties of the surface being measured. The algorithm assumes that the surface is a front surface reflector and is smooth relative to the wavelength of the laser. The Control Unit will always calculate and display an RMS Roughness result and it is the responsibility of the user to determine if the result is meaningful.

The Control Unit also calculates a maximum allowable RMS Roughness based on the laser wavelength and incident angle. This is the level at which the algorithm can no longer provide reasonable estimates of RMS Roughness. If the RMS Roughness result is larger than this maximum value, the Control Unit will display a message in the form

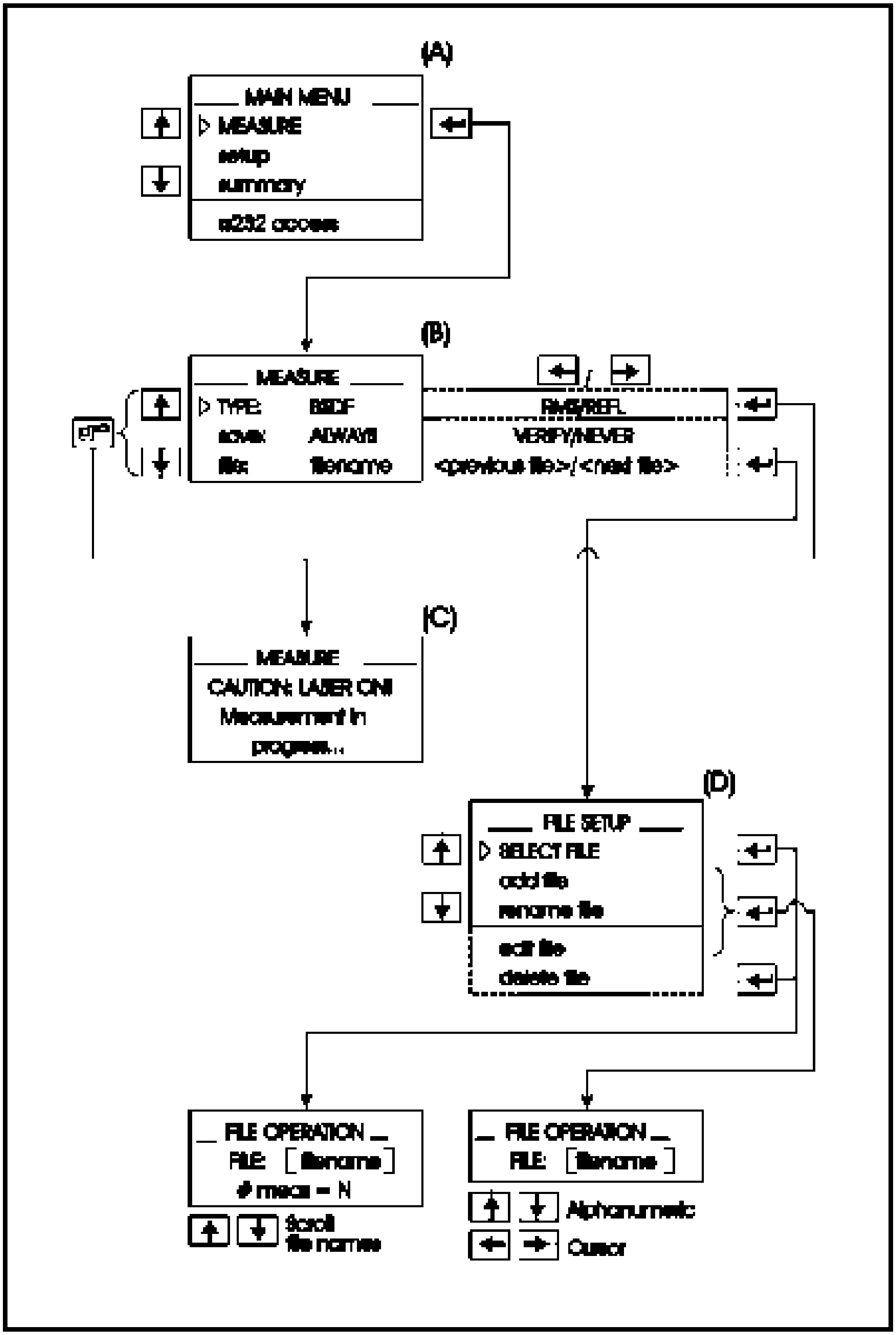


Figure 4 Measure

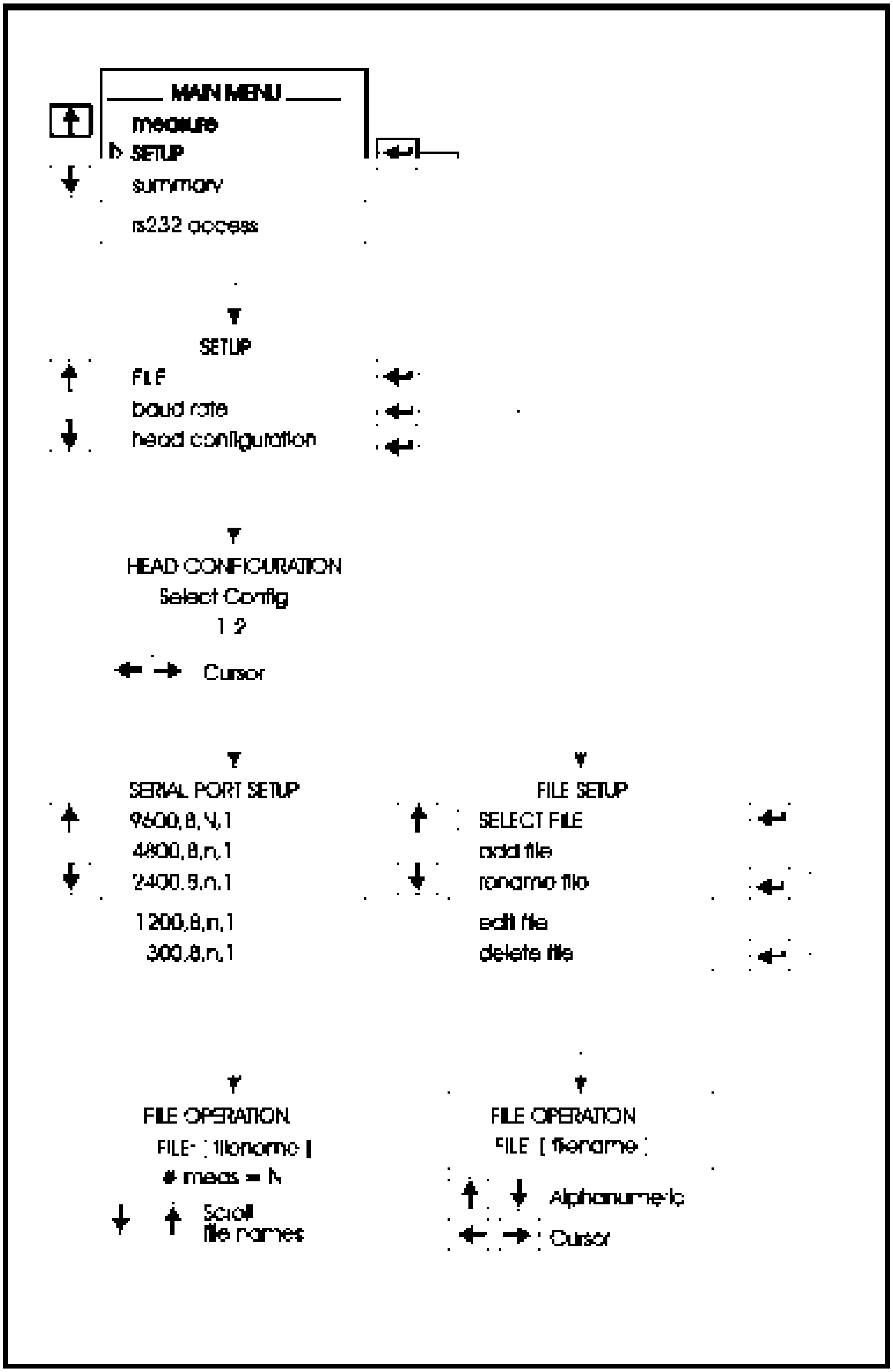


Figure 5 Setup

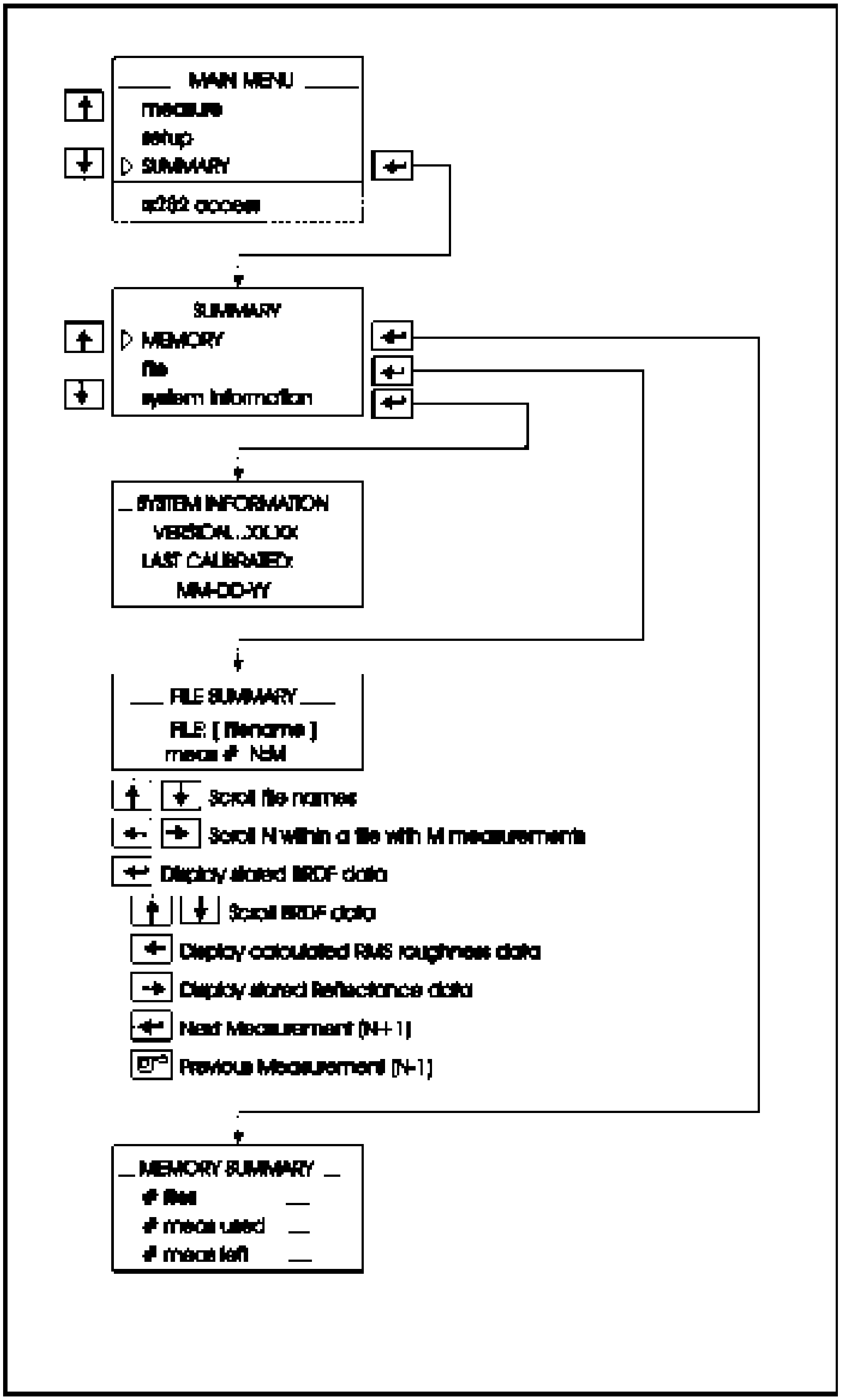


Figure 6 Summary

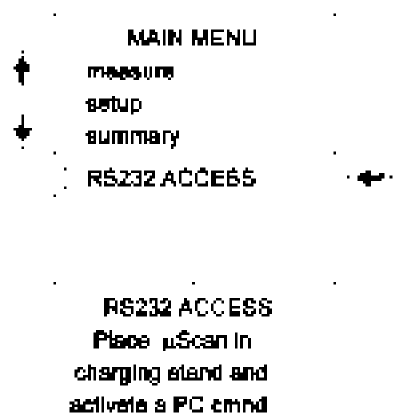


Figure 7 RS-232 Acess

σ><max RMS>

where <max RMS> is the calculated maximum allowable RMS Roughness.

