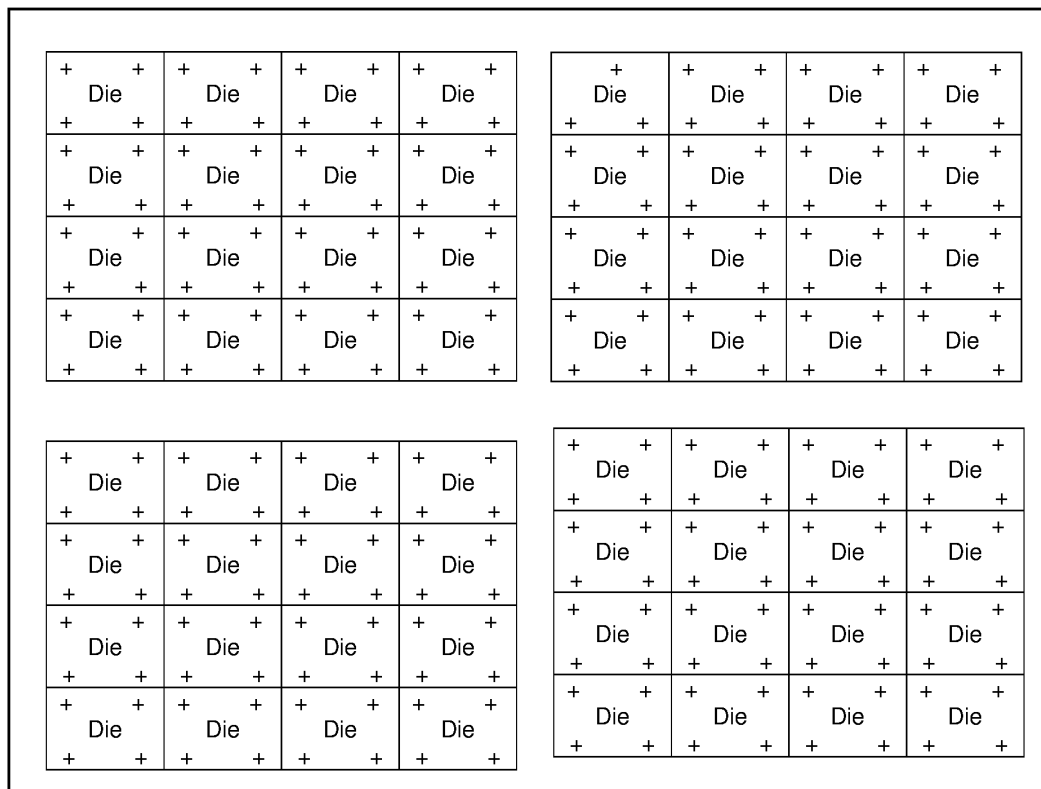


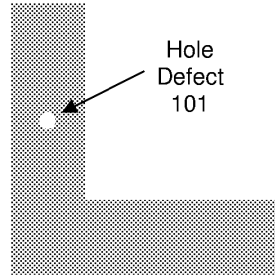


Wafer or Circuit Board Substrate with
Numerous Die
Figure 1A

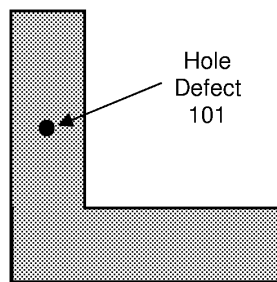


Reference Image of
Conductor (Black)

