SPATIAL UNIFORMITY OF
OPTICAL DETECTOR RESPONSIVITY

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Abstract: A scanning system for measuring the spatial uniformity of the responsivity of optical detectors and methods of quantifying the degree of uniformity are described. Surface plots and contour maps of the measured responsivity are presented along with a statistical treatment. Factors which can affect the accuracy of the uniformity measurement are described, including sampling theorem restrictions and interference artifacts produced when coherent light is used. Examples of these artifacts are presented along with scans of actual Si, Ge, and InGaAs detectors.

INTRODUCTION

At NIST the uniformity measurement system has been very useful in determining whether calibration problems are caused by detector uniformity. Nonuniform detectors give different results depending on the intensity profile of the beam and where the beam strikes the detector. Calibrating a nonuniform detector or using it to measure the power in a beam can be difficult because the detector's responsivity can change whenever the detector is aligned. The responsivity can also change with time if the beam parameters change. The system is helpful in determining which detectors are suitable for use as transfer standards: a detector with poor uniformity would not make a good standard.

THE MEASUREMENT SYSTEM

A detector uniformity measurement system was originally developed at NIST for the United States Air Force. The original measurement system[1] was developed by A. L. Rasmussen. We later modified the system and presented it at the 1992 Measurement Science Conference.[2] New findings not presented at the earlier conference are included here.

The modified system, shown in Figure 1, is simpler and more accurate than the original design. The system directly measures the responsivity of the detector at each sample point by measuring the detector's output when illuminated by a stable beam. Unlike the original system, the modified system uses a laser diode or LED optical source mounted directly to the translation stages. These sources are more stable than the gas lasers used in the original system. The detector being tested remains stationary in the modified system. High quality amplifiers and

A – Control Computer   B – Motion Controller
C – Digital Voltmeter   D – Spotsize Detector
E – X- and Y-Axis Positioning Stages
F – Optical Source Plate with Monitor Detector
G – Motion Controller Joystick   H – Laser Diode Power Supply
I – Monitor Detector Temperature Regulator
J – Transconductance Amplifiers for Detectors
K – Amplifier Power Supply
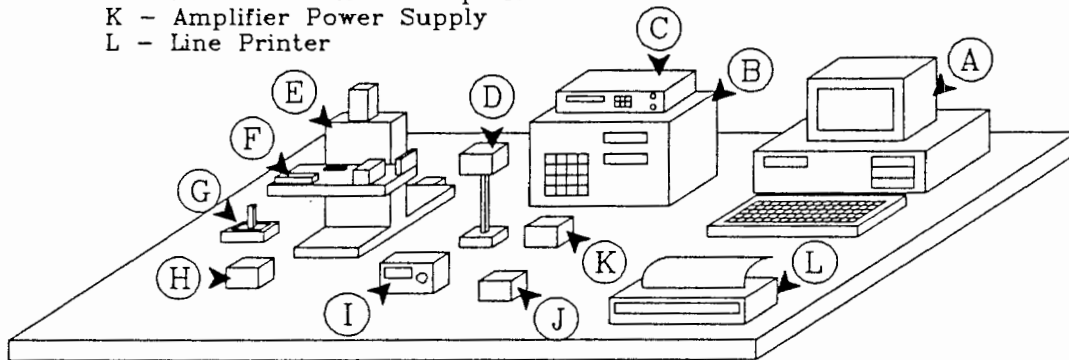L – Line Printer

Figure 1. Main components of the uniformity measurement system.

voltmeters are used to accurately measure the detector's responsivity, and sophisticated computer software controls the scan and processes the results.

The measurement system nominally requires an analog voltage output from the test detector, but detectors with a digital output can be scanned with the help of a second computer. The second computer reads the digital output and converts it to an analog voltage using a digital-to-analog converter. A monitor detector is used to correct for power fluctuations during the scan, but the absolute beam power is not measured so the system cannot be used to calibrate a detector's responsivity absolutely. The system can only measure relative changes in responsivity.

The system's software can automatically locate the detector's center and can integrate and average multiple scans to reduce noise. Uniformity measurements are typically reproducible to 1 or 2 tenths of 1 percent. The system can run for hours or days without operator intervention. Scanning large detectors with a small source beam can take hours, and averaging multiple scans can take days. The resulting scan can be presented in a variety of formats including contour maps and surface plots, and a statistical analysis is available to quantify the degree of uniformity.
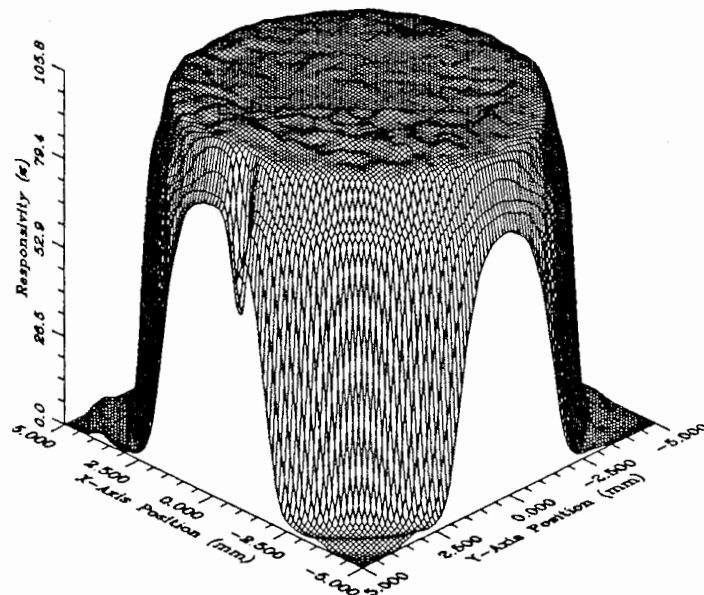
Figure 2. Overall view of a germanium detector.

To simplify interpretation of the results, the scan data are usually scaled before viewing. Typically the lowest point is scaled to 0, and the average of the points in the detector's center is scaled to 100 %. Four views of the detector's uniformity are commonly used, a scan of a good germanium detector is used as an example in Figures 2 to 5. Figure 2 shows the overall view of the detector; it is the easiest to interpret. This view gives a good qualitative measure of the uniformity; if features in the detector's active area are visible in this view they must be significant (greater than 1 percent). In this example, small features are visible so the detector is clearly not perfect.
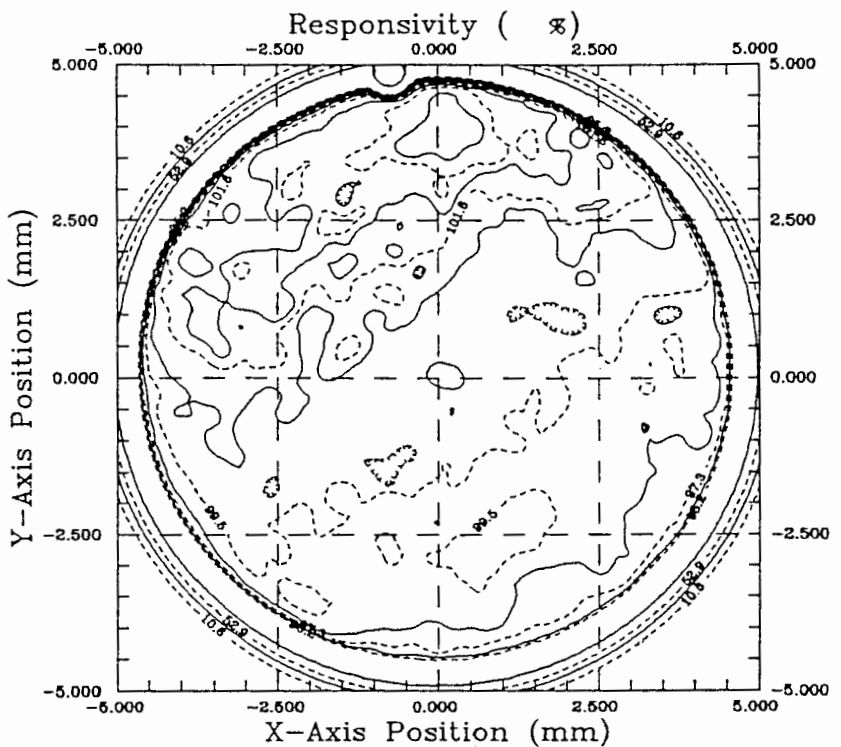

Figure 3. Contour map of germanium detector, 1 % contour line spacing.