RMS Roughness and Reflectance values may also be reported with a + or – sign, if predetermined threshold values have been set using the PC Software.

This display screen also reports the bandwidth:

$$BW(\mu^{-1})=[0.010,1.00]$$

The Bandwidth (inverse µmeters) is a function of the spatial frequency and is described in the Optical Scatter Measurement Tutorial. The default limits of the bandwidth for this calculation are 0.010 and 1.00 μ-1. (Bandwidth limits can be changed if PC Software is used.)

REFLECTANCE

Reflectance is reported with a percentage value and a bar graph gives a visual indication.

SAVE

There are three options for handling data when making measurements. These are **Always**, **Never**, and **Verify**. When selected, **Always** saves data to the selected file. **Never** means these measurements are not saved. **Verify** forces you to either accept or reject data before storing. This message is presented when <ENTER> is selected with the Verify option in use.

Save? Y/N

NOTE

In order to save data, a file must have been created. If no files have been established only the NEVER option will appear.

FILE

When the File option is selected the display will change to the FILE SETUP menu (see Figure 4 (D)).

SETUP MENU

The Setup menu is the second choice of the Main Menu. Its selection makes it possible for you to create **Files**, select **Baud Rate**, and examine **Head Configuration**. Figure 5 is a tree diagram for these operations. Activate the Setup menu by moving the cursor to SETUP using the up or down arrow keys and then press <ENTER> (bent arrow key). The first option is **File**.

FILE

Selection of FILE makes it possible to **Select, Add, Rename, Edit**, or **Delete** options using the up or down arrow keys. It is also possible to reach this menu directly from the Measure Menu.

Select File

The choice of SELECT FILE makes it possible to scroll through the list of file names stored in the Control Unit with the use of the vertical arrow keys. As each file name is displayed, the number of measurements stored in that file is also given, as illustrated in Figure 5. If no files are stored in the Control Unit, an error message will be displayed. **Press <ENTER> to select the file name of choice.**

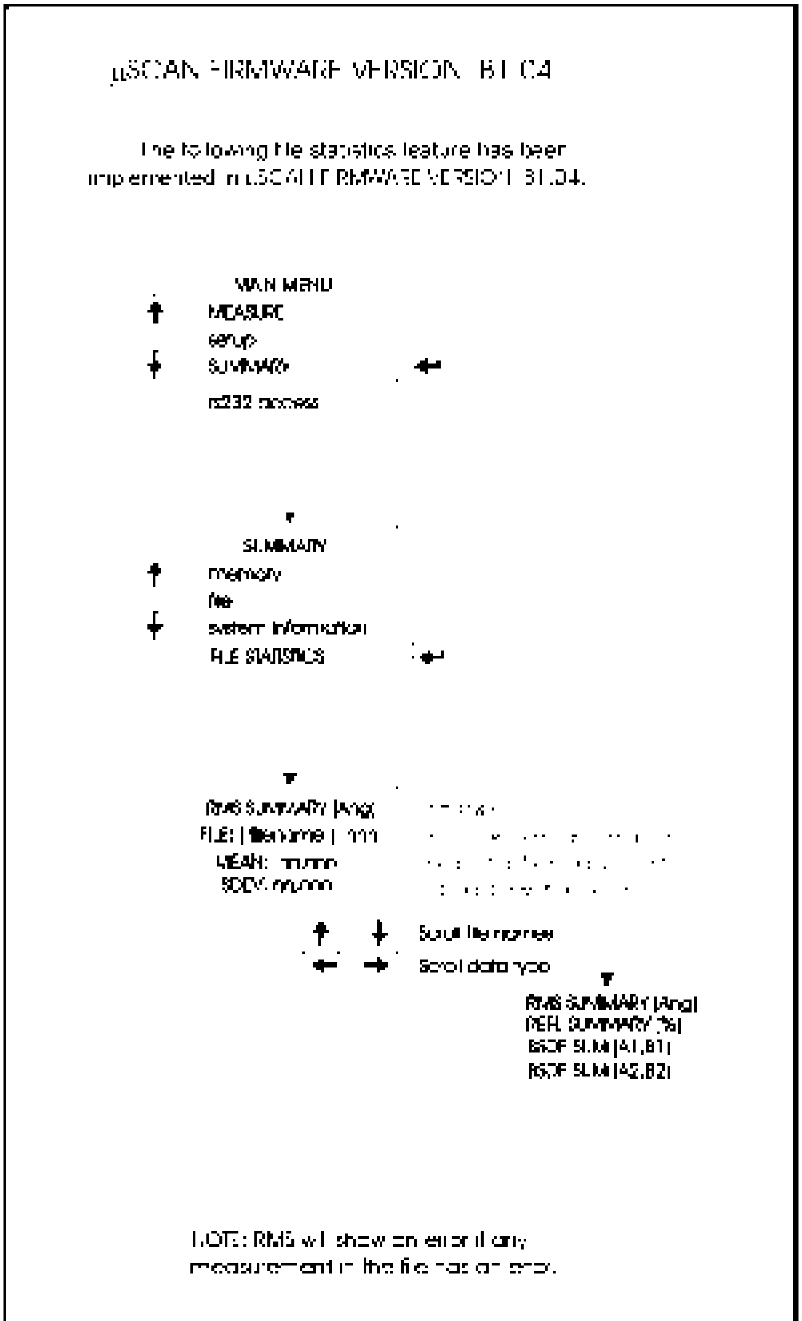


FIGURE 8
STATISTICS SUMMARY

Add File

The Add File selection makes it possible to create and name new files in which to store measured data. File names can be 8 characters in length. Any leading or trailing blanks will be deleted. Any intermediate blanks will be replaced with underscore (_). File names can be made up of any of the characters in the alphanumeric character set (described in Arrow Keys section above). Duplicate and blank file names are not allowed. While in this menu selection, the vertical arrow keys scroll through the alphanumeric character set, as the horizontal arrow keys move the cursor charac-

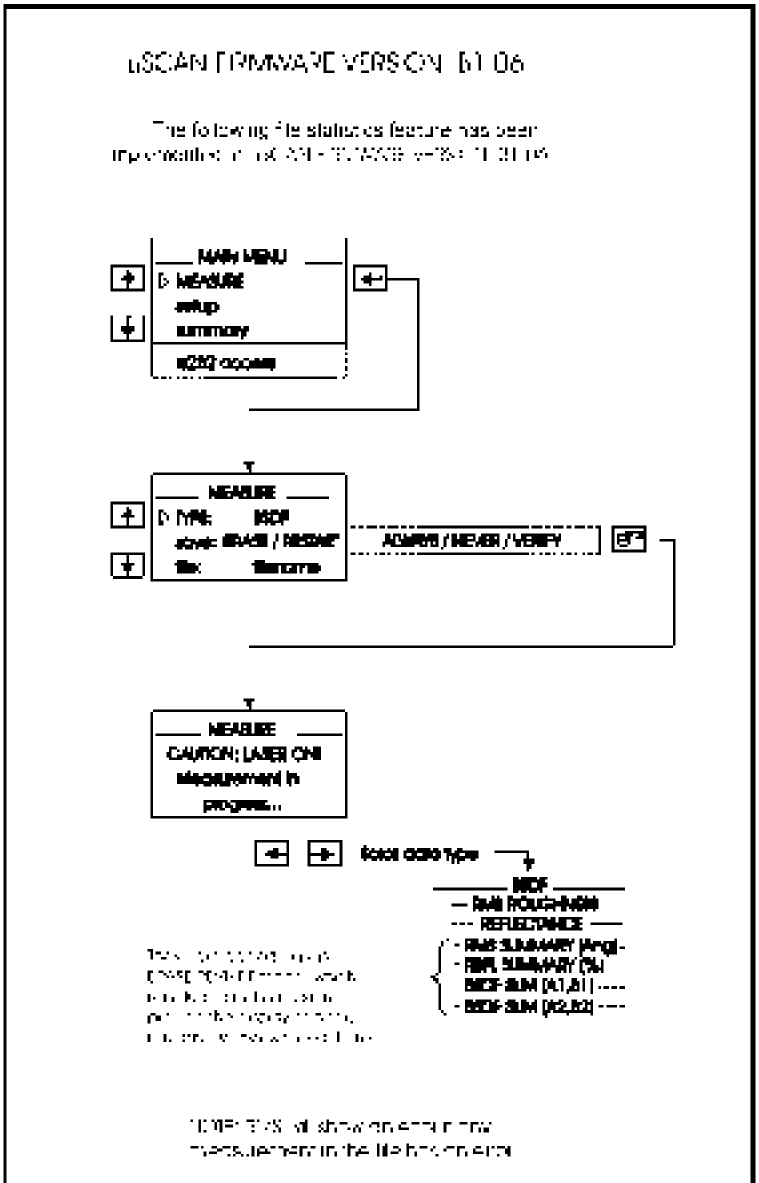


FIGURE 9
STATISTICS SUMMARY

ter along the line. **Press <ENTER> to place the new file name into memory.**

Rename File

The Rename File menu selection makes it possible to rename an existing file. All data in the existing file will be identified with the new file name. The procedure for changing the name is the same as for Add File. An error message will be displayed if no files are stored in the Control Unit.

Edit File

This menu entry makes it possible to change the name of an existing file without having to enter the entire name again. It is useful when a series of measurements are made that are similar, and only one or two file name characters need to be changed to keep track of these tests. Files added under this command will be blank until measurements are made and stored. For example, a file named “TEST001” can be quickly edited to create “TEST002,” “TEST003,” etc. Use the horizontal arrow keys to edit the file. Move the cursor to the character to be changed and use the up and down arrow keys to select the desired character. Once again, an error message will be displayed if no files are stored in the Control Unit.

Delete File

The Delete File selection makes it possible to delete the file and all data contained therein. You will be asked:

_ _ _ _ DELETE FILE _ _ _ _
File [filename]
will lose all data!
Delete y/N

Again, if no files are stored in the Control Unit, an error message will be displayed.

BAUD RATE

Selecting the menu entry for Baud Rate makes it possible to choose parameters for the serial port. There are 5 possible baud rates as shown in Figure 5. These are 9600, 4800, 2400, 1200, and 300. (Baud rate is a measure of how fast data can be transmitted over the cable connected to the serial port.) The remaining parameters are the same for all baud rates. They are 8 bits, no parity and 1 stop bit. **Press <ENTER> to select the baud rate indicated by the cursor.**

NOTE

Selecting too high a Baud Rate may result in some data being lost. The correct Baud Rate is a function of the cable length from the RS232 port and the PC computer and the size of the buffer on the receiver (PC). The recommended Baud Rate for the provided cable is 9600.

HEAD CONFIGURATION

Measurement Heads containing several different combinations of sources and detectors can be connected to the µScan instrument. Each head is factory configured with sources and detectors mounted at various angles. As configured, up to 3 variations may be stored per head. (Information on head configuration is sent to the Control Unit from the head upon initial connection and power up.) Selecting Head Configuration makes it possible to choose one of the 3 options. If there is only 1 possible configuration, the display will so indicate. A blinking cursor will indicate which head configuration is selected. The cursor can be moved to select other configurations using the horizontal arrow key. Press <ENTER> to activate your configuration choice. See the Measurement Head documentation about specific Measurement Head models.

SUMMARY

The 3rd Main Menu entry is **Summary** as shown in Figure 6. There are 3 options within **Summary**. They are **Memory**, **File** and **System Information**. This feature makes it possible to see how much **Memory** has been used and allows you to examine data stored in files in the **File** selection.

MEMORY

Selection of Memory provides a summary of the number of files stored, and the numbers of measurements both complete, and left to be made. There can be as many as 255 files. The total number of measurements that can be stored in the Control Unit memory is 700. A maximum of 255 measurements can be stored in a single file. The combined number of stored measurements from all files cannot exceed 700.

FILE

Selection of **File** makes it possible to examine the data contents of each named file. The LCD display shows the currently selected file name as well as the measurement number. For example, **meas# 1:8** indicates that data to be displayed (if this file is selected) is the 1st of 8 measurements. The vertical arrow keys scroll file names, while horizontal arrow keys scroll the present measurement number for the selected file. Press **<ENTER>** to select the chosen file and measurement within the file.