Figure 1B

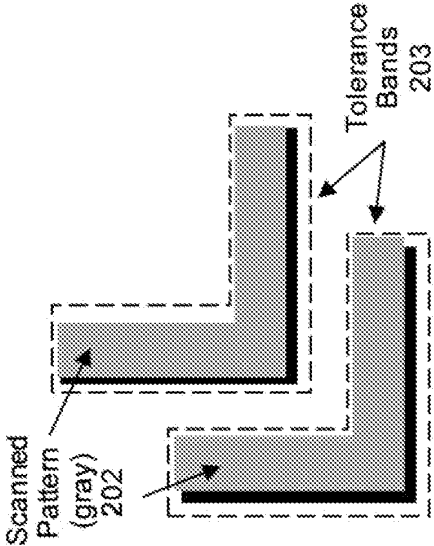


Scanned Camera Image
of Conductor (Gray)
Figure 1C



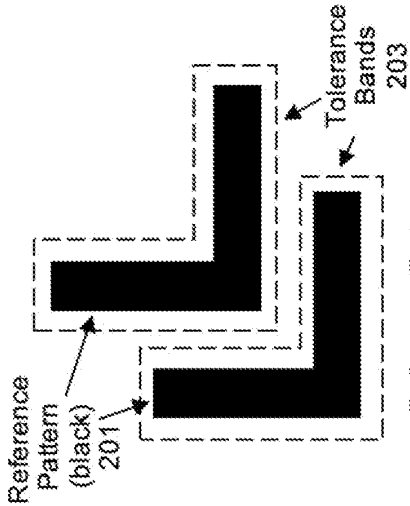
Perfect Superposition of Scanned Camera Image Over Reference Image Showing Defect

Figure 1D



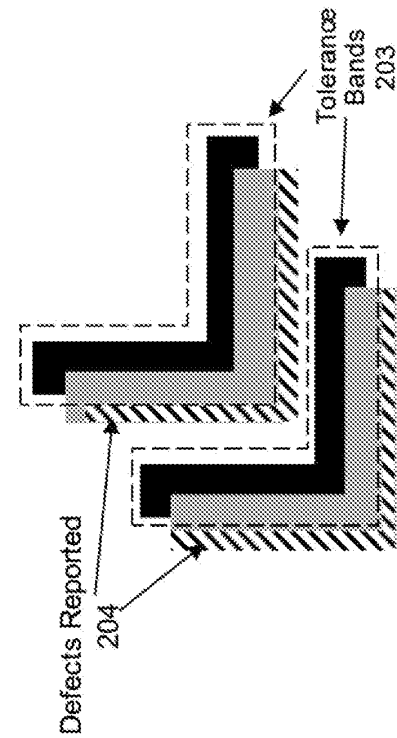
Scanned Pattern Classified as Good Because
it lies within Tolerance Band when
Superimposed over Reference Pattern

Figure 2B



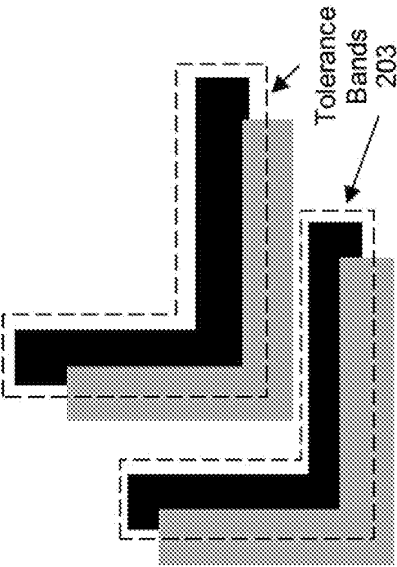
Dashed Lines Indicate Allowed
Spatial Tolerance Band to
Accommodate Manufacturing
Limitations and Stage Inaccuracies

Figure 2A



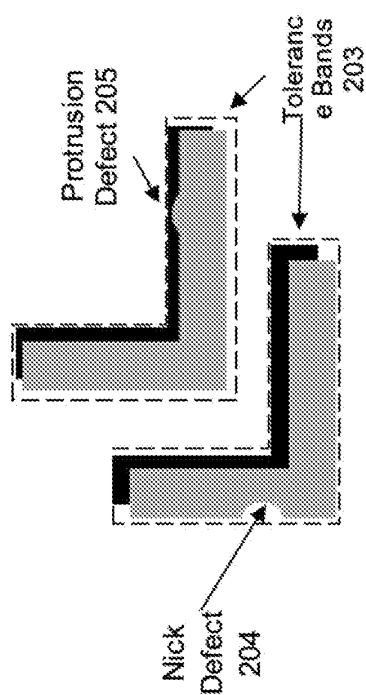
Defects Shown as Regions Where
Scanned Pattern Differs from Reference
Pattern Outside of Tolerance Band