Figure 3 shows a contour map of the detector's uniformity, contours in the active portion of the detector are spaced closer together for clarity. This view can be used to obtain more quantitative information. The actual size of the features can be estimated by counting the number of contour lines and multiplying by the contour spacing. In this example, when moving from the center to the top of the feature at (x,y) = (0,4) mm, 5 contour increases and 1 contour decrease are crossed so the responsivity at the top of the feature is 4 % higher than the responsivity in the center. Contour lines with hachures, like the line around the feature at (x,y) = (2,1) mm, represent a depression as opposed to a hill. Labeled contours are drawn with a dashed line.
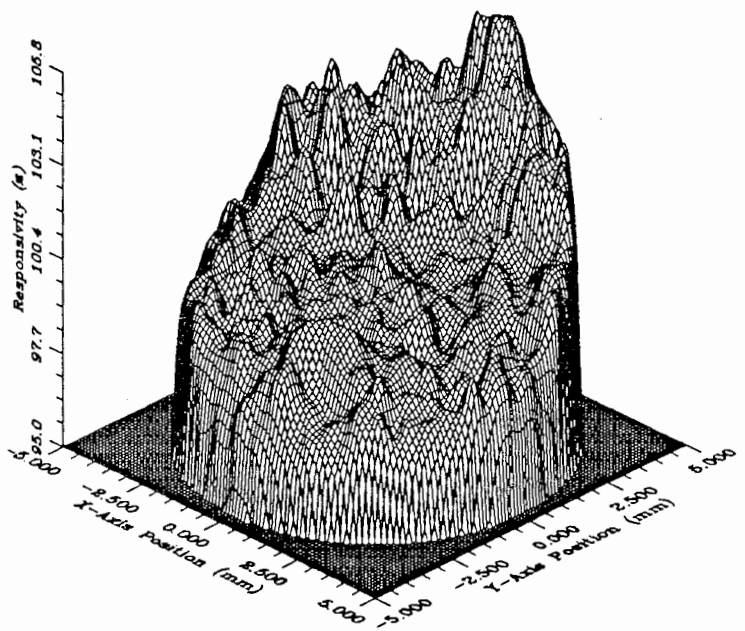

Figure 4. Germanium detector responsivity over 95 %.

Figure 4 shows the detector's uniformity in greater detail than in the overall view. The increased detail is obtained by raising the baseline of the surface plot, to 95 % in this case. The viewing angle was also changed to give a better view of the features. Figure 5 shows the uniformity around the detector's center in the greatest detail. It is obtained by zooming into the detector's central area. In the remainder of this document only a few of the views will be presented, and statistical processing will be described later.
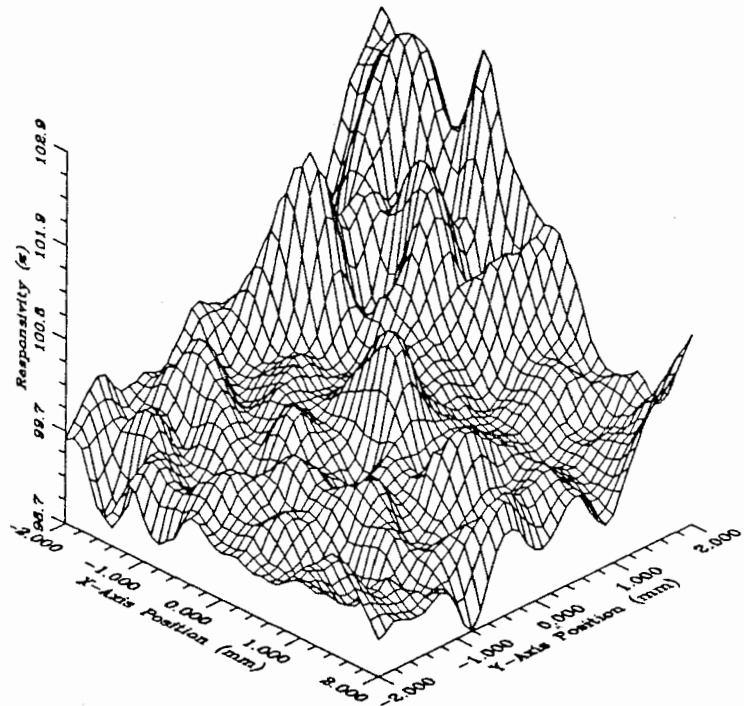
OBTAINING AN ACCURATE RESPONSIVITY SCAN

Obtaining an accurate responsivity scan is not trivial. The system is capable of sampling the responsivity accurately, but in certain circumstances an erroneous model of the actual uniformity can result. There are two main problems, measurement system errors and aliasing in the sampled data.

Figure 5. Area around the germanium detector's center.

Measurement System Errors - Two main sources of error in the measurement system can degrade the accuracy of the responsivity scan. Noise in the detector and measurement system is one obvious source. This source of error is reduced by using proper amplification and integrating the detector's output with the digital voltmeter. The voltmeter used with the system can integrate for 1, 10, or 100 power line cycles (16.7 ms, 167 ms, or 1.67 s). The longer integration times are useful with noisy signals. The integration essentially provides a low-pass filter that reduces noise.

Temporal variations in the power, wavelength, or polarization of the optical source can also cause error in the responsivity scan. The system uses a power fluctuation correction algorithm which compensates for such variations, with a few caveats. The optical sources used incorporate a beam splitter and power monitor. Ideally if the power received by the monitor changes, the power transmitted to the test detector also changes by the same amount. The test detector's output can therefore be corrected for the power change. The main problem with this technique is that the beam splitter ratio is not entirely stable. A fused-fiber coupler is used as a beam splitter. The coupler and the beam collimator contribute to the instability.

Plate Identifier: LD-1320-1 314 µW
Plate Wavelength: 1320 nm
Spotsize (x,y): (0.450, 0.447) mm
Spotsize Measured at a Distance of: 15 mm
Beamsplitter Ratio: 0.884
Beamsplitter Ratio Standard Deviation: 0.029 %
Beamsplitter Ratio Spread: 0.125 %
Ratio Last Measured On: 07-21-1993

Box 1. Example optical source information.

Wavelength and polarization changes can also cause the ratio to change.

To estimate the error caused by the variation of the beam splitter ratio, two parameters are stored with each scan. The stability of the beam splitter ratio is measured before the scan. The results are stored with the optical source information, as illustrated by the list shown in Box 1. The ratio is measured for a period of an hour, and the standard deviation and peak-to-peak spread are stored. The spread is a worst case measurement: the fluctuation is not usually random so the spread is typically much larger than the standard deviation. Some sources are much more stable than others but the source used in the example is typical.

The standard deviation of the monitor readings is measured during the actual scan. This number contains both the actual power fluctuations and the beam splitter ratio drift encountered. This figure is provided on the run information list, as shown in Box 2. These two errors combine in some fashion to add to the uncertainty in the responsivity scan. Additional errors can occur if the test detector is not the same type as the monitor detector because dissimilar detectors can respond to wavelength, polarization, and temperature changes differently.