Data for each of three data formats (BSDF, RMS Roughness, Reflectance) are displayed. Each can be accessed using horizontal arrows. Vertical arrows are used to scroll through displayed data. The **<ENTER>** and **<MEASURE>** keys become scroll keys to increment or decrement the displayed measurement number within the selected file.

SYSTEM INFORMATION

Selection of system information provides the Control Unit's calibration date and firmware version.

RS232 ACCESS

The final option on the main menu is **RS232 ACCESS**. This will only appear on the LCD screen when the display is scrolled down. The RS232 Access Main Menu selection allows the transferring of data from the Control Unit to the PC computer (also see PC Software Documentation). This places the Control Unit in the Serial Port Mode. The charging stand provides the internal connections to the computer from the Control Unit via pins on the Control Unit/Charging Stand connector. A user supplied IBM PC Compatible Computer can be used to control data transmission. Figure 7 provides the menu structure for this feature.

NOTE

> **Caution**
>
> The External Power connection (Pin 8) supplies power to the µScan Control Unit and the Measurement Head without the Charger Stand. The external power source must have a voltage in the range of 9 to 11 VDC and should be capable of supplying 200mADC. To prevent damage do not exceed these voltage limits.

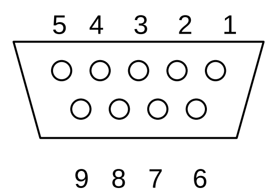
When the RS232 Access (serial port mode) is activated and the Control Unit is not in the charger stand, or the Control Unit is in a charging stand that is not turned on, the power drain on the Control Unit battery is increased. In addition, when the Control Unit's serial port is active, the battery voltage is not continually sampled, nor is the automatic power-off feature active. Therefore, whenever the serial port is to be used for extended period of time. It is important to either place the Control Unit in the Charging Stand, with the charger turned on so that the Control Unit's battery remains charged, or to apply external power to the Control Unit (see PC/CONTROL UNIT INTERFACE section).

PC/CONTROL UNIT INTERFACE

There may be a need to connect the Control Unit directly to a PC computer without using the charger stand. Since using the RS232 Access feature requires more power (see RS232 ACCESS), it may also be necessary to provide external power to the Control Unit without placing the Control Unit in the Charging Stand. This section describes the Serial Port connectors and commands needed for remote operation.

SERIAL PORT CONNECTION

The µScan Control Unit uses a 9-pin female D-Sub Connector located at the bottom of the unit for Serial communications and external power. Of the 9 pins, only 4 of them are needed. The remaining pins are used for special control purposes so external connection to these pins is not allowed.



9-pin D-Sub Connector

PIN#	Description
2	RxD (Receive Data)
3	TxD (Transmit Data)
5	Ground (Signal and Power)
8	External Power (9.0 to 11.0 VDC)

1,4,6,7,9 Do not connect

µScan SERIAL PORT COMMANDS

The µScan Control Unit can be used as a remote measuring device by using the serial port. The Control Unit uses a three-wire interface and supports the Software Handshaking protocol (XON/XOFF). The commands necessary to do this are described below. Note that all commands must be terminated with a carriage return character <cr>. The serial commands can be either upper or lower case, since the Control Unit is case insensitive.

<u>INITIALIZE CONTROL UNIT</u>

SERIAL COMMAND <CNTRL>+B<cr>

DESCRIPTION This command is part of the requirement for setting the µScan

Control Unit into serial port mode. The following steps must be per formed before the Control Unit is properly initialized:

1) Connect µScan Control Unit to host (PC or other serial host).
2) Turn µScan Control Unit ON.
3) Select 'RS232 ACCESS' from µScan Control Unit main menu.
4) Send<CNTRL>+B<cr> from host computer to µScan Control Unit.

RETURN MESSAGES *** RS232 PORT READY TO COMMUNICATE<cr>

MEASURE

SERIAL COMMAND M<cr>

DESCRIPTION This command is used to start a measurement. A head must be attached to the µScan Control Unit for a measurement to be made. If a head is not attached, an error message will be returned.

RETURN MESSAGES
*** MEASUREMENT COMPLETE<cr>
*** HEAD ERROR ... MEASUREMENT NOT ALLOWED!<cr>

RETRIEVE MEASUREMENT RESULTS

SERIAL COMMAND RX<cr>

DESCRIPTION This command is used to retrieve the data following a measurement. This command should immediately follow the MEASURE command. Data is returned as a µScan MEASUREMENT RECORD (see section µScan MEAU- REMENT RECORD FORMAT for information about the format), followed by a transfer complete message. Note that this command will always return the last VALID measurement record. This is important to know because a MEASURE command can fail because of an unconnected head, yet this command would still return data.

RETURN MESSAGES

<µScan MEASUREMENT RECORD>
*** TRANSFER COMPLETE<cr>

RETRIEVE DATE AND TIME

SERIAL COMMAND T<cr>

DESCRIPTION This command is used to retrieve the date and time from the µScan Control Unit. The time is returned in 24 hour format.

RETURN MESSAGES
YY:MM:DD:HH:MM:SS<cr>

SET DATE AND TIME

SERIAL COMMAND
YY:MM:DD:HH:MM:SS<cr>

DESCRIPTION This command is used to set the date and time in the µScan Control Unit. The time must be in 24 hour format. It is important that the form of the date and time string be EXACTLY as shown, with leading zeros for years, months, days, hours, minutes, or seconds having a value less than 10.

RETURN MESSAGES
YY:MM:DD:HH:MM:SS<cr>

µScan MEASUREMENT RECORD FORMAT:

One **MEASUREMENT RECORD** consists of one SOURCE INFORMATION RECORD followed by several DETECTOR INFORMATION RECORDS. Every measurement requires one measurement record. A large number of measurements can be stored in a single µScan file by appending measurement records to the end of the file. This format uses spaces as delimiters, thus allowing decoding to be very simple.

SOURCE INFORMATION RECORD:

The first line of each MEASUREMENT RECORD is the SOURCE INFORMATION RECORD. This line has the form

\# <DATE> <TIME> $< \lambda >$ $< \theta_{inc} >$

where:

#	start of SOURCE INFORMATION RECORD indicator
<DATE>	date of measurement <MM-DD-YYYY>
<TIME>	time of measurement <HH:MM:SS>
$< \lambda >$	laser wavelength in nanometers

$< \theta_{inc} >$	laser incident angle in degrees
	if (0 θ_{inc} < 90) then
	Reflective Measurements
	if (90 θ_{inc} 180) then
	Transmissive Measurements

DETECTOR INFORMATION RECORDS:

The lines that follow the SOURCE INFORMATION RECORD define the detector locations and measurement results. DETECTOR INFORMATION RECORDS have the form

& $< \theta_s >$ $< \phi_s >$ <BSDF/REFL/TRANS>

where:

&	start of DETECTOR INFORMATION RECORD indicator
$< \theta_s >$	detector angle from sample normal in degrees
$< \phi_s >$	detector angle from the specular reflection in degrees

	<BSDF/REFL/TRANS> measurement result
	if ($\theta_s = \theta_{inc}$) and ($\phi_s = 0$) then
	result is REFLECTANCE in the range
	0.001 < REFLECTANCE < 0.999
	if ($\theta_s = 180 - \theta_{inc}$) and ($\phi_s = 0$)
	then result is TRANSMISSION
	otherwise result is BSDF

The number of DETECTOR INFORMATION RECORDS per MEASUREMENT RECORD is determined by the number of detectors in the measurement head including the reflectance detector (if one is installed). A<BSDF/REFL/TRANS> value greater than or equal to 5.0 indicates an overload on the detector.

EXAMPLE: SERIAL TRANSFER

The following example should help to understand the serial transfer format. Underlined commands are originated from the PC or terminal. The carriage return character is denoted here by <cr>.

```
<CNTRL> + B<cr>
*** RS232 PORT READY TO COMMUNICATE<cr>
M<cr>
*** MEASUREMENT COMPLETE<cr>
RX<cr>
# 11-30-1990 11:40:10 670.0 25.0<cr>
&   0.0   0.0  1.082E-03<cr>
&  50.0 180.0  5.857E-04<cr>
&  25.0   0.0  4.100E-01<cr>
*** TRANSFER COMPLETE<cr>
M<cr>
*** MEASUREMENT COMPLETE<cr>
RX<cr>
# 11-30-1990 11:40:15 670.0 25.0<cr>
&   0.0   0.0  1.064E-03<cr>
&  50.0 180.0  5.955E-04<cr>
&  25.0   0.0  4.300E-01<cr>
*** TRANSFER COMPLETE<cr>
```

Notes:

-The laser wavelength is 670, 900 or 1300nm.
-The incident angle is 25 degrees.
-The measurement head has a total of three detectors, two BSDF and one REFLECTANCE. For this example, the REFLECTANCE detector is the third detector of each MEASUREMENT RECORD since $\theta_s = \theta_{inc} = 25$ degrees and $\phi_s = 0$ degrees.

FIGURES

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Part 3: Measurement Head

INTRODUCTION

The SMS µScan Scatterometer System can utilize various interchangeable SMS Measurement Heads. This provides a wide range of measurement capabilities for various samples including both reflective and transmissive applications. Use of one of the hand held Measurement Heads makes accurate readings possible with portable operation, both indoors and outside.

PRECAUTIONS AND SAFETY

WARNING

All laser equipment is labeled for operator and individual safety protection. Four levels or classifications have been established. Each classification has its own set of recommended safety precautions which should be followed for the protection of the operator as well as others near the laser system.

Laser Safety Classifications

Lasers are classified by the Bureau of Radiological Health (BRH) of the US Food and Drug Administration and by ANSI Z-136. The classification philosophy is based upon human access and potential hazard. Class I levels of radiation are not considered to be hazards. Class II lasers are those visible lasers which do not have enough output power to accidentally injure a person but which may cause eye damage from chronic exposure. Class II lasers are often termed low-power or low-risk laser systems. They are hazardous only if the viewer overcomes his or her natural aversion response to bright light and continuously stares into the source. A Class II laser has an output power below 1 mW.

Class II laser products emit at levels at which biological damage to human tissue is possible from acute direct exposure. Class III, moderate risk or medium power lasers, are those that can cause injury within the natural aversion response time, i.e., faster than the blink reflex (0.25 s). Class III has been subdivided into IIIa and IIIb. Class IIIa lasers are not hazardous when viewed with the unaided eye but may be hazardous when the energy is collected and directed into the eye, as with binoculars. These lasers are visible wavelength lasers in the 1 -5 mW regime. Class IIIb lasers can produce a chance of accidental injury if viewed directly. The primary danger is exposure to the direct or specular reflected beam. Continuous wave lasers with an output between 1 mW and 0.5 W are classified as Class III.

Laser systems which are "High Power," present a "High Risk" of injury and can cause combustion of flammable materials are designated Class IV. They may also cause diffuse reflections that are eye hazards and may also cause serious skin injury upon direct exposure. A more restrictive warning label is required and even more restrictive control measures are necessary.

NOTE

The SMS µScan instrument using the Model H-900 or Model H-1300-01 Measurement Head is a Class I Instrument. The Model H-670-01 Measurement Head is a Class II Instrument.

Class II levels of laser radiation are considered to be a chronic viewing hazard.

Caution

Users are responsible for adhering to safety precautions for any lasers used with SMS Scatterometer Instruments. Lasers delivered with SMS Scatterometers are clearly labeled according to Title 21, CFR 1040.10 and 1040.11 specifications. It is the user's responsibility to follow the appropriate safety procedures. Contact the Center for Devices and Radiological Health, Food and Drug Administration, 2094 Gither Road, Rockville, MD 20850, (800) 532-4440 if you have specific safety concerns or questions. The following precautions are suggested for your safety.

Safety Maintenance

It is important that this instrument be maintained such that it continues to meet all laser safety requirements. Periodically (at least weekly) examine the Measurement Head to see that the compliance labels are securely attached. Inspect the beam attenuation cover to see that it fits securely and is not damaged.

Eye Protection

Operation of this instrument does not require special devices for eye protection. However, users of any SMS Scatterometer system are cautioned not to stare directly into the beam or into its reflections from shiny or diffuse surfaces.

Specific Hazards

The models H-900-01 and H-1300-01 Measurement Heads are Class I lasers of low power and do not emit hazardous radiation under normal operating conditions. The model H-670-01 instrument is designed to reduce concerns of using a Class II laser device. The laser source is enclosed in the optics assembly as are the other two Measurement Heads to reduce the possibility of stray laser radiation and the only exit aperture is clearly marked. Looking into the aperture should be avoided when the laser is turned on.