Figure 2D



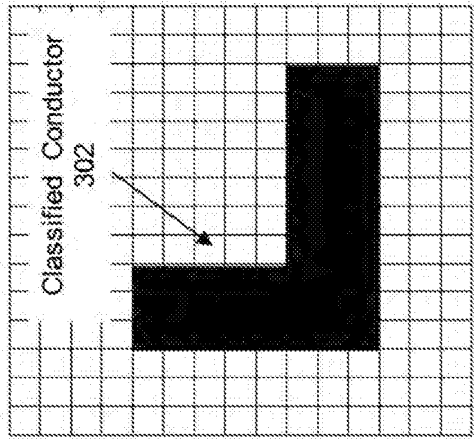
Scanned Pattern Classified as Defective
Because it lies Outside Tolerance Band
when Superimposed over Reference Pattern

Figure 2C



Defects Not Detected Because They Lie Within Tolerance Band
Figure 2E

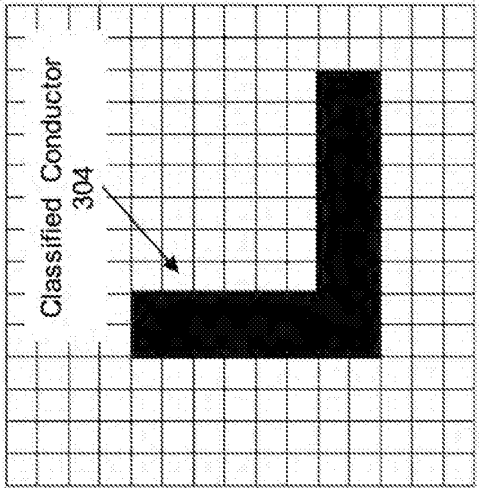
If illuminated area $\geq 50\%$ then quantized pixel is set equal to conductor (black)
If illuminated area $< 50\%$ then pixel is set equal to insulator (white)