Plot Title: none
Acquired 12-09-1992 at 14:14:03
Saved File: temp.
Amp. Gain: 100000
Detector Identifier:
    Ge Detector Example
Optical Source: 845 nm
    LD-845-1 190 uW
Spot Size: 0.562 X 0.558 mm
Sample Spacing: 0.10000 mm
Samples Taken: 101 X 101
Monitor Deviation: 0.031 %
Power Fluctuations Corrected
Background Level Subtracted
Measurement Delay: 0.320 s
Plot Rotation: 135 degrees
Plot Tilt: 30 degrees
DVM Integration: 167 ms
Ref Orient Win. Rot. Tilted 5 deg

Box 2. Example run information list.

These errors are not effectively reduced by the voltmeter integration because the drift usually occurs relatively slowly. They can, however, usually be reduced by averaging multiple scans. To perform this averaging, the system acquires multiple scans over exactly the same area of the detector, then averages the results. The scans are usually acquired hours apart. If the fluctuations are random over this time scale the averaging will be effective at reducing the fluctuations. This technique can also reduce the effect of slow drift in the power and detector responsivity, and is effective at reducing detector noise.

Aliasing Distortion - Distortion can also result if the spacing between detector responsivity samples is too large. The data acquired by the measurement system is a discretely spaced sampling and is subject to sampling theorem limitations. If the sampling rate is too low, the signal is undersampled and aliasing can occur.[3] The sampling theorem states that to exactly represent a signal with a uniformly spaced sampled data set, the sampling must be performed at a frequency sufficiently greater than the highest frequency present in the signal. Specifically the signal must be uniformly sampled at or above the Nyquist rate of $2f_h$, where the signal has no frequency components at or above f_h.[4] Here the signal is the detector's responsivity as a function of position, the frequencies are spatial but the sampling theorem still applies.

Two factors determine whether the sampled data is a complete representation of the detector's responsivity: the spatial frequencies in the responsivity and the sample spacing. The detector's responsivity recorded for each sample point is not the actual responsivity at an exact point on the detector; it is the convolution of the beam's intensity profile and the detector's true responsivity.

A Gaussian beam actually provides a spatial low-pass filtering of the detector's responsivity and thus limits the spatial frequency range present in the measured responsivity (for the given beam diameter). Since the beam limits the spatial frequency present, choosing a sufficiently small sample spacing for the beam is the only requirement for preventing aliasing.

The maximum sample spacing that should be used with a Gaussian beam of given diameter can be determined experimentally. The system uses a beam diameter defined as the distance between the points where the intensity drops off to $1/e^2$ of its maximum. If too large a sample spacing is used, the true responsivity can be aliased. An example of such aliasing is shown in

Figure 6. Oversampled scan of a nonuniform detector.

Figures 6 to 10. Figure 6 shows the center portion of a scan from a detector which has parallel ridges in its uniformity. The sample spacing used in the scan is 11.2 times smaller than the $1/e^2$ beam diameter, so the responsivity is oversampled and is an accurate representation of the actual responsivity within the bandwidth of the scanning beam. Samples were removed from this dataset in the later figures to show what would have happened if a larger sample spacing had been used.
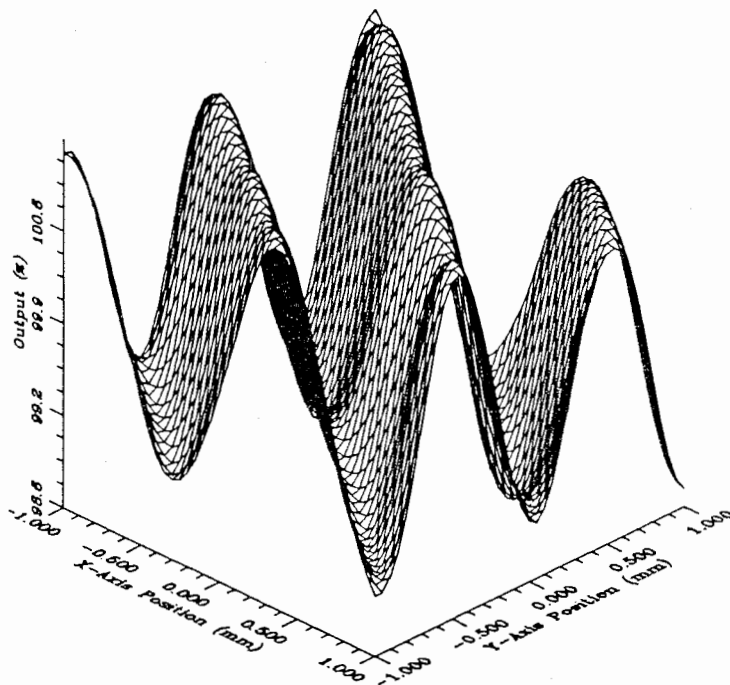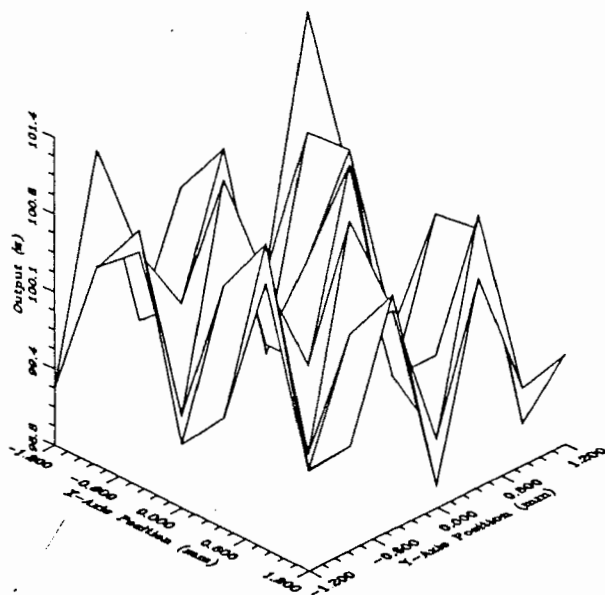
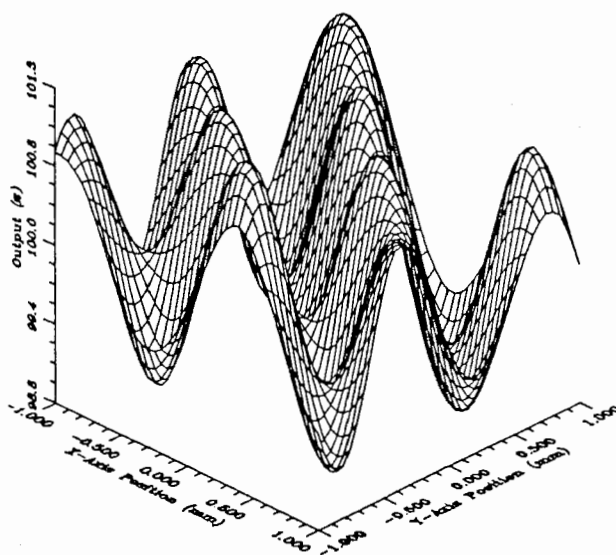Figure 7. Marginally sampled scan with beam size to sample spacing ratio of 1.4.