Model H- 670-01, H-900-01 and H-1300-01 MEASUREMENT HEAD DESCRIPTION

The Model H-670-01, H-900-01 or H-1300-01 hand held Measurement Head consists of a single laser diode source, two scatter detectors and a reflectance detector. Figure 1 shows the placement of these components within the head's housing.

This head is designed to make in-plane measurements on either flat or convex surfaces with a minimum radius of curvature of 4.5". The source is a laser diode, located at 25° from surface normal.

Two scatter detectors are located at 0° and 50° from surface normal. These detectors are both located on the same side of the reflected beam, thus making it possible to calculate RMS Roughness. (See the Optical Scatter Measurement Tutorial of this manual for more information on RMS Roughness and other data formats such as BSDF and Reflectance.)

As indicated in Figure 1, the specular reflection exits through the beam dump into the reflectance detector. Thus the only source of scatter is from the sample itself.

OPERATION

The Model H-670-01, H-900-01 or H-1300-01 Measurement Head is used with the µScan Control Unit (described in the Control Unit Section of this manual).

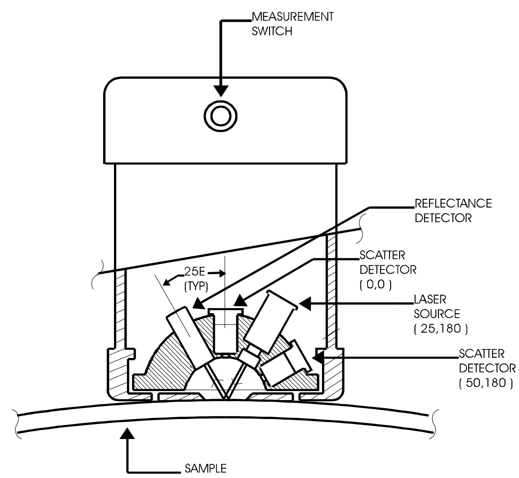

FIGURE 1
MODEL H-670-01, H-900-01 or MODEL H-1300-01
MEASUREMENT HEAD

NOTE

ALWAYS TURN THE CONTROL UNIT POWER OFF BEFORE CONNECTING OR DISCONNECTING THE MODEL H-670-01, H-900-01 or H-1300-01 MEASUREMENT HEAD.

With the Control Unit turned off, connect the Measurement Head to the Control Unit with the cable provided with the head. Do this by placing either end of the cable into the cable socket near the top of the Model H-670-01, H-900-01 or H-1300-01 housing. Make sure the red dots on the connector and plug are aligned prior to inserting. Connect the other end of the cable to the socket at the top of the µScan Control Unit.

When the Control Unit is turned on, specific information about the Model H-670-01, H-900-01 or H-1300-01 Measurement Head is transferred to the Control Unit memory. This information and Control Unit operating instructions are presented in the CONTROL UNIT section of this manual.

HANDLING AND USE

The Model H-670-01, H-900-01 or H-1300-01 Measurement Head is easy to handle and use. Once the Control Unit has been set up for measurements, the actual measurement can be taken by pressing (activating) the red button near the top of the Measurement Head housing. An audible warning is given from the Control Unit when the laser is operating. Activate the laser only when the Measurement Head is placed on the sample.

There are a few comments, which can help to get the maximum accuracy and flexibility from this product.

Press the head against the sample with sufficient pressure to ensure a good contact. Be sure the sample surface touches the head at the aperture opening as the distance from the source and detectors to the sample is important. If the sample is curved be sure that the aperture in placed firmly in contact with the surface. If the aperture is placed over a valley, the distance from sample to detector may be too large for accurate measurements.

Always set the head on the sample, and lift it to remove. Dragging the head across the sample may result in damage to very smooth surfaces. Be sure the sample is completely covering the aperture. Measurements on a sample, which does not fully cover the aperture, may be in error.

Readings from samples having low scatter (BSDF <1E-4) may be affected by dust particles. Using an air “puffer” to blow dust particles away from the sample may improve measurement accuracy. Always keep the aperture cover on the head when measurements are not being made. This is not only a good safety procedure, but it also helps keep the head optics clean.

The head is not designed to operate on wet samples. Avoid measuring moist or wet surfaces. When larger temperature variations are encountered, it is also a good idea to let the head reach temperature stability after moving the unit. Place the head on a flat surface with the aperture at the bottom and the aperture cover removed. Any moisture caused by condensation will be forced toward the aperture by doing this.
Some samples may be small enough to be covered by the Measurement Head. If so, it will be difficult to accurately locate the head on the sample. One solution to this is to place the head on a flat surface with the aperture facing upward. The sample can then be accurately placed.

Consistent measurements will result if the head is not moved from the sample between measurements. It is difficult to precisely relocate the head to the exact position once it has been moved and returned. Accuracy is maintained if the head is no more than 1mm above the sample.

MAINTENANCE

There is very little maintenance required with the SMS Model H-670-01, H-900-01 or H-1300-01 Measurement Head. It is suggested that you routinely use a “puffer” to blow dust out of the head aperture area. If the measurement environment is dusty, then use the puffer more frequently.

It is important that laser safety precautions be followed. At least once per week check the head to see that all labels are securely fastened.

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Part 4: PC OPERATION AND SOFTWARE

INTRODUCTION

The SMS µScan™ hand held Scatterometer can be connected to an optional Personal Computer (PC) system. The purpose of this option is to provide significantly more data storage as well as greater data analysis, comparison and presentation capabilities. The operator can make measurements, and delete, edit and save data files while using the PC. The PC can be used to retrieve data files from the µScan Control Unit. These files can be displayed and/or printed. The PC option also makes it possible to initiate remote measuring and to have threshold (pass/fail) data analysis.

This documentation describes the PC hardware requirements and installation of the optional SMS PC Software. The Operation section tells you how to use the menus in order to operate this instrument using the PC. A listing of error messages is presented in Appendix A and a description of data formats is in Appendix B.

PC SYSTEM

MINIMUM PC REQUIREMENTS

The minimum requirements for the PC system include:

* 100% PC/AT IBM™ Compatibility
* 512K available memory
* 1 serial data port (to connect the Control Unit)
* DOS version 3.3 (or greater)
* Two flexible disk drives or one flexible and one hard drive

SMS µScan software is supplied on 3½” (1.44 MB) diskettes.

RECOMMENDED PC CONFIGURATION

The SMS Software designed for this application has many features that make operation of the PC more useful and efficient. It is recommended that the following hardware be added to obtain full capability of the instrument and software:
+Hard disk drive
+Parallel port
+Parallel printer
+Mouse (Microsoft™ compatible)
+Additional serial port (if Mouse is added)
+CGA/EGA/VGA video card and monitor

USER INTERFACE WITH PC

Basic operation of the PC is with the keyboard and all PC functions can be accessed with it. Once the software is installed you will be able to choose functions using pull down (window) menus. Information supplied with the PC will describe how to use the keyboard. The Mouse option, if used, provides a fast way of moving the cursor to access and operate the instrument. Special key usage is described in the Operation section (below).

ERROR MESSAGES

Software for the PC contains several messages to help you determine what may be wrong when operational errors happen. These messages have a unique number and are displayed on the screen as they occur. These messages are also listed in numerical order in Appendix A. Each message provides a description of the problem as well as the necessary command syntax and an example if pertinent. Appendix A may contain additional information concerning the problem.

INSTALLATION

SMS µScan Software is supplied on 3½” (1.44 MB) diskettes. This software will be saved in the directory you specify. It is assumed that the PC and selected peripherals have been connected and their operation verified. Connect the µScan Charging Stand to a PC serial port using the connection cable supplied. (Note this serial port number, as you will have to use this number when configuration changes are entered into the software.) Place SMS Software Disk into the flexible disk drive. Now perform these steps (you must follow each with command with <ENTER>)

Type **A:**
This command places you at drive A. Use B: if the disk was placed in that drive.

Type **DIR**
The contents of the directory should be:

SAMPLE.USN
INSTALL.EXE
USCAN.CFG
USCAN.EXE

If these titles are not displayed, either you have the wrong disk or there is an error. Contact SMS if these files are not found.

Type **INSTALL**
This will cause an error message to be displayed. We chose this method of forcing you to enter your directory path name at this step. Our example (shown in the error message) suggests a path directory of C:\USCAN. (This assumes use of a hard disk drive. Use B: if your second drive is a flexible disk.)

NOTE: The letter " U " is often substituted for " µ " as a keyboard entry convenience. The meaning should remain clear to the user.

Type **INSTALL C:\USCAN**
This assumes our example path name. Use the path name you have chosen. The software on the install disk should now be transferred to your directory. A horizontal **Activity Bar** indicates that the copying is in progress and estimates the percentage of completion.

Type **C:**
Type **CD C:\USCAN**
Change to the directory you have just specified. Again, we assume our example path name.

Type **DIR**
List the directory contents. Three of the four previously listed file names should appear. The only file not transferred is INSTALL.EXE since it is no longer needed.

Remove the install disk and store it in the event a future installation is required. This concludes the installation.

Type **USCAN**
The USCAN Main Menu will appear and you are now ready to use the software.

OPERATION

Operation of the PC is based on selection of functions from menu screens displayed on the monitor. The **MAIN MENU** is displayed at the top of the screen and it has these functions:
File **D**ata **O**utput **E**dit **M**easure o**P**tions e**X**it **H**elp

Each menu entry has one capital letter. The capital letter in conjunction with the <ALT> key is used in the keyboard selection of the menu entry. For example, let us activate Help:

Hold <**ALT**> and type **H**

Note that the Help option in the Main Menu becomes highlighted, and a Pull Down Menu (submenu) appears. The Help menu has two options:

Using µScan
About µScan

The cursor now highlights "Using µScan." Use the up and down arrow keys to move this cursor. Place the cursor on Using µScan:

Press <**ENTER>** (i.e. Return)

An explanation of keystrokes needed for keyboard operation of the instrument is now displayed.

USING µScan

The **Using µScan** screen lists various key functions for accessing functions through menus. Starting at the top of the list, <**ALT**> + <**CAP LETTER**> and <**ENTER**> have been described in the example commands above. In many menu windows, pressing <**ENTER**> will automatically move the cursor to the EXIT selection as well.

Sub-menu selections can also be activated by just typing the highlighted letter of the menu entry. This is a fast and convenient way to choose a function in a long menu list.

The <**ESC**> key will terminate the current operation and return you to the next higher menu. The only time <**ESC**> does not function in this way is when you must answer either YES or NO to a menu selection. In many menu windows you may also activate CANCEL. As with <**ESC**>, CANCEL will cause you to leave that menu <u>without</u> parameter modification.

The <**TAB**> and <**SHIFT-TAB**> keys move the cursor to either the next or the previous window selection box. The **cursor keys** (arrow keys) move the cursor within the selection boxes. Function <**F1**> **-** <**F10**> keys become active (**HOT**) at various levels in the menu structure. The menu displayed will indicate what function is active for the particular key at that point. A few minutes of exploration of menus using these keys will teach you how to use them.

MOUSE OPTION

This system supports the use of a Microsoft™ compatible mouse. Only the left mouse button is active. Controlling the cursor with the mouse option can be very fast.

ABOUT µScan

The **About µScan** screen provides a brief functional description of the instrument software. It includes the address of SMS should you need it. Follow those steps described above to access this screen.

OPTIONS

The **oPtions** feature makes it possible to set up communications with the µScan Control Unit. The Control Unit must be placed in the Charging Stand and the cable from the PC to the stand must be connected. Turn on the Control Unit and activate RS232 ACCESS from the Control Unit Main Menu. (See Control Unit documentation, for information about the Control Unit operation and Charging Stand.) Each sub-menu function is accessed as described above. We begin by setting serial port communications.

SETUP SERIAL PORT

The **Setup Serial Port** function causes a screen to appear which allows selection of the baud rate for the communications port to which you connected µScan. There are 5 possible baud rates. Choose a baud rate that is supported by your PC. Note that you may need to choose a slower rate if the connection to the Control Unit is over a longer distance or a communications buffer overflow occurs. Using either the <**TAB**> or <**ARROW**> keys, move the cursor to the desired baud rate and activate your choice by pressing <**SPACE**> or <**ENTER**>. (The selected choice is noted by a special symbol.) Now move the cursor to the **PORTS** section and activate the correct PC communications port (for example **com1**:) that was selected when the connection was made between the PC and the µScan Charging Unit.
Any changes that you made will be ignored if CANCEL or <ESC> is activated. If you activate EXIT, any new selections will remain in use as long as the PC program is not exited. Permanent changes (changes that will remain whenever the PC program is executed) are made using the update configuration file function.