Conductor = 3 pixels wide

How Conductor Image Pixels
of Figure 3A are Classified

Figure 3B

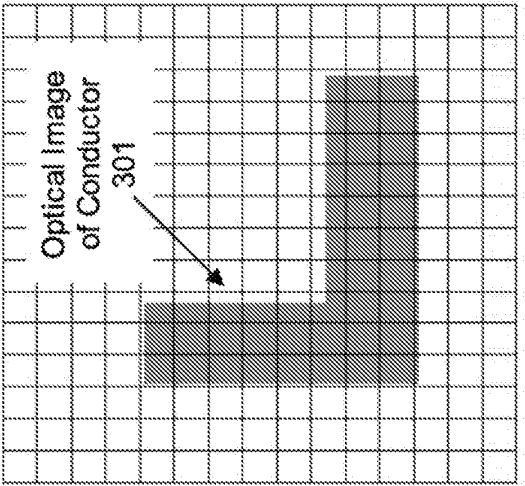


Conductor = 2 pixels wide

How Conductor Image Pixels
of Figure 3C are Classified

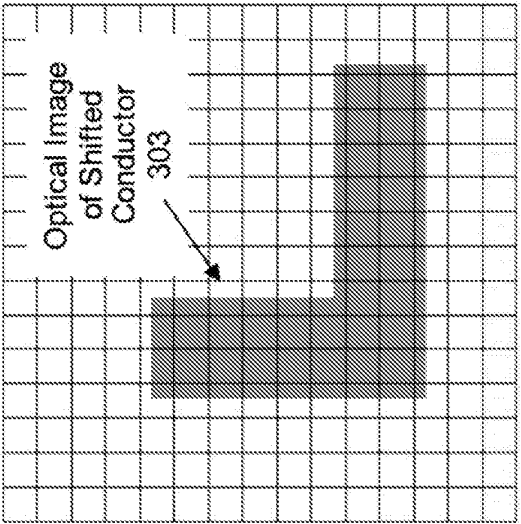
Figure 3D

How Gray Scale Camera Pixels Are Classified as Conductor or Insulator



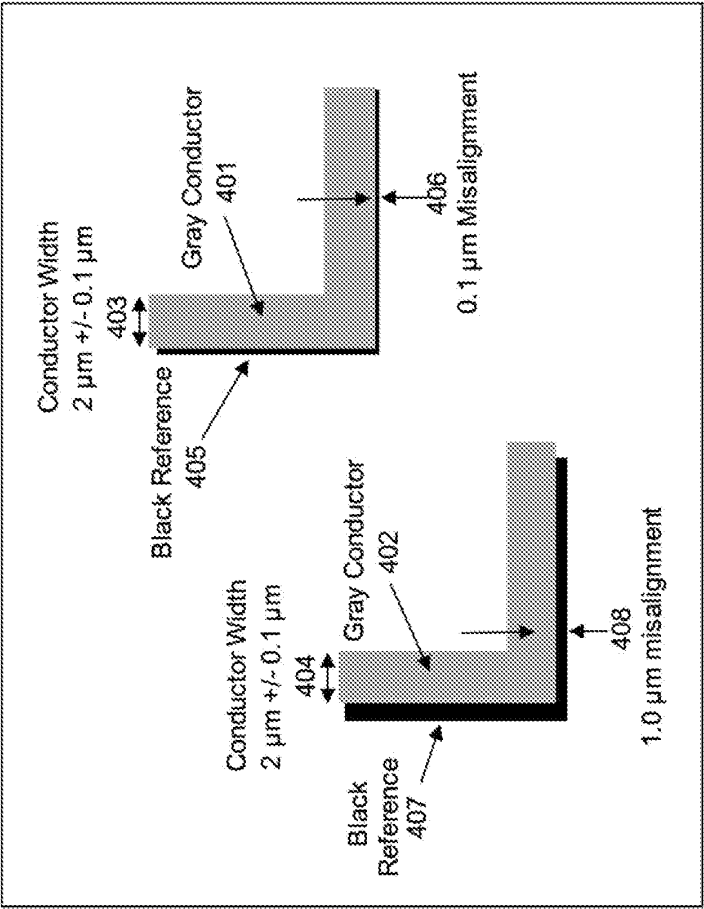
2.7-pixel wide line projected onto camera
with a spatial position such that:
100% 100% 70% 0%

Figure 3A



2.7-pixel wide line projected onto camera
with a spatial position such that:
35% 100% 100% 35%

Figure 3C



Scanned Image Subsection Compared to CAD Data

Within the same image subsection being compared to Reference data, conductor 401 aligns to Reference data to within $\pm 0.1\ \mu\text{m}$ tolerance, but conductor 402 does not and is misaligned by $1\ \mu\text{m}$ due to limitations in the manufacturing placement process.