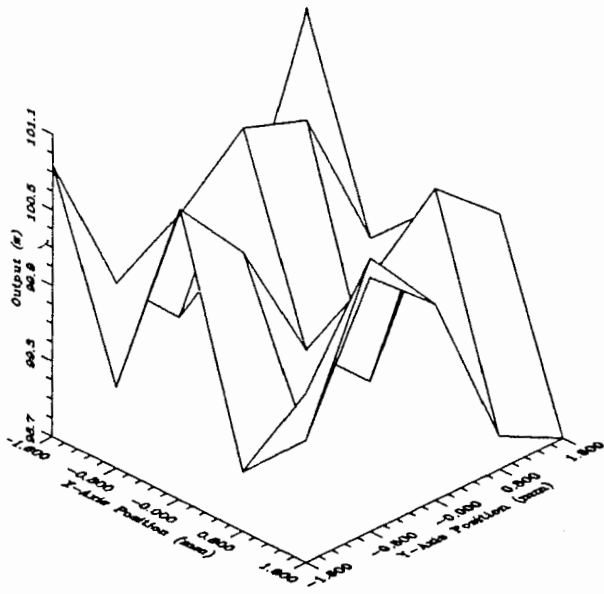Figure 8. Marginally sampled scan after spline interpolation.

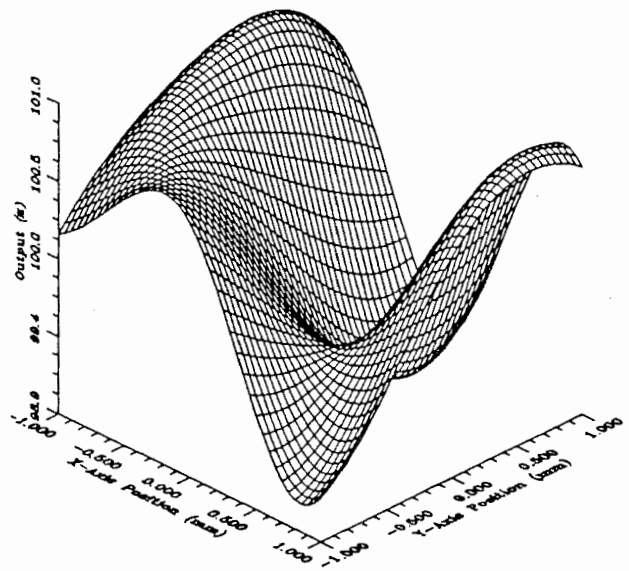Figure 9. Undersampled scan with beam size to sample spacing ratio of 0.7.

Figure 10. Undersampled scan after spline interpolation.

Figure 7 shows how the uniformity would have looked if a sample spacing 1.4 times smaller than the beam diameter was used. This figure bears little resemblance to that in Figure 6, but actually contains almost the same information. When the data in Figure 7 are expanded using spline interpolation, the uniformity shown in Figure 8 results. The expanded data are almost identical to the oversampled data, but some aliasing distortion is present in the form of bumps on the ridges and a slight change in amplitude. Figure 9 shows how the uniformity would have looked if a sample spacing 0.7 times smaller than the beam diameter was used. This figure does not look much worse than that in Figure 7, but when it is expanded by spline interpolation the uniformity shown in Figure 10 results. Figure 10 bears no resemblance to the oversampled scan shown in Figure 6 because the uniformity was aliased. The sample spacing of 0.7 times smaller than the beam diameter is therefore too large.

Since slight aliasing is evident when a sample spacing 1.4 times smaller than the beam diameter is used, the maximum sample spacing to prevent aliasing must be slightly smaller. The actual maximum sample spacing can be different for beams with a different profile than the one used here; for example, a beam with more of its power in the center would require an even smaller sample spacing. So it is advisable to use maximum sample spacing of one-half the $1/e^2$ beam diameter.

One final sampling theorem requirement remains. The sampling theorem states that to reconstruct the continuous signal from the sampled data, the sampling frequency must be filtered out.[5] The measurement system relies mainly on the operator's eye to filter out the sample frequency; the more the uniformity is oversampled the easier is the filtering. This is why the surface shown in Figures 7 looks so irregular. Adding lines to the surface with spline interpolation or oversampling by using a smaller sample spacing results in a surface that is much easier to interpret. Using a sample spacing one-quarter times the beam diameter usually oversamples the responsivity enough to produce a smooth, easy to interpret surface without spline interpolation.

INTERFERENCE ARTIFACTS

Interference is a common problem whenever coherent light is used. When an element of the detector causes multiple reflections or etalon effects, interference artifacts may appear on the responsivity scan when coherent light is used. These artifacts are usually unstable; they can change location or shape when a slight change is made to the detector's alignment and are wavelength dependent. A detector which exhibits these artifacts probably should not be used with laser sources because the interference can cause significant changes in the detector's calibration factor. A 4 % change in responsivity due to interference is not uncommon. Interference artifacts are frequently caused by the detector's window.
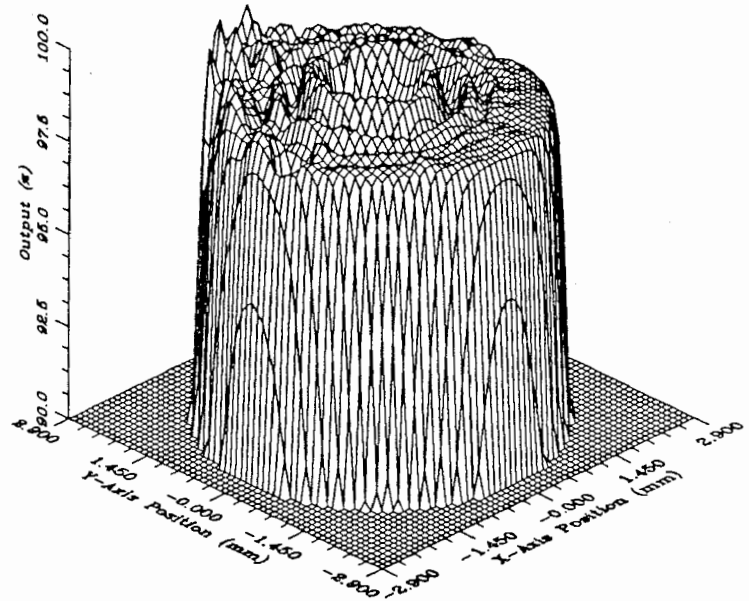

Figure 11. Detector with interference ring artifact.

Identifying interference artifacts is usually a simple task. If a suspicious feature is seen in a responsivity scan, simply tilt the detector a few degrees relative to the illuminating beam and perform another scan. If the feature moves or changes shape, it is probably caused by interference. If the feature stays the same, it may still be caused by interference; try tilting the detector the other direction or rotating it around the propagation axis of the beam. If the detector is rotated, a real feature will move with the rotation. Otherwise, it is probably an interference artifact. Scanning the detector with a less coherent LED source of the same wavelength also identifies interference artifacts: interference artifacts usually disappear when a LED is used. Scanning the detector with a slightly different wavelength of light should change the appearance of any interference artifacts, but a large change in wavelength can also cause real features of the uniformity to change.

<u>Interference Rings</u> - One detector, shown in Figure 11, exhibited interference rings. The poorly defined rings were concentric with the detector's center. Their position shifted slightly when the detector was tilted, and the ring
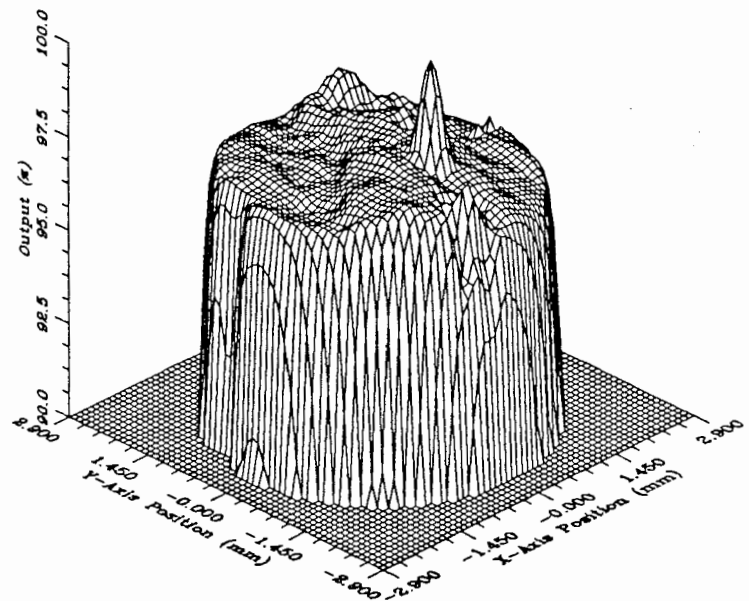

Figure 12. Detector with a point interference artifact.

spacing was a function of wavelength. This artifact is rare. It could have been caused by a curved window or etalon caused by reflections between the detector and the collimating lens.