SET µScan TIME & DATE

The time and date in the µScan Control Unit can be synchronized with the clock in the PC using **Set µScan Time & Date** menu. The current time and date of the PC is displayed with this format:

Hour: Minute: Seconds Month-Day-Year

Activating window "EXIT" will set the Control Unit clock with the PC clock. Activating "CANCEL" or <**ESC**> will not change the Control Unit time.

SELECT µScan CONFIGURATION

The **Select µScan Configuration** menu provides information about the Measurement Head currently connected to the Control Unit. (An error message will result if a head has not been attached.) The laser source mounted in the measurement head is listed in the table with its angle of incidence (θ_{inc}), and wavelength (λ). In addition, those detectors that are active with the particular laser are specified by their angles.

Use the <**TAB**> to move the cursor to the desired window box. Select the laser desired for your measurements and activate EXIT. The chosen laser will be used for the next measurements. Laser choices will frequently depend upon need for reflective versus transmissive scans.

DISPLAY SYSTEM INFORMATION

Information about your µScan system is available using the **Display System Information** menu. There are three categories of information for your use. These are **µScan HEAD INFORMATION**, **µScan CONTROL UNIT INFORMATION** and **STATISTICS**. Information for the Measurement Head (that is currently attached) and the Control Unit includes serial numbers and date of last calibration. The Control Unit software version number is also listed. Total time in use, measurements and data transfers for the Control Unit are reported in the Statistics window. This information will be required should you need to contact SMS concerning your system.

UPDATE CONFIGURATION FILE

This software uses the file **USCAN.CFG** to store a variety of system operating parameters. These parameters include communication port and baud rate, printer port and type, SAVE type (**always/never/verify)**, DOWNLOAD type (**append/overwrite**), CONVERT type (**casi/ascii**), CONVERT mode (**confirm/overwrite**), Bandwidth limits, and the default subdirectory path and drive. When the µScan Software program begins, the program reads **USCAN.CFG** to obtain the default values for each of the parameters. Any changes to the default parameters via Main Menu options are valid only during the current session unless the **Update Configuration File** option is activated. Activating this option will cause the existing **USCAN.CFG** file to be renamed **USCAN.BAK** and the present parameter values to be written to a new **USCAN.CFG** file. Therefore, the next time the program is used, these new default values will automatically be used.

The default path is useful for specifying the default drive and subdirectory path in which µScan data files are stored. When the configuration file is being updated, the currently active drive and subdirectory path will be stored as the default path. When the program is first started, it tries to change to this default subdirectory, but if for some reason it fails (drive not ready, disk has been removed, invalid path specified, etc.), the program will use the presently active drive and subdirectory as the default.

Activating this option will cause an "updating" message to be displayed briefly on the screen.

MEASURE

BEGIN

Making measurements starts by activating **Begin .... <F5>**. (It is assumed that a measurement head is connected to the Control Unit and that the Control Unit is properly connected to the PC.) If the specified measure file already contains data, the user will be asked if the file should be appended, overwritten or the operation cancelled.

If Appending is desired, the present file will have the new measurements added to the end. However, if "overwrite" is selected the present file will be renamed with a ".USB" extension and a new file will be created. This means that even the comments are cleared. Selecting "CANCEL" will abort the operation. A screen will then appear telling you that a measurement is in progress. Upon completion, the measurement table screen will be updated.

Examine the Measure screen that is displayed and note the top line specifies the measurement file name and the SAVE option (either ALWAYS, VERIFY or NEVER). The next 3 lines are available for inserting comments. Use <**TAB**> to move the cursor to these lines and enter comments as desired. (Please refer below to the section describing Main Menu option Data\Display Table for an explanation of parameters presented on the Measurement screen.)
Command boxes associated with this feature include **measurement** (to initiate additional measurements), **previous** and **next** to examine measurements stored in this file, and **exit**.

SAVE

There are three options for saving data using the **Save......** function. These are **always**, **verify**, and **never.** These choices have the same meanings as described in the SAVE section of Control Unit documentation. The choice made via the PC will supersede the choice made directly at the Control Unit. The current choice is displayed in the window menu whenever the Measure function is activated as, for example, "**Save....NEVER**."

MEASURE FILE NAME

File

The sub-menu choice **File** provides a means of naming or selecting a file into which measured data are to be stored. If a file name has not been assigned, **MEASURE FILE NAME** window will appear. You may enter your own file name within the brackets of the top line. File names can be up to 12 characters, but must follow DOS format. For example:

File Name: [SAMPLE.USN]

This screen also lists files that have previously been used. Use <**TAB**> to move to the file window and use the cursor keys to select SAMPLE.USN and activate using <**ENTER**>. (SAMPLE.USN is an example file containing data, which we use in this chapter to help describe software features.) This will become the selected file and the name will appear on the top line. Activating EXIT will cause the PC to store data in the named file when the next measurement is made. Note that upon returning to the Measure menu, the last selected file will appear in the menu as, for example, **File...SAMPLE.USN**. The directory path is also specified on this screen.

FILE

The Main Menu option **File** provides file management capability for the instrument. There are three functions in this option. These include µScan file handling (Add, Delete, Clear and Download), reading files from PC disk storage, and file format conversion.

µScan FILE HANDLING

One of the main advantages of the PC is the availability of much more file storage than exists in the Control Unit. Using the PC, you can name files and add them to Control Unit storage. You can also delete, clear and obtain (download) files from the Control Unit. The Control Unit must be placed in the Charging Stand, turned on and RS232 ACCESS selected before activating these functions, otherwise ERROR 2200 - SERIAL PORT NOT RESPONDING will occur.

Upon selection of one of these µScan File functions, the Control Unit will send to the PC names of all files currently stored in the Control Unit. See (Setup/File section of the Control Unit documentation for more information.) These file names are alphabetically displayed so that you can see what files already exist in the Control Unit. There can be more files (as many as 255) than can be displayed at one time on the screen. When there are more than a screen full of files, the bottom line of the file listing window box will become an action line. This tells you to scroll using arrow keys to view additional file names. (The optional Mouse cursor can be used with the action line for scrolling as well.)

NOTE

If for any reason the Control Unit is turned off while being used with the PC, it will be necessary to re-access any functions starting again at the PC Main Menu. The reason for this is that the Control Unit may have been removed to make other measurements and thus additional files may have been stored in its memory. The PC would not be aware of new files unless a complete re-load was initiated.

A window for File Name: [   ] makes it possible to select or edit a new file. The last file that was active in the Control Unit is displayed in the File Name window when these file handling screens first appear.

The <*****> serves as a wild card character for file handling. It can be used to identify all files having similar names to save time. It functions just like it is used in MS-DOS™ operations. The <**?**> wildcard character is not recognized.

Add

The **Add** feature makes it possible to add new files to the Control Unit. Just begin typing the new name, or use the <**BACKSPACE**> to edit the existing name. Use <**ENTER**> or select the window “add” to transfer the file name. The new name will appear in the list if transfer is successful. The software will provide error messages if the file already exists, or if the Control Unit memory is too full to accept more files.

Delete

The **Delete** file option makes it possible to delete files from the Control Unit. The <*> wild card character is useful in this function. By itself, <*> will delete the entire file list. Once again, the <**?**> wildcard character is not recognized.

Upon selection of DELETE a sub-window will appear with this message:

Are you sure you want to Delete file “   “ ?

This is followed by two boxes for either “YES” or “NO.” You must select either “YES” or “NO” using the left/right arrow keys and activate your choice at this time. The <**ESC**> key is disabled at this point, forcing you to make the desired choice. Another window appears to tell you that a selected file is being deleted and remains while deletion occurs. The time for deletion depends upon how full the file is, how many files exist and where it is located in the file list.

CLEAR

The **Clear** feature empties the file of its contents. The wild card <*> is useful when many files of similar names are being processed.

The Clear function can also be used to alphabetize the file list in the Control Unit where files are not stored alphabetically. Since the PC stores files alphabetically, clearing of all files (with use of the wild card <*>) will cause the cleared files to be returned (added) to the Control Unit in alphabetical order. **DO NOT DO THIS UNLESS FILE CONTENTS HAVE PREVIOUSLY BEEN DOWNLOADED.**

DOWNLOAD

Files can be sent from the µScan Control Unit (download) by the use of **Download**. As with other file handling options, existing Control Unit files are presented on the screen, with the last active file listed in File Name: [   ]. Use of the wildcard <*> is permitted with this function. Files stored in the µScan will be transferred and stored to a PC file having the same file name except that the ".USN" (**US**ca**N**) extension is added to the disk file name.

The **Download** function has two command windows, **Overwrite** and **Append**. The currently selected mode is displayed in brackets just above the overwrite window. Activating overwrite will cause a PC file with the same name to be overwritten with new data. The original file will be renamed with a ".USB" (**US**can **B**ackup) extension. Files stored in the µScan Control Unit that have no measurements will not be downloaded.   Activating **Append** will cause the downloaded data to be added to the end of a PC file if the corresponding PC file exists. As with **Overwrite**, empty µScan Control Unit files will not be downloaded.

The destination path for the downloaded files can be specified in the path-input area. The path can include the drive designator and subdirectories, but if subdirectories are specified, the subdirectory must already exist. Subdirectories cannot be created from within the µScan PC software. Invalid operations will result in an appropriate error message. If a directory must be created without leaving the µScan PC software, use the **Shell to DOS ... <F9>** command (see **EXIT** section).

READ FROM DISK

The **Read From Disk** feature places files stored on a disk drive of the PC into program data memory so that the software can access these files. For example, to display the contents of SAMPLE.USN, you must first use the **Read From Disk** option to obtain the file before you could use the Main Menu **Data** option to examine the contents.

Files may be stored in various disk drives. The drive must be specified from those drives listed in the window displayed to the left of the files list.

You may type in the file name to be read. If a file with no extension is specified, the software will append the ".USN" extension and check to see if the file exists.

SELECT CONVERSION TYPE

The **Select Conversion Type** menu provides the means of changing the data format within the selected file. There are two formats, **CASI** and **ASCII**. CASI files have the extension ".XXX" where XXX is the measurement number in the range ".001" to ".255". ASCII files have the extension ".PRN" which is the default for comma delimited ASCII files in Borland's Quattro™. These file formats are explained in Appendix B.

CONVERT

Menu selection **Convert** is used to specify the file(s) to be converted into the data format that was activated by Select Conversion Type (above). This function provides a choice of direct Overwriting or Confirming and the selected choice is displayed on the screen. Use of the wildcard <*> is permitted for both the filename and the extension in this function. The default extension is ".USN".

EDIT

The Main Menu selection **Edit** is used to set frequency bandwidth limits and threshold values on measurements so that calculations can be specified over a known range, or pass/fail limits set for certain applications.

BANDWIDTH LIMITS

Activation of **Bandwidth Limits** allows you to set the upper and lower frequencies over which RMS Roughness calculations are made. When the EDIT BW LIMITS screen appears, use <**TAB**> to move the cursor to set the minimum frequency (Fmin) and enter your value. Repeat for the maximum frequency (Fmax). Units for these entries are 1/wavelength in ìmeters (1/ì). An error message will be displayed for values that are in error.

THRESHOLD VALUES

In some applications the desired information might be the knowledge that a reading is greater or less than a selected level. This is the basis for a Pass/Fail measurement. The **Threshold Values** option allows you to set a threshold value for each datum point. Threshold limits are sent to the Control Unit. Parameters with thresholds set (BSDF, Reflectance and RMS Roughness) will be displayed in the Control Unit with one of four prefixes. The characters +, -, =, or blank (no threshold) will be inserted in front of Control Unit data.

When activated, the EDIT THRESHOLD VALUES screen appears. This screen presents the angle of incidence and the wavelength of each laser (in the connected Measurement Head). This is followed by a listing of detectors (by their angle locations), Reflectance and RMS Roughness. The threshold for each detector as well as Reflectance and RMS Roughness is entered between the bracketed field [ ]. Entering a space (blank) will mean that no threshold value is require for that parameter.

PC Software REV C and later

The selection REFLECTANCE was added to the EDIT menu in the PC Software.

The user may wish to calibrate the reflectance of the mScan Control Unit from a known standard. Upon averaging a large number of measurements, the user will have a reflectance generated for the sample which may be different from the desired value. To change the calibration so that the measured value will match the desired value:

Make sure the Control Unit is in the charging stand, connected to the PC via the serial cables, and in RS232 communications mode.

Select EDIT then REFLECTANCE from the PC program main menu. The EDIT REFLECTANCE window will be displayed. In the PRESENT field type the average measured value of the sample. Select the SAVE button in the window. The new calibration value will be written to the Control Unit Configuration. If either the PRESENT or DESIRED values are greater than 100.0%, then divide BOTH entries by 10, enter them again, and try to SAVE again.

After the SAVE operation is complete, the µScan will not use the new calibration value until the unit is turned off and then turned back on. Be sure to turn the µScan unit off and then back on before trying to verify the new calibration values.

DATA

The **Data** menu makes it possible to examine contents of data files and to look at some statistics of repeated measurements.

DISPLAY TABLE

Display Table……<**F2**> displays contents of a previously selected data file. {If you have not yet done so, use menu option File and Read From Disk to put SAMPLE.USN into memory. (See Read From Disk, above.)} Your screen should now have the window titled: Data Display Table: [File Name}.

Please refer to the screen on Figure 1 for the following discussion.

The first 3 lines of the display are for **COMMENTS**. The <TAB> Key will move the cursor to this window where as many as three lines of comments can be stored. This useful feature

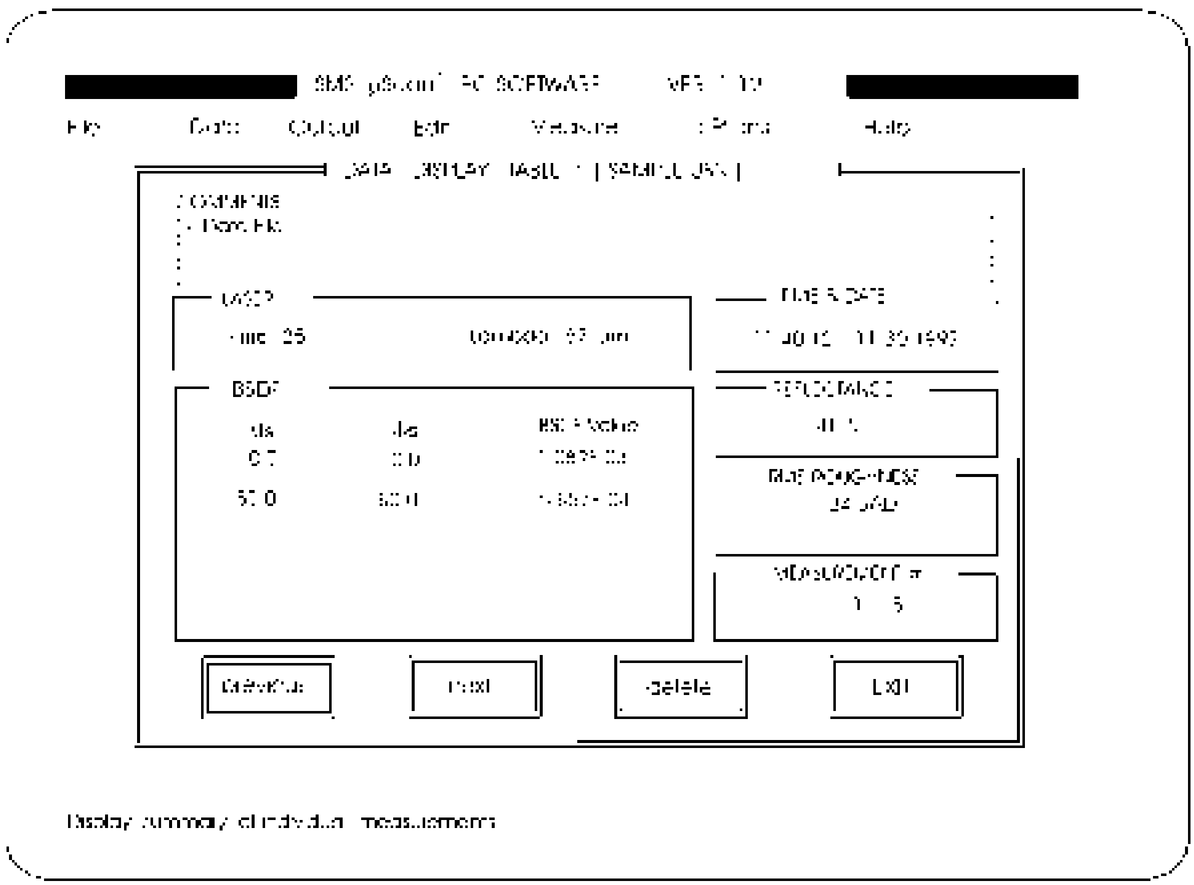

Figure 1 Data Display

makes it possible to save information about the measurement with measured results. If comments are changed, upon exiting the user will be asked if the changes should be saved.
The next window is labeled **LASER**. Information about the laser and detectors in the attached measurement head is stored in this table. For this example, the laser has an angle of incidence (θ_{inc}) of 25° with a wavelength (Lambda) of .67 µm. Incident angles greater than 90° indicate transmissive measurements.

Measured BSDF values for each detector are displayed in the **BSDF** window. For this measurement head there are two detectors. One detector is located at {θ_S, ϕ_S} of 0.0°, 0.0° and the other is located at 50.0°, 180.0°. (See Beam Coordinates section of Optical Scatter Measurement Tutorial for information about these angles.) The associated measured BSDF values are also listed.

(There can be as many as 7 detectors in a measurement head.)

The **TIME & DATE** is displayed as hours:minutes:seconds and day-date-year and indicates the Time/Date of the actual measurement.

REFLECTANCE is displayed as a percentage and below it is the **RMS ROUGHNESS** in angstroms. The frequency bandwidth limits (inverse wavelength {1/ìm}) for which RMS Roughness is calculated, is presented in brackets as well.

The last information window is **MEASUREMENT #**. The example format is 1 : 5 which says the first measurement (of the 5 stored in this file) is being displayed. Use the **previous** and **next** windows or <**UP**> and <**DOWN**> arrow keys to scroll through these five measurements. Note that the measure-

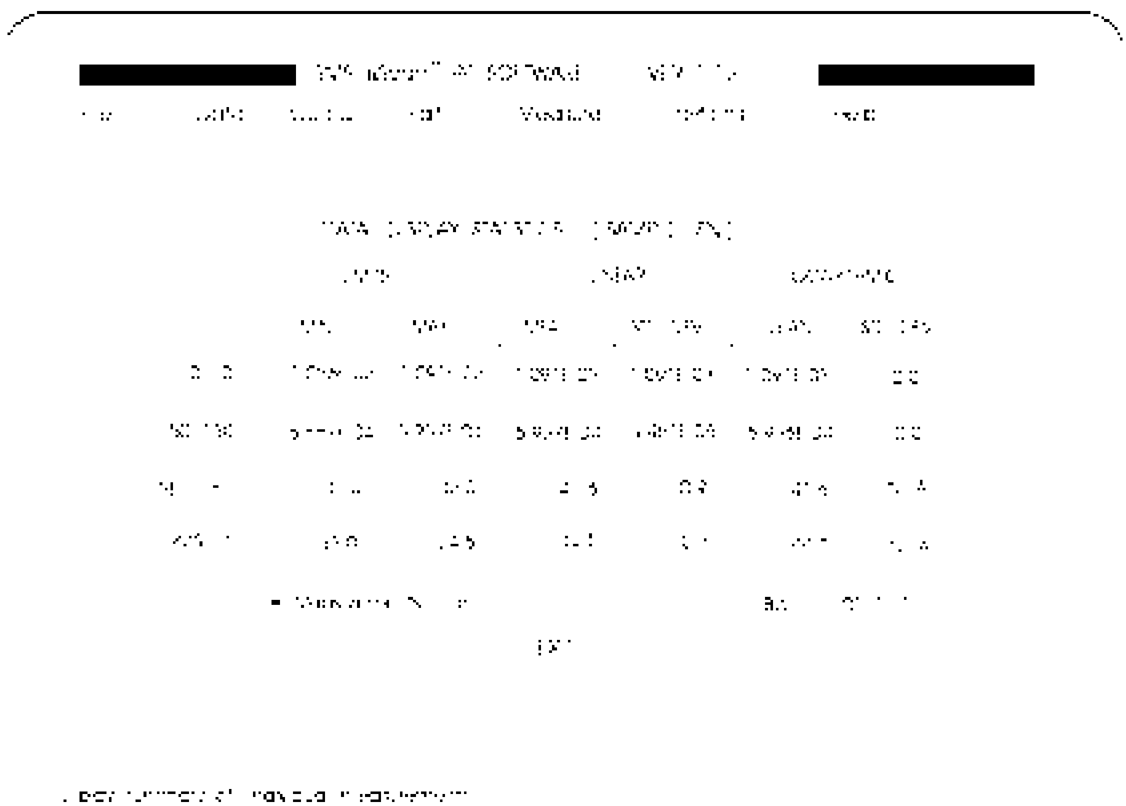

Figure 2 Statistics

ment numbers, as well as other data values change as scrolling takes place.

The Display Table option also contains the activation window **DELETE** that allows you to delete undesired or invalid data points from a measurement file. The delete operation is performed on the current measurement being displayed, and will cause the total number of measurements to decrease by one. An error will result if all of the measurements in the file are deleted. The user will be asked to confirm the changes if at least one point is deleted or the comments have changed. A backup file (.USB extension) will be created if the changes are saved.

DISPLAY STATISTICS

The **Display Statistics .. <F3>** menu provides statistical information for measurements in a selected file. Please refer to your screen or Figure 2 for the following discussion.

This table of statistics is based on those five measurements stored in SAMPLE.USN as noted by **# Measurements = 5**. Also, to the right of the screen the bandwidth (**BW**) for RMS Roughness calculations is listed.

The left column of the table lists the angle locations of detectors (as described in the BSDF paragraph of the Display Table menu description above). For this example file there are 2 detectors. Reflectance and RMS Roughness values are the last two items in the table.

Statistics in this menu include **LIMITS** (both **MAX** and **MIN**) for all BSDF detectors, Reflectance and RMS Roughness. The **MEAN** and standard deviation (**STD DEV**) for both **LINEAR** and **LOGARITHMIC** scales is presented.

(The logarithmic STD DEV is defined as the number of orders of magnitude for one standard deviation.)

SMS µScan™ VER 1.12 SAMPLE.USN 12:00:00 10-08-1997 Page 1

COMMENTS:
Data File

SOURCE INFORMATION:
Wavelength 670 nm Incident Angle 25.0 degrees
RMS ROUGHNESS BANDWIDTH LIMITS:
[0.010 - 1.000] 1/µm

MEASUREMENT SUMMARY

#	0.0 / 0.0	50.0 / 180.0	[%] REFL	RMS	TIME	DATE
1	1.082E-03	5.975E-04	41.0	34.3	11:40:10	9-30-1997
2	1.064E-03	5.956E-04	43.0	33.2	11:40:15	9-30-1997
3	1.091E-03	5.957E-04	41.0	34.5	11:40:20	9-30-1997
4	1.026E-03	5.957E-04	42.0	33.0	11:40:25	9-30-1997
5	1.073E-03	5.957E-04	41.0	34.2	11:40:30	9-30-1997

STATISTICS SUMMARY

			--- LINEAR ---		-- LOGARITHMIC --	
	MINIMUM	MAXIMUM	AVERAGE	STD. DEV.	AVERAGE	STD. DEV.
[0.0 0.0]	1.026E-03	1.091E-03	[illegible]	[illegible]	[illegible]	0.0
[50.0 180.0]	5.857E-04	[illegible]	5.937E-04	[illegible]	5.936E-04	0.0
REFL [%]	41.0	43.0	41.6	0.9	41.6	N/A
RMS [Angstroms]	33.0	34.5	33.8	0.7	33.8	N/A

Measurements 5

Figure 3 Example Printout for file Sample.USN

OUTPUT

It is possible to obtain a printed output of a selected file. Two sub-menus exist for this option. These are used for printing as well as to set up the printer.

PRINT

The **Print** option is used to select the quantities you want printed. After activation, the PRINT TO LPT1: window appears. (This assumes the optional parallel printer was connected to LPT1.) Use the <**TAB**> key to select the **Display** window. You may select any combination of items to be printed. Use the <**SPACE**> bar to select or eliminate choices. An “o” in front of a quantity means it will not be printed.