Point Interference - This is probably the most common interference artifact seen. The artifact is called point interference because it usually occurs in only one area of the detector. It can be caused by parallel surfaces that occur at only one point in space. For example, if a detector's window is rounded it will be parallel to the detector's surface at only one point.

Figure 13. Detector with a point interference artifact when tilted.

Point interference artifacts are easily identified. A slight change in detector tilt angle usually causes the artifact to change dramatically. It typically changes position and magnitude and sometimes even sign. Figures 12 and 13 show such an artifact. The large peak near the center of the detector in Figure 12 is due to point interference. Tilting the detector several degrees caused the artifact to change from the peak shown in Figure 12 to a deep hole in Figure 13. This type of artifact is usually caused by a detector's window.

Interference Fringes - Interference fringes are a fairly common artifact. The detector used in the aliasing example, shown in Figures 6 through 10, has interference fringe artifacts. The fringes form parallel ridges in the uniformity. The detector is presented again as a contour map in Figure 14, the fringe spacing of 0.78 mm is easily obtained from the map.
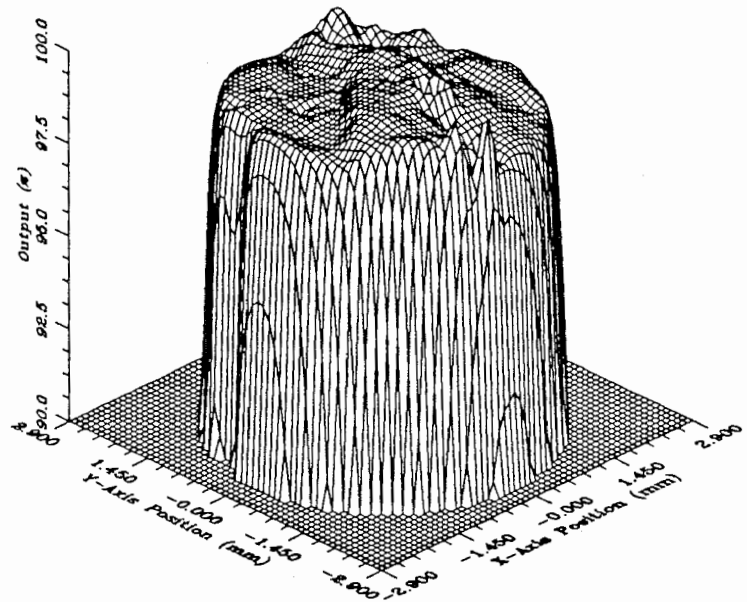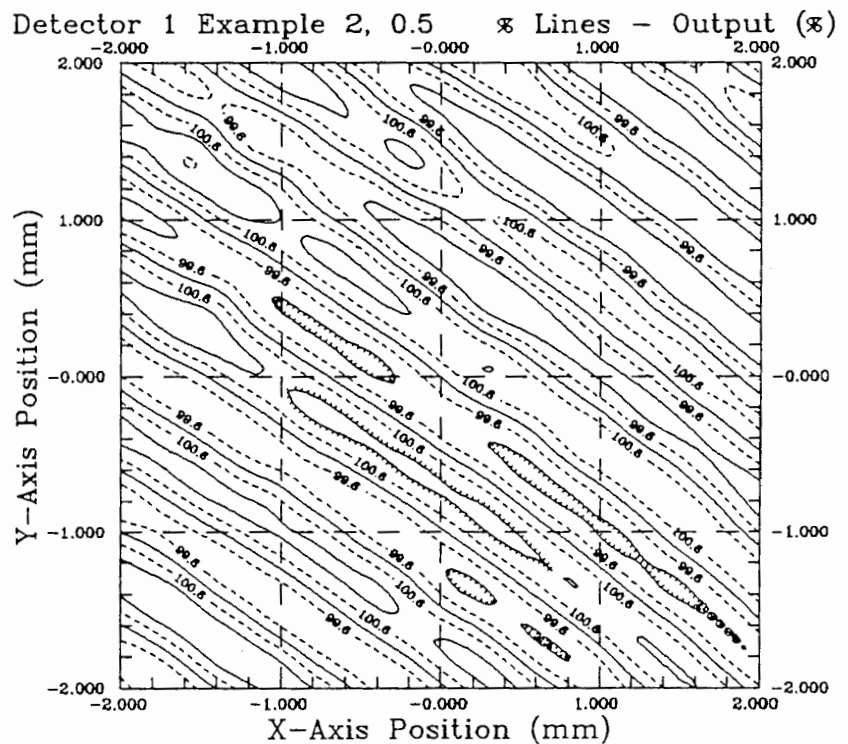

Figure 14. Detector with interference fringe artifact, 1320 nm source.

Interference fringes can be caused by a detector's window being flat or only slightly wedged. Wedged windows are usually a good idea because the wedge helps prevent the other kinds of interference from occurring. But if the wedge angle is too small, interference fringes can be produced. The following equation defines the effect:

$$\theta = \lambda/2nd.$$

The equation relates the window's wedge angle θ to the distance between fringes d. The window's index of refraction n and the wavelength of the source λ are also used in the equation. If the index of refraction is 1.5, the wedge angle is 0.032°. Scanning the detector with a 1557 nm source resulted in

Figure 15. Detector with reflection artifact.

similar fringes and gave the same wedge angle. The fringes were too close together to be resolved in a 845 nm scan. This wedge angle is slight indeed!
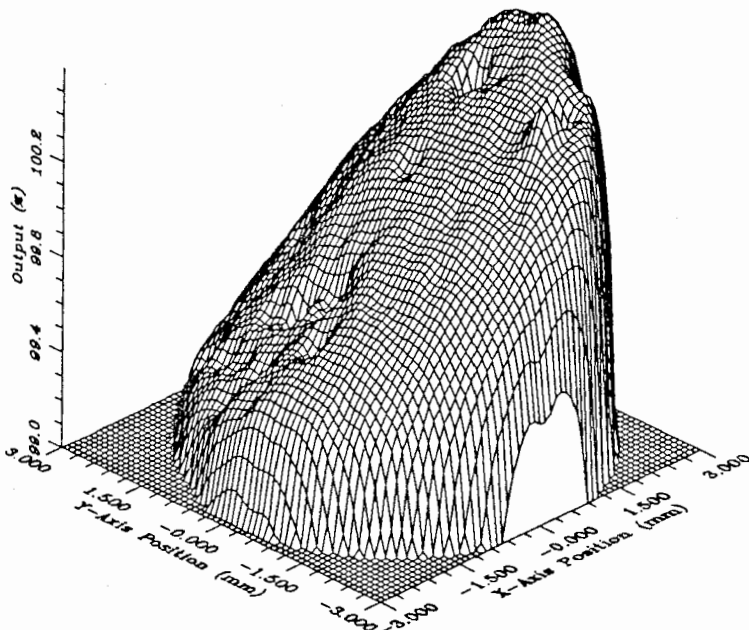
REFLECTION ARTIFACTS