Printing can be with page breaks or continuous as shown under **FORMAT**. The print software will handle paging and compression needs according to the amount of data to be printed. Figure 3 is a complete printout of file SAMPLE.USN with Page Breaks format. Activate printing with window PRINT. If “statistics” is selected, the statistical summary will be printed on the same page as the measurement summary if there is enough room on the page. If the entire statistical summary will not fit, it will appear on the next page.

Data shown in Figure 3 is the same as shown in Figure 1 and 2 explained above. Note again, that there are two scatter detectors in the head used for this example. The BSDF for the (0.0°, 0.0°) detector location is 1.082E-03 as shown in the Measurement Summary. The BSDF value for the (50.0°, 180.0°) detector is 5.857E-04. BSDF values for additional detectors would be presented in the same vertical format in the space just before % REFL.

SETUP PRINTER

The choice of printer type and printer port can be made using menu choice Setup Printer. The currently selected printer is displayed with a “ * “ character. Just below is a list of available printers. There are three classes of printers supported by this software. These are Generic, HP Paintjet, and Epson Compatible. The software will support any parallel printer or serial printer assigned as a parallel printer using the DOS “MODE” Command. However, only the HP Paintjet and Epson Compatible printers will automatically change to compressed mode when more than 80 columns of data are printed. (This may easily be the case if all file parameters are selected for printing in the Print option and the head has a large number of detectors.) If your printer is “Generic,” you must manually set your printer to compressed data format if you print more than 80 columns.

The port choice for your printer is also activated in this option within the PRINTER PORT window. The EXIT window is used to activate your choices.

EXIT

There are two possible selections under the **eXit** MENU. One of these (**Shell to DOS .. <F9>**) makes it possible to leave and return to the µScan Software without reloading the software. The second exit (**Exit to DOS ... <F10>**) is a true exit from the SMS Software. This is useful when the user wants to rename files or display file contents.

APPENDIX A ERROR MESSAGES

***** ERROR 1000 - DESTINATION DRIVE/PATH NOT SPECIFIED**

The INSTALL program was invoked without a path and drive specified. Both the drive and the path must be included or an error will occur.

Syntax: INSTALL <drive:><destination path> Example: INSTALL C:\USCAN

*** ERROR 1010 - DESTINATION DRIVE

NOT SPECIFIED

The DRIVE/PATH parameter did not include a drive designator. A drive must be specified.

Syntax: INSTALL <drive:><destination path> Example: INSTALL C:\USCAN

***** ERROR 1020 - COMPLETE PATH NOT SPECIFIED**

The DRIVE/PATH parameter was invoked without the complete path. The parameter must include the complete path originating from the root directory of the specified drive.

Syntax: INSTALL <drive:><destination path>Example: INSTALL C:\USCAN

***** ERROR 1030 - INVALID PATH SPECIFIED**

The DRIVE/PATH parameter included an invalid path name.

***** ERROR 1040 - INVALID DRIVE NAME SPECIFIED**

The specified drive name is not valid.

***** ERROR 1050 - INVALID DRIVE NAME OR DRIVE NOT READY**

The specified drive name is not valid or is not ready. Check the system configuration or close the drive door.

***** ERROR 2000 - DISK FILE NOT FOUND**

The specified file was not found in the current subdirectory. Check spelling or change to the correct directory.

***** ERROR 2010 - INVALID/RESERVED DOS FILE NAME**

The specified file is either an invalid DOS file name or has a reserved extension. Please check the spelling, specify a new file, or change the extension.

reserved extensions	DOS:	.EXE
		.COM
		.BAT
		.SYS
	ASCII:	.PRN
	CASI :	.0* .1* .2*

***** ERROR 2020 - INVALID DATA FILE FORMAT**

The selected file is not a µScan Data file. If the data file has been edited using a text editor, be aware of extraneous characters at the end of the file.

***** ERROR 2030 - INVALID SUBDIRECTORY NAME**

The specified subdirectory was not found. Please check the spelling or insert the correct disk.

***** ERROR 2040 - INVALID DRIVE NAME**

The specified drive was not found on this system. Please select a valid drive.

***** ERROR 2050 - DRIVE NOT READY**

The specified drive is not ready. Please check that a disk is inserted and that the drive door is closed.

***** ERROR 2060 - µScan DISK FILE NOT OPEN**

A file must be read in before the specified operation can be performed. Use the File - Read From Disk option to read in a file.

***** ERROR 2070 - MEASUREMENT FILE NOT OPEN**

With the present 'SAVE' type, a file must be specified before a measurement can be made. Either specify a file using the 'MEASURE - FILE' option or select 'NEVER' as the SAVE type.

***** ERROR 2080 - MEASUREMENT FILE TOO LARGE**

The specified file has more than 255 measurements stored in it. Only the first 255 will be analyzed. The file can be broken into smaller separate files using a standard text editor. If a text editor is used, be aware of bad characters at the end of the file.

*** **ERROR 2090 - MORE THAN ONE CONFIGURATION IN FILE**

The specified file contains data for more than one head configuration. The data file must be separated before this file can be analyzed.

*** **ERROR 2100 - NO MEASUREMENTS TO SAVE**

The file that you are trying to save does not contain any measurements. A zero-length file will not be created and the existing file will not be overwritten.

*** **ERROR 2110 - OPTION NOT AVAILABLE ON DEMO SOFTWARE**

The selected option has been disabled for the demo software. All options that utilize the serial port have been disabled.

*** **ERROR 2200 - SERIAL PORT NOT RESPONDING**

The serial port connection to the µScan Control Unit is not responding. Check these items before continuing:

- Connect the charger stand to a PC Serial Port.
- Place the µScan Control Unit in the charging stand.
- Set the baud rate on both the PC and µScan Control Unit.- Select the 'RS232 ACCESS' option from the MAIN MENU of the µScan Control Unit.

*** **ERROR 2210 - PRINTER NOT READY**

The specified printer port was not ready. Verify that:

- the printer is turned on
- the printer is ON-LINE
- paper is properly installed

*** **ERROR 2220 - SERIAL PORT NOT INSTALLED**

The PC that is presently being used does not have a DOS recognized serial port installed. A serial port must be installed before communications between µScan and the PC can occur.

*** **ERROR 2230 - PARALLEL PORT NOT IN-STALLED**

The PC that is presently being used does not have a DOS recognized parallel port installed. A parallel port must be installed before communications between the PC and the printer can occur.

*** **ERROR 3000 - µScan FILE NOT FOUND**

The specified file was not found in the µScan CPU. Please check spelling or select a different file.

*** **ERROR 3010 - µScan FILE LIST IS FULL**

The maximum number of files (255) are already stored in µScan. Old files must be deleted before new files can be added.

*** **ERROR 3020 - µScan FILE ALREADY EXISTS**

Specified µScan File already exists.

*** **ERROR 3030 - µScan FILE LIST IS EMPTY**

No Files stored in µScan.

*** **ERROR 3100 - BANDWIDTH LIMITS ARE EQUAL**

The min and max bandwidth limits cannot be the same. Specify non-equal limits in the range

$0.001 < Fmin,Fmax < 2.000\ \mu^{-1}$

*** **ERROR 3110 - BANDWIDTH LIMITS OUT OF RANGE**

These specified bandwidth limits are not within the acceptable range

$0.01 < Fmin, Fmax < 2.000\ \mu^{-1}$

***** ERROR 3200 - HEAD NOT INSTALLED**

The desired operation cannot be performed without a head connected! Perform these steps when installing the head:

- Turn the µScan Control Unit OFF
- Connect the head
- Turn the µScan Control Unit ON
- Select 'RS232 ACCESS' from the MAIN MENU on the µScan Control Unit

***** ERROR 4005 - ILLEGAL FUNCTION CALL**
***** ERROR 4006 - FLOATING POINT OVERFLOW**
***** ERROR 4007 - OUT OF MEMORY**
***** ERROR 4008 - DIVISION BY 0**
***** ERROR 4009 - OUT OF STRING SPACE**
***** ERROR 4024 - DEVICE TIMEOUT**
***** ERROR 4025 - DEVICE FAULT ERROR**
***** ERROR 4027 - OUT OF PAPER**
***** ERROR 4050 - FIELD OVERFLOW**
***** ERROR 4051 - INTERNAL ERROR**
***** ERROR 4052 - BAD FILE NAME OR NUMBER**
***** ERROR 4053 - FILE NOT FOUND**
***** ERROR 4054 - BAD FILE MODE**
***** ERROR 4055 - FILE ALREADY OPEN**
***** ERROR 4057 - DEVICE I/O ERROR**
***** ERROR 4058 - FILE ALREADY EXISTS**
***** ERROR 4059 - BAD RECORD LENGTH**
***** ERROR 4061 - DISK FULL**
***** ERROR 4062 - INPUT PAST END OF FILE**
***** ERROR 4063 - BAD RECORD NUMBER**
***** ERROR 4064 - BAD FILE NAME**
***** ERROR 4067 - TOO MANY FILES**
***** ERROR 4068 - DEVICE UNAVAILABLE**
***** ERROR 4069 - COMMUNICATIONS-BUFFER OVERFLOW**
***** ERROR 4070 - PERMISSION DENIED**
***** ERROR 4071 - DISK NOT READY**
***** ERROR 4072 - DISK-MEDIA ERROR**
***** ERROR 4073 - ADVANCED FEATURE UNAVAILABLE**
***** ERROR 4074 - RENAME ACROSS DISKS**
***** ERROR 4075 - PATH/FILE ACCESS ERROR**
***** ERROR 4076 - PATH NOT FOUND**
***** ERROR 40XX - UNKNOWN ERROR**

APPENDIX B DATA FORMATS

µScan FILE FORMAT

The µScan data file format consists of comments and sets of measurement records.

COMMENTS:

The first three lines of a µScan file are used for COMMENTS. The first character in the line must be the "!" character followed by at least one space.

The maximum length of a comment line is 57 characters. Comments longer than this will be truncated by the µScan PC Software.

It is valid to have comment lines anywhere in the data file as long as the first character of the line is "!". However, only the first three lines are recognized, the others are disregarded.

MEASUREMENT RECORD:

One **MEASUREMENT RECORD** consists of one SOURCE INFORMATION RECORD followed by several DETECTOR INFORMATION RECORDS. Every measurement requires one measurement record. A large number of measurements can be stored in a single µScan file by appending measurement records to the end of the file.

SOURCE INFORMATION RECORD:

The first line of each MEASUREMENT RECORD is the SOURCE INFORMATION RECORD. This line has the form

    # <DATE> <TIME> <I> <θ_{inc}>

where:

#start of SOURCE INFORMATION RECORD indicator

<DATE> date of measurement <MM-DD-YYYY>

<TIME> time of measurement <HH:MM:SS>

<l> laser wavelength in nanometers

<θ_{inc}> laser incident angle in
if (0 θ_{inc} < 90) then
Relfective Measurements
if (90 θ_{inc} 180) then
Transmissive Measurements

DETECTOR INFORMATION RECORDS:

The lines that follow the SOURCE INFORMATION RECORD define the detector locations and measurement results. DETECTOR INFORMATION RECORDS have the form

& <θ_S> <F_S> <BSDF/REFL/TRANS>

where:

& start of DETECTOR INFORMATION RECORD indicator

<θ_S> detector angle from sample normal in degrees

<ϕ_S> detector angle from the specular reflection in degrees

<BSDF/REFL/TRANS> measurement result
if ($\theta_S = \theta_{inc}$) and ($\phi_S = 0$) result is REFLECTANCE in the range [0.001< REFLECTANCE < 0.999]
if ($\theta_S = 180-\theta_{inc}$) and ($\phi_S$=0) result is TRANSMITTANCE in the range [0.001 < TRANSMITTANCE < 0.999] otherwise value is BSDF

The number of DETECTOR INFORMATION RECORDS per MEASUREMENT RECORD is determined by the number of detectors in the measurement head including the reflectance detector (if one is installed). A <BSDF/REFL/TRANS> value greater than or equal to 5.0 indicates an overload on the detector.

EXAMPLE:

The following example should help to understand the format.

```
------------- SAMPLE.USN -----------------
! - Data File    degrees
!
!
# 11-30-1990 11:40:10   670.0   25.0
&   0.0   0.0  1.082E-03
&  50.0 180.0  5.857E-04
&  25.0   0.0  4.100E-01
# 11-30-1990 11:40:15   670.0   25.0
&   0.0   0.0  1.064E-03
&  50.0 180.0  5.955E-04
&  25.0   0.0  4.300E-01
# 11-30-1990 11:40:20   670.0   25.0
&   0.0   0.0  1.091E-03
&  50.0 180.0  5.957E-04
&  25.0   0.0  4.100E-01
# 11-30-1990 11:40:25   670.0   25.0
&   0.0   0.0  1.026E-03
&  50.0 180.0  5.957E-04
&  25.0   0.0  4.200E-01
# 11-30-1990 11:40:30   670.0   25.0
&   0.0   0.0  1.073E-03
&  50.0 180.0  5.957E-04
&  25.0   0.0  4.100E-01
-<EOF>-----------------------------------
```

Notes:
-The first three lines are used for comments.
-The laser wavelength is 670 nm.
-The incident angle is 25 degrees.
-The measurement head has a total of three detectors, two BSDF and one REFLECTANCE. For this example, the REFLECTANCE detector is the third detector of each MEASUREMENT RECORD since $\theta_S = \theta_{inc}$ = 25 degrees and ϕ_S = 0 degrees.
-The file contains five measurements.

ASCII File Format

The ASCII FILE FORMAT is compatible with spread sheet programs such as Borland's Quattro(™). The spread sheet can be used to analyze the data and plot the results. The ASCII FILE FORMAT consists of a comma delimited ASCII Text file with labels and comments stored as quoted strings. The file format is described below.

Comments:

The first three lines of the file are always used for comments. These comments are enclosed in quotes.

Wavelength:

Line four contains the quoted string "Lambda" followed by the numeric value of the laser wavelength (in μm).

Incident Angle:

Line five contains the quoted string "Incident Angle" followed by the numeric value of the incident angle (in degrees).

Bandwidth Limits:

Line six contains the quoted string "BW Limits" followed by the minimum and maximum spacial frequency bandwidth limits (in inverse μmeters) that were used for the RMS Roughness calculations.

θ_S Angles:

Line seven contains the quoted string "$_S$->" followed by the θ_S angles (in degrees) of the BSDF detectors.

ϕ_S Angles and Column Labels:

Line eight contains a quoted string "μ_S->", the μ_S angles (in degrees) of the BSDF detectors, followed by the quoted strings "REFL", "RMS(Å), "TIME", and "DATE". The number of BSDF detectors is dependent upon the type of head used when the measurements were taken.

Data:

The remaining lines are used for the measurement number, the BSDF results, the reflectance, the RMS Roughness (in Angstroms) and the time and date. These values are all separated by commas, with the time and date being quoted strings.

CASI DATA FILE FORMAT

This section provides the definition of the CASI data file format. This format is needed if SMS Data Software (CASI) is optionally utilized.

The CASI software runs under the MS-DOS operating system version 2.1 or greater. Legal MS-DOS file names and conventions are adhered to in the CASI software. A CASI data file can have any legal file name. CASI data files are differentiated from non-CASI files by the use of a catalog file. The catalog file must have the name CCATALOG.CAT.

Catalog File - CCATALOG.CAT

The catalog file (CCATALOG.CAT) is an index to all the CASI files that reside in a specific subdirectory. There is a different catalog file in each directory that contains CASI data files. The file stores information derived from the data file to differentiate the contents of one data file from another. If the catalog file is deleted, the scatterometer software cannot find its data files in the data directory. A data file should not be deleted, copied, or renamed from DOS. If this is done the catalog file will not be updated. The CASI software (EDIT module) should be used to perform these functions and will automatically update the catalog file. DOS may be used to make high speed copies by copying an entire data directory (all the data files and the catalog file) to another empty directory. This may be most useful when performing a data backup to floppy disk.

Catalog files are written as random access files and cannot be edited by an ASCII text editor. Each record in the file is fixed in length and the records are not separated by carriage returns or line feeds like an ordinary text file. Each record is divided into five text fields as follows:

Item	Length	Function
Name	12	Name of the file being catalogued
Delete	1	Nullifies the record if set to"D" (deleted)
Date	10	Date of the data scan
Time	8	Time of the data scan
Comment	49	1st 49 characters of comments from the data file

Data Files

Data files store data measured during an angle scan as well as the parameters used to run the scan. Identification of the sample and comments about its condition and the sample measurement environment are part of this file.

These files are written as sequential ASCII text files. Information in these data files is position dependent. These files may be read and written by an ASCII text editor as long as care is taken not to alter the format or sequence of information. Adding or deleting lines in the file will render the file unreadable by the CASI software.

CASI data files consist of two parts; a header followed by a sequence of blocks of data. Each line in the header contains one numeric or string item and is enclosed in double quotes. The last header item is the number of data blocks to follow. Data blocks follow the file header without any blank lines separating headers and blocks. Data blocks consist of lines with one data item in each line. Each line in a block contains a numeric string which is not enclosed in quotes. The block contains a block header followed by an iteration of data point values in the block. The number of points in the block is contained in the block header.

Note: The length column is in number of characters and does not include the double quotes for header items or new-line characters. When the length is listed as a number, the item is a single precision number and can be up to 13 characters long. All fields are terminated by new-line characters (carriage return - line feed pair). Spare fields are not currently used by the CASI software and are reserved for future expansion and enhancement.

The arrangement of items in the data file is as follows:

Data File Header	Length
Date of DATA SCAN (file creation date)	10
Time of DATA SCAN (file creation time)	8
1st comment	up to 78
2nd comment	up to 78
3rd comment	up to 78
4th comment	up to 78
5th comment	up to 78
Spare field - not used yet	0 [1]
Signature file name	12
Incident angle in degrees	number
Wavelength in micrometers	number
Sample type [S]ignature, [T]ransmissive, [R]eflective	1
Specular Transmittance or Reflectance	number
Direction of sweep [+], [-]	1
Total signal amplitude in watts	number
X position of spot from sample center in millimeters	number
Y position of spot from sample center in millimeters	number
Alpha angle of sample in degrees	number
Spare field - not used yet	0
Spare field - not used yet	0
Start angle in degrees	number
Stop angle in degrees	number
Aperture type [C]ircular, [S]lit	1
Index of refraction of sample	number
Kappa or n*Kappa of sample	number
Number of files averaged in this file	number
Beam spot size on sample in millimeters	number
Tilt angle of sample in degrees	number
Spare field - not used yet	0
Spare field - not used yet	0
Signature Total Signal	0
Number of data blocks to follow	number

1st Data Block Header	
Aperture size in microns	number
Sweep radius (sample to receiver) in centimeters	number
Step angle between data points in degrees	number
Amplifier gain	number
Spare field - not used yet	number
Gain factor (not presently used)	number
Filter neutral density number	number
Spare field - not used yet	number
Spare field - not used yet	number
Number of data points following in this block	number

Data Points	
1st data point value	number
2nd data point value	number
.	number
. (Repeated for the number	.
. of points defined	.
in block header)	.

. .
Nth data point value number

Subsequent data blocks
Consisting of data block header and data points as described above.

Definitions of Data File Fields

Date:

This is the date the file was generated and is in the form: mm-dd-yyyy. This is descriptive information and is not presently used in calculations by the CASI software.

Time:

This is the time the file was created and is in the form: hh: mm: ss. This is descriptive information and is not presently used in calculations by the CASI software.

Comment 1 to 5:

Five lines of descriptive comments. Not presently used in calculations by the CASI software.

Signature file name:

This is the name of the signature file with which the data file is linked. This signature file is used in the ANALYZE routines to calculate BSDF of the sample, absolute scatter, and the PSD for sample data. The information is used for calculations by the CASI software.

Incident angle in degrees:

The angle at which the incident beam strikes the sample as measured from sample normal in the sweep plane of the receiver. The range is from 0° to 90°. This information is used for calculations by the CASI software.

Wavelength in micro meters:

This specifies the wavelength of the source used to illuminate the sample. This value is use for PSD and CTIS calculations in the CASI software. This information is used for calculations by the CASI software.

Sample type [S]ignature, [T]ransmissive, [R]eflective:

This field describes the type of sample that was measured. The letter S, T or R is used here. The field is case sensitive and must be capitalized. The information is used for calculations by the CASI software.

Specular Transmittance or Reflectance:
This field contains the specular reflectance or transmittance of a sample.

Direction of sweep [+], [-]:

This field defines the sweep direction in which the data was taken. Reference is from above the receiver sweep plane, and positive (+) is counterclockwise and negative (-) is clockwise. Typically + sweeps are for signature scans and transmissive samples and - sweeps are for reflective samples. The sweep direction for reflective samples must be opposite that for a signature scan, while transmissive samples must be swept the same direction as the signature scan if the signature scan and sample scan are to be compared. This information is used for calculations by the CASI software.

Total signal amplitude in watts:

The total specular signal is measured at the receiver with the sample in place. The signature is scaled by this value when sample data are compared to signature data. This value is used as the total incident power for samples if this is a signature file. The information is used for calculations by the CASI software.

X position of spot from sample center in millimeters:

This is the X position on the sample of the illuminated spot relative to the defined reference center of sample. A right hand, sample based coordinate system is used with respect to the incident beam. This is descriptive information and is not presently used in calculations by the CASI software.

Y position of spot from sample center in millimeters:

This is the Y position on the sample of the illuminated spot relative to the defined reference center of sample. A right hand, sample based coordinate system is used with respect to the incident beam. This is descriptive information and is not presently used in calculations by the CASI software.

Alpha angle of sample in degrees:

This is the sample rotation angle about the incident beam. This is descriptive information and is not presently used in calculations by the CASI software.

Start angle in degrees:

This is the angle from specular at which the scan starts. If it is negative and the stop angle is positive, the sweep will be through the specular beam regardless of sweep direction. This information is used for calculations by the CASI software.

Stop angle in degrees:

This is the angle from specular where the scan will stop. This information is used for calculations by the CASI software.

Aperture type [C]ircular, [S]lit:

This field must be a capital S or C to designate the receiver aperture type. This information is used for calculations by the CASI software.

Index of refraction:

The index (n) for transmissive samples. This is descriptive information and is not presently used in calculations by the CASI software.

Kappa or n*Kappa:

Used to indicate the imaginary part of the index of refraction of the sample. This is descriptive information and is not presently used in calculations by the CASI software.

Number of files averaged in this file:

Used if the data represents the average of more than one data file. This information is used for calculations by the CASI software.

Beam spot size on sample in millimeters:

The diameter (e^{-2}) of the incident beam at the sample. This is descriptive information and is not presently used in calculations by the CASI software.

Tilt angle of sample in degrees:

The angle of the sample normal with respect to the receiver sweep plane. The angle represents sample rotation about the Sample X axis. This is descriptive information and is not presently used in calculations by the CASI software.

Signature Total Signal (watts):

The total signal of the signature file to which the data file is linked. This is the total incident power. This is descriptive information and is not presently used in calculations by the CASI software.

Aperture size in μm:

This is the diameter (circular apertures) or width (slit apertures) of the aperture in μm for all the data points in the current block. This information is used for calculations by the CASI software.

Sweep radius (sample to receiver) in centimeters:

The sweep radius is the distance from the center of rotation of the receiver arm (sample surface) to the receiver aperture for all the data points in a block. This value is used along with the receiver aperture size to calculate the solid angle of the receiver for BSDF calculations. This information is used for calculations by the CASI software.

Step angle between data points in degrees:

For a given block the angular step between points must be the same. As a guideline, a step size of ¼ to ½ of the angle subtended by the aperture diameter works well. This information is used for calculations by the CASI software.

Amplifier gain:

This value is a multiplying factor of the raw data values. When BSDF is calculated from the raw data, the raw data is divided by this number. This information is used for calculations by the CASI software.

Filter neutral density number:

This is a dividing factor of the raw data values. When BSDF is calculated from the raw data, the raw data is multiplied by 10 raised to this power. This information is used for calculations by the CASI software.

Number of data points following in this block:

Number of raw data points that follow in the block. This information is used for calculations by the CASI software.

Calculations of BSDF using Data File Parameters

$$BSDF = \frac{P_s}{P_i \, \omega_r \cos(\theta_s)}$$

Where:

P_s = ((Raw Data) 10^F)/Gain

F = Filter neutral density number

Gain = Amplifier gain to convert raw data into watts

Raw data = Data point value

P_i = Total signal amplitude in watts from the signature data file.

w_r = ((da/(R*2000))²)*π receiver solid angle for circular apertures

w_r = da/(R*1000) receiver solid angle for slit apertures

da = Aperture size (diameter or width in μm)

R = Sweep radius (cm)

θ_s = θ - (Sweep direction) θ_i for Reflective samples

θ_s = θ + (Sweep direction) θ_i for Transmissive samples

$\theta_s = \theta$ for signatures

θ = Angle from specular, equal to the start angle plus all the accumulated steps.