If a detector is aligned exactly perpendicular to the optical beam, any reflection from the detector can re-enter the optical system or reflect off the optics back to the detector. The reflection usually superimposes a slope on the uniformity, like that shown in Figure 15. When the detector was tilted with respect to the beam, the slope completely disappeared revealing the uniformity shown in Figure 16. This artifact is not caused by interference, but can be identified by tilting the detector. It can occur with incoherent sources. Note the greatly improved uniformity in Figure 16, and the appearance of what may be a point interference artifact near the edge of the detector.
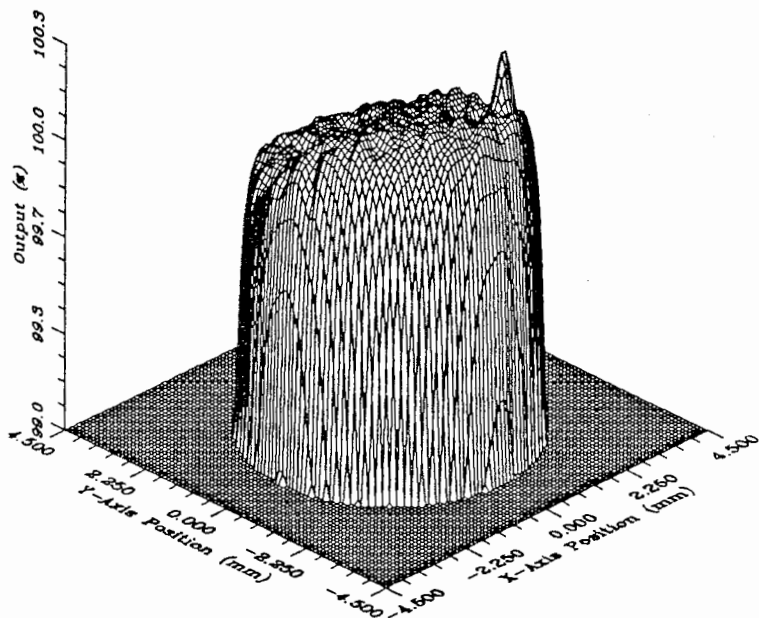
This effect is believed to be caused primarily by the reflection bouncing

Figure 16. Detector with reflection artifact when tilted.

back to the detector, but if the beam re-enters the optical source interference effects may be generated in laser diodes too. This effect can be avoided by aligning the detector at a tilt so that the reflection strikes the collimator's aperture stop.

TEMPORAL DRIFT ARTIFACTS

Here the term temporal drift refers to an apparent fluctuation in the detector's responsivity with time. If the fluctuations are random and fast compared to the voltmeter's integration time, they can be reduced by integration and averaging just like noise. Fast temporal drift artifacts are caused by fluctuations that occur less frequently but cause a rapid change. Fast temporal drift is commonly manifested as large noise spikes in the uniformity. It usually occurs only with fast detectors, such as the monitor.

Whenever a responsivity sample is taken, the monitor detector's output is measured immediately before the test detector's. Thus, there is a time delay between the two measurements. If a change in power level occurs between measurements, the power fluctuation correction algorithm (described earlier) will fail for the current sample. This type of failure results in a single noise spike. Similar in appearance to actual detector noise, fast temporal drift can be reduced only by averaging. Integration probably will not help in this case.

Slow temporal drift is more bothersome. If the drift occurs slowly relative to the sampling rate, slow temporal drift artifacts can occur. Slow drift can come from a number of different sources. For
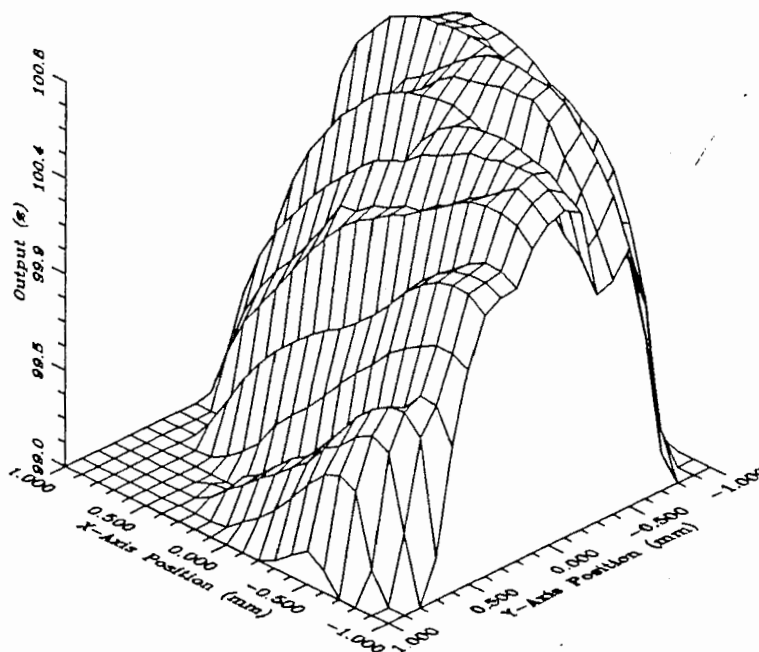

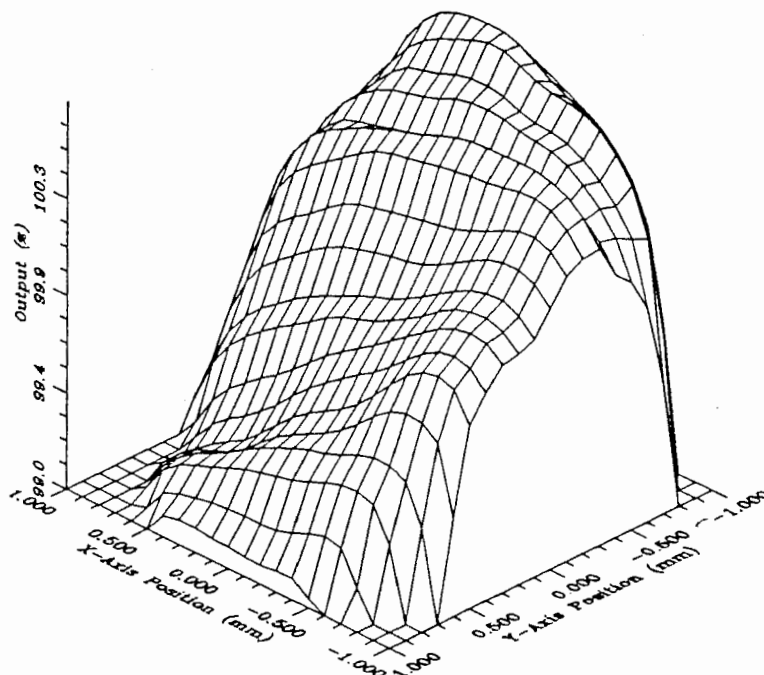Figure 17. Detector with slow temporal drift artifacts.

Figure 18. 16 run average of detector with slow temporal drift.

example, drift can be caused by a slow change in the environment such as a temperature drift, or a slow change in the optical source. Drift in some of the source parameters is reduced by the power fluctuation correction algorithm.

Slow temporal drift artifacts occur when the drift: is in the beam splitter ratio, is a wavelength change which is not tracked in the same way by the monitor and test detectors, or is caused by an actual responsivity change in a detector. When such drift occurs during a responsivity scan, it is manifested as ridges parallel to the x-axis with discontinuities along the y-axis. This artifact results because the system scans along the x-axis and shifts y-axis positions only at the end of each scan line.

Slow temporal drift artifacts occurred in the InGaAs detector scan shown in Figure 17. The drift was apparently caused by wavelength changes in the source which were not tracked identically by the germanium monitor and InGaAs test detector. Using an identical InGaAs monitor may have prevented the drift. The optical source used in the scan has a tendency to mode-hop, causing the changes in wavelength. The slow temporal drift artifacts can be reduced by averaging, if the drift averages to zero in the time required to make a scan. Figure 18 shows the same detector after a 16 scan average. The magnitude of the drift artifacts is ideally reduced by a factor of 4, and the resulting scan is much smoother and more accurate.

While there is a striking similarity between Figures 15 and 17, the two surfaces are created by entirely different phenomenon. The sloping uniformity in Figure 15 is entirely the result of a reflection artifact, while the sloping uniformity of the InGaAs detector in Figures 16 and 17 is a true feature of the detector. InGaAs detectors are notorious for their poor uniformity.

UNUSUAL DETECTORS

Some detectors cause special problems. Detectors needing chopped inputs can be scanned by the system, but the chopper wheel must be fixed in relation to the optical source or distortion similar to the reflection artifact can occur. The chopper wheel must move with the optical source for an accurate scan. Autoranging detectors cause problems for the centering algorithm. If autoranging cannot be turned off, it may be necessary to manually center the beam on the detector and scan only the area around its center. Detectors requiring a certain polarization can be scanned by attaching a polarizer to the optical source. However, the power fluctuation correction algorithm would not be effective in this case. Pulse detector uniformity cannot be measured by the system at this time.

QUANTIFYING DETECTOR UNIFORMITY

Two techniques for quantifying a detector's uniformity are proposed here. Poor uniformity can lead to two sources of error when a detector is calibrated or used to calibrate a beam. The first source is alignment error, and the second is beam diameter fluctuation. Both techniques are described here; the latter technique is, as far as we know, new.

Alignment Error - When an operator aligns a detector, the beam may not be placed perfectly in the detector's center. A method for quantifying the alignment error associated with centering, called misalignment statistics, has already been proposed.[2] Assuming the centering error can be limited to some distance, error statistics can be generated from the responsivity scan. For example, suppose that the operator can align the detector so that the beam's center is always placed within 1 mm of the detector's center. Then the responsivity results for all the points

within 1 mm of the detector's center can be used to generate uncertainty statistics. The scanning system software can find these points and generate a standard deviation and peak-to-peak spread for them. The resulting standard deviation is a measure of how much uncertainty is encountered when the scanning beam is randomly aligned within the given distance of the detector's center. The peak-to-peak result is a worst case measure. Applying the following technique allows misalignment statistics for beams larger than the original scanning beam to be derived.

Beam Diameter Fluctuation Error - This new technique allows the uniformity for beams larger than the original scanning beam to be estimated. Ideally the scan should be performed with a beam the same size and profile that will be used with the detector in practice. This is not always possible because the measurement system can produce only crude Gaussian beams with a limited range of sizes. So it is desirable to extrapolate the uniformity for other beam diameters and profiles from a scan made with the system's beam. It is also desirable to obtain a measure of how much the responsivity in the detector's center will change when the beam diameter fluctuates.

It is possible to obtain these results theoretically if the equivalent of an impulse response for the detector can be derived. Then an arbitrary beam's profile can be convolved with the impulse response to obtain the uniformity for the arbitrary beam. Or a transform from the source beam to the desired beam can be generated and used to calculate the desired uniformity. These calculations can be performed with Fourier transforms and deconvolution.[6] The scanning system's beam profile can be measured by placing a pinhole over a stable test detector. Unfortunately performing the required transforms has proven difficult and has not yet been completed. However a method which gives approximate results has been derived.

Responsivity scans are usually performed using the smallest beam available in the system. The scan made with the small beam can be used as an approximate impulse response for the detector in certain cases. If the uniformity for a beam much larger than the original small scanning beam is desired, using the small beam scan as the impulse response will be accurate. However it is not accurate for beams close to the size of the scanning beam or smaller. For these beams the technique will give overly optimistic results because the impulse response was not used.

Once the impulse response (or approximate impulse response) is found, determining the uniformity for a desired beam is simple. The desired beam's profile is convolved with the impulse response to obtain the uniformity for the desired beam. The results may not be scaled correctly. Beams which contain higher spatial frequencies than can be resolved by the sample grid will also give false results; this factor limits how small a beam can be used. In the following examples, synthetic Gaussian beams are used. Actual beam profiles could have been used just as easily.

```
Stats for Area, Radius:  1.00 mm
   Mean  =      100.000
   Std. Dev. =   0.289
   Std. Dev. =   0.289 %
   Maximum =   100.958
   Minimum =    99.436
   Spread =      1.522 %
   N =          317
```

Box 3. Misalignment statistics for example germanium detector.

```
Stats for Area, Radius:  1.00 mm
   Mean  =      100.000
   Std. Dev. =   0.241
   Std. Dev. =   0.241 %
   Maximum =   100.615
   Minimum =    99.612
   Spread =      1.004 %
   N =          317
```

Box 4. Misalignment statistics for germanium detector after synthetic 3 mm beam scan.

Example 1 - The responsivity scan for the germanium detector shown in Figures 2 to 5 is used in this example. The scan was acquired using a 0.56 mm beam. Box 3 lists the misalignment statistics for the area around the detector's center with a radius of 1 mm. These statistics are valid for the 0.56 mm beam used in the scan. The misalignment statistics show that if the beam is randomly placed within 1 mm of the center, the responsivity will vary with a standard deviation of 0.29 %, and can change a maximum of 1.5 %.
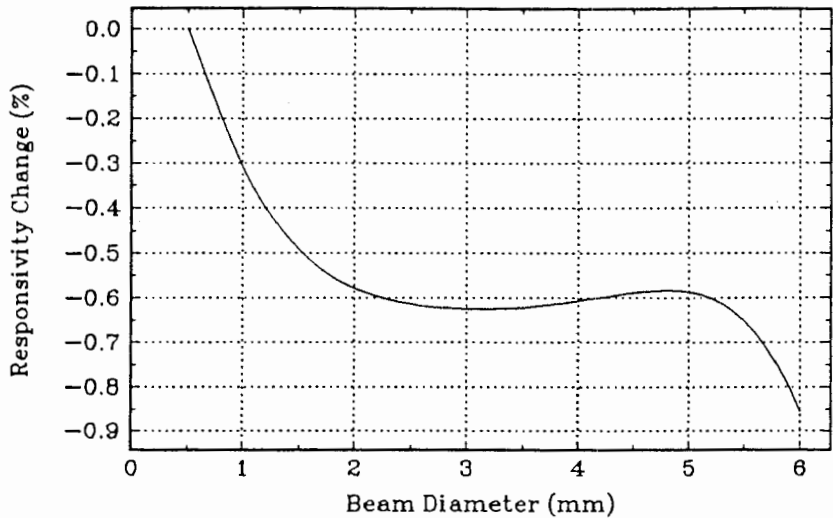

Figure 19. Responsivity variation with beam diameter for example germanium detector.

Figure 19 shows how the responsivity in the detector's center will change when the beam diameter is changed. The results for beam diameters near 0.5 mm are overly optimistic because the true impulse response was not used. Even with the optimistic results, the responsivity is very sensitive to beam diameter when small beams are used. The graph also shows that the responsivity is very consistent for beams 2 to 5 mm in diameter. If the responsivity change for these beam diameters is analyzed, the standard deviation is found to be only 0.016 % with a peak-to-peak spread of only 0.047 %. This result shows that this detector will work well with a 2 to 5 mm beam.

Figure 20 shows the detector's overall uniformity when synthetically scanned with a 3 mm Gaussian beam. The uniformity looks much better than in Figure 2, but looks can be deceiving. Box 4 lists the misalignment statistics for the 3 mm beam scan. The misalignment statistics are
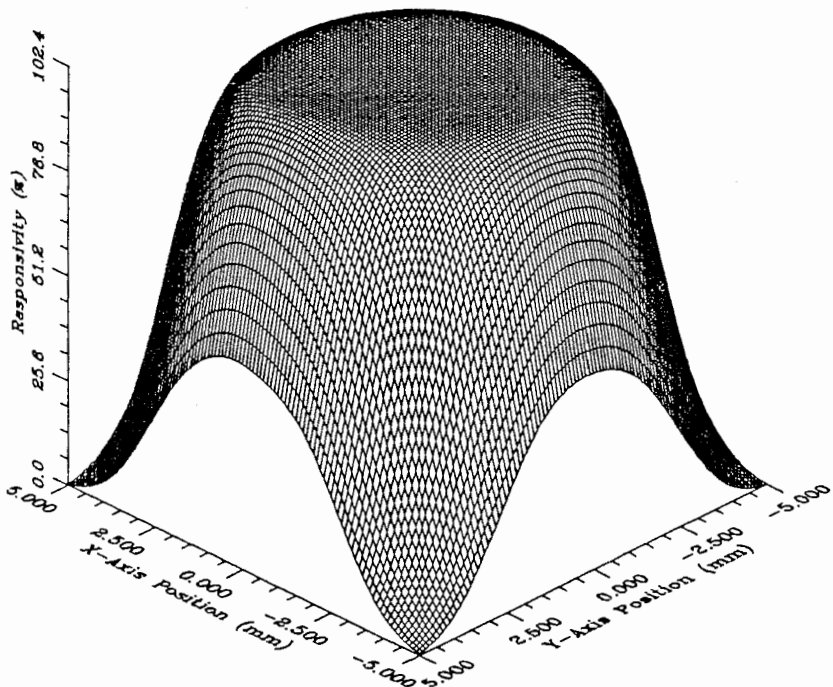

Figure 20. Germanium detector after synthetic 3 mm beam scan.

not much better than those for the original 0.56 mm beam.

Example 2 - Silicon detectors usually have very good uniformity; the detector shown in Figure 21 is an exception. Its extremely poor uniformity makes it a more interesting example. The detector was scanned with a 0.56 mm beam; misalignment statistics for the scan are listed in Box 5. The statistics for this scan are somewhat worse than those for the example germanium detector.
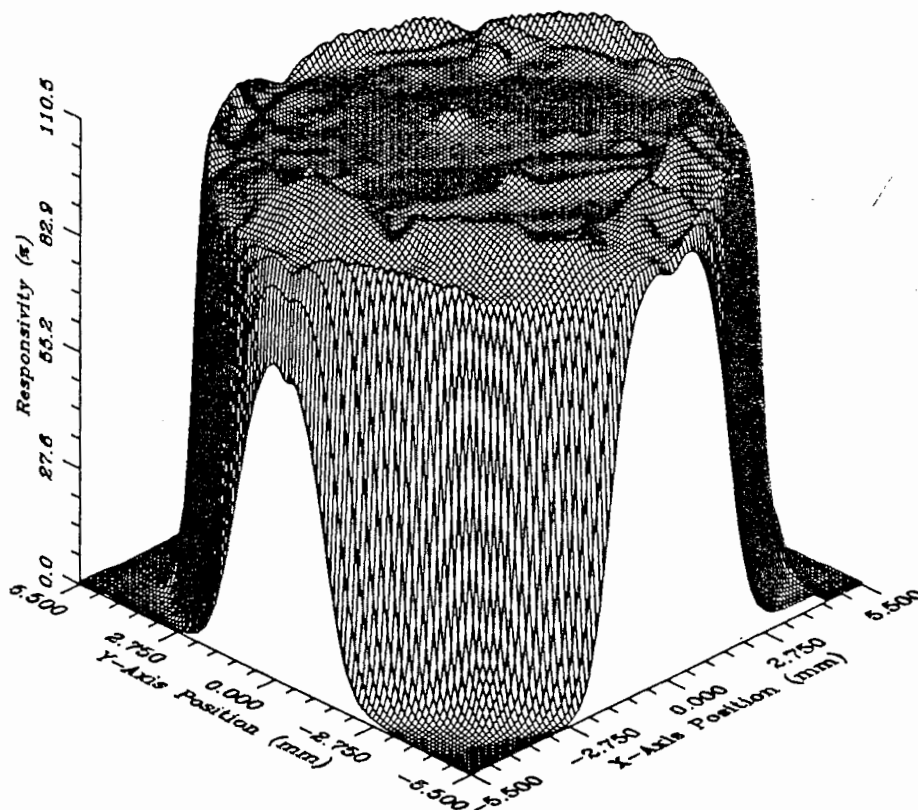

Figure 21. Overall view of example silicon detector.

After synthetically scanning the detector with a 4.5 mm beam, the misalignment statistics shown in Box 6 result. In this case, the misalignment statistics for the larger beam are significantly improved. The statistics for the large beam scan are even better than those obtained for the example germanium detector.

Figure 22 shows the responsivity variation with beam diameter for the silicon detector. The graph shows that the responsivity is fairly flat for 4 to 5 mm beams. Analyzing the data for these beam diameters results in a standard deviation of 0.04 % and a peak-to-peak spread of 0.12 %. These deviations are small, but much larger than that for the example germanium detector.

CONCLUSION

A uniformity measurement system was presented here. Artifacts

Stats for Area, Radius: 1.00 mm	
Mean =	100.000
Std. Dev. =	0.372
Std. Dev. =	0.372 %
Maximum =	101.185
Minimum =	99.327
Spread =	1.858 %
N =	317

Box 5. Misalignment statistics for example silicon detector.

Stats for Area, Radius: 1.00 mm	
Mean =	100.000
Std. Dev. =	0.169
Std. Dev. =	0.169 %
Maximum =	100.347
Minimum =	99.679
Spread =	0.667 %
N =	317

Box 6. Misalignment statistics for silicon detector after synthetic 4.5 mm beam scan.

typically encountered during uniformity measurement were described, and methods of identifying the artifacts were detailed. The procedures should help others acquire and analyze responsivity scans. The scans can help diagnose problems encountered in detector and beam calibrations.

Two methods for quantifying the degree of uniformity in a detector were proposed. We hope that these methods or some derivation of them will be developed by the measurement community.

Figure 22. Responsivity variation with beam diameter for example silicon detector.

Examples which show that significant error can be caused by detectors with poor uniformity were presented. Uniformity artifacts can also be significant, and their inconsistent nature is likely the cause of many measurement problems. Interference artifacts in particular are the source of many calibration problems at NIST. A proper treatment of these error sources could be a benefit to the entire measurement community.
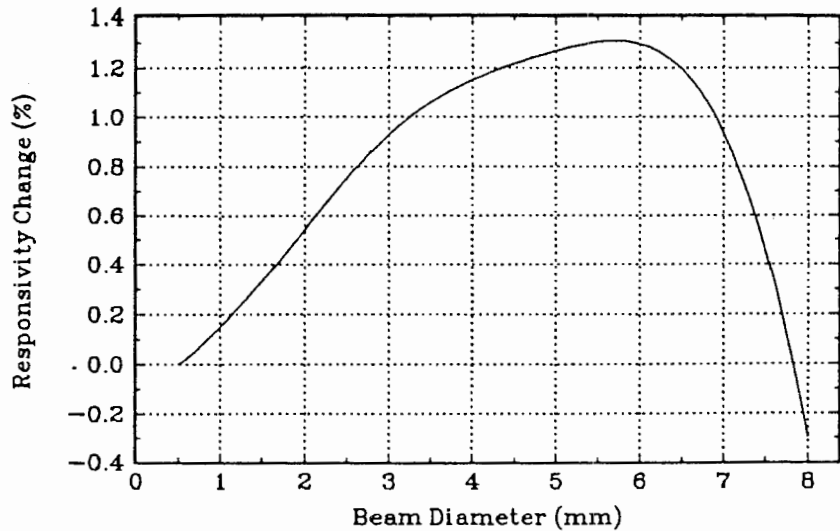
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