Figure 4

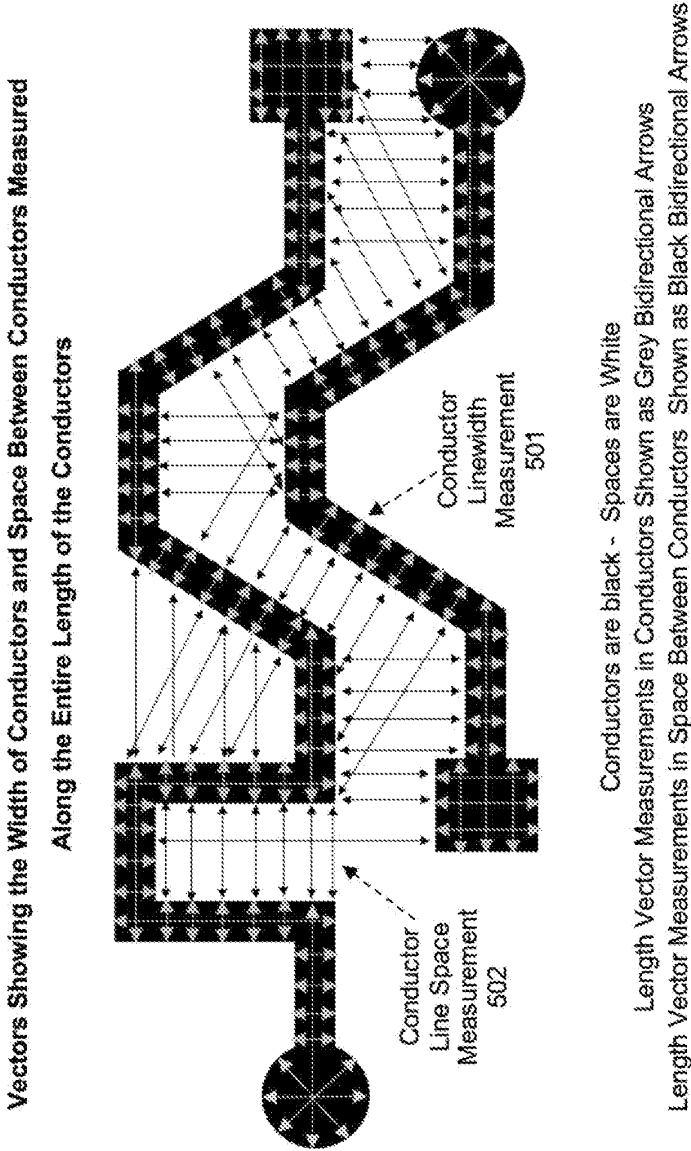


Figure 5

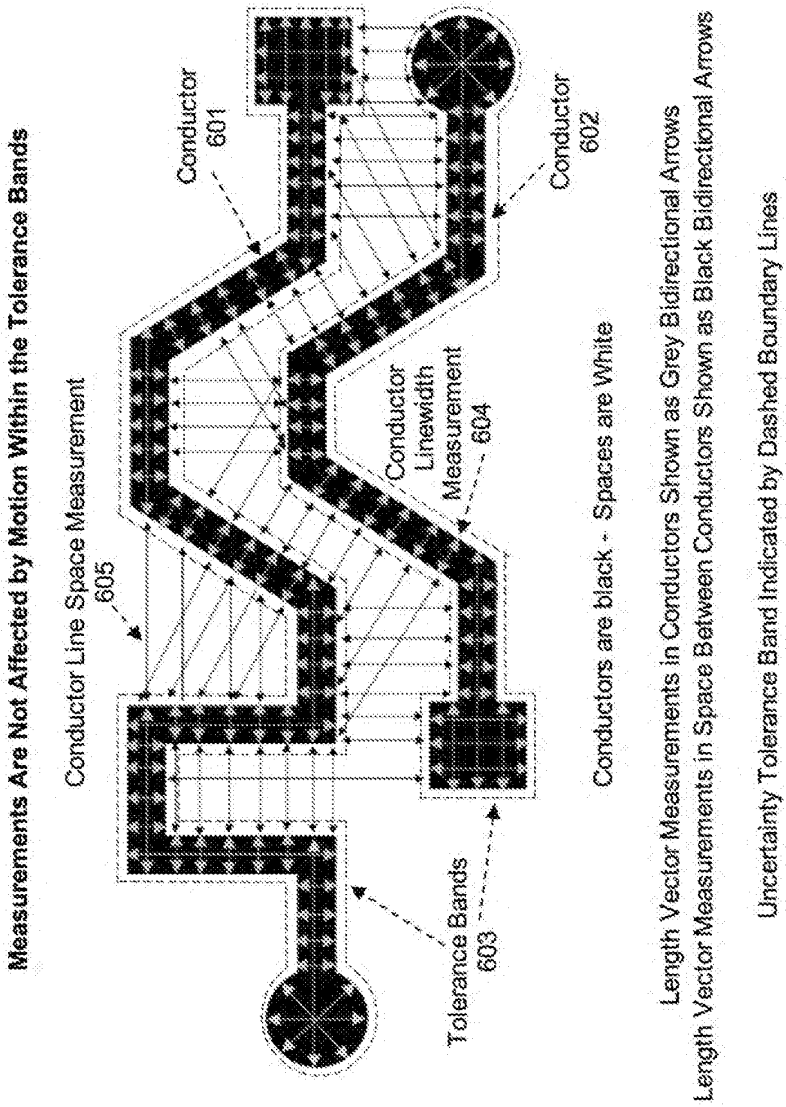
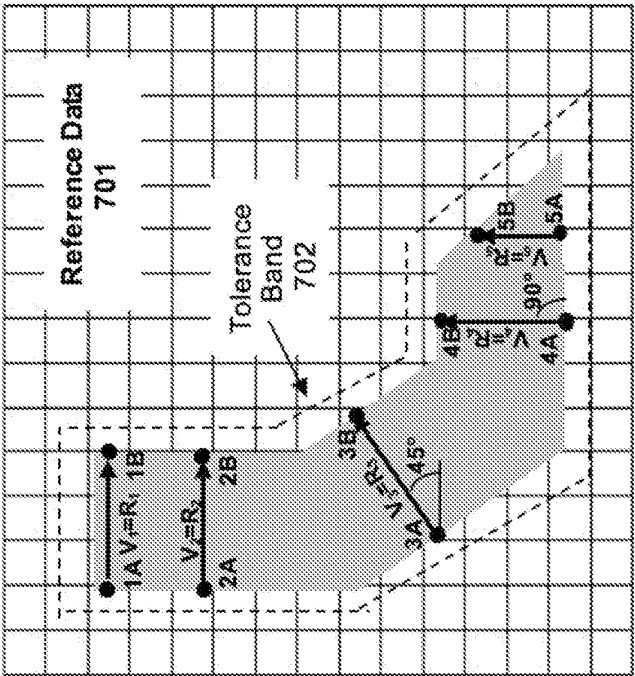


Figure 6



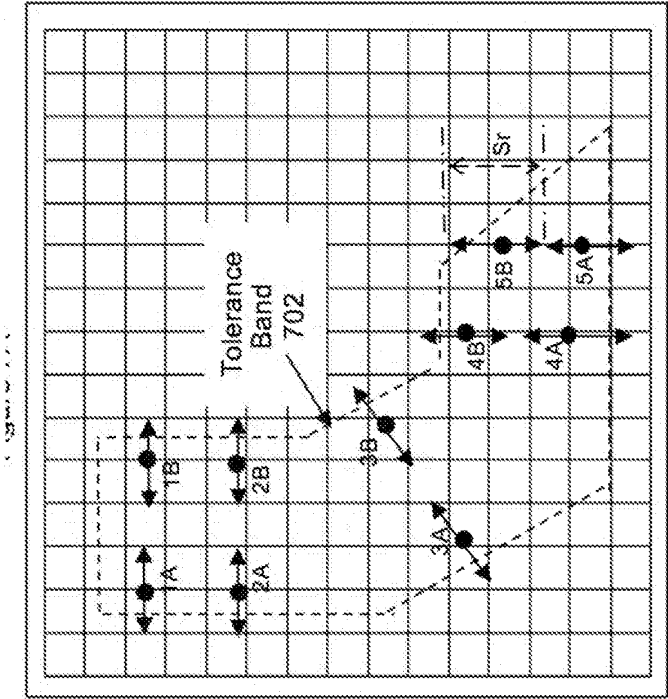
Vector Measurements Computed
from Reference Data

Conductor is Gray, Insulator is White
Reference Data Showing Feature Edges (●)
Computed Length Measurement Vectors →
Angle of Measurement and Tolerance Band - - -

Figure 7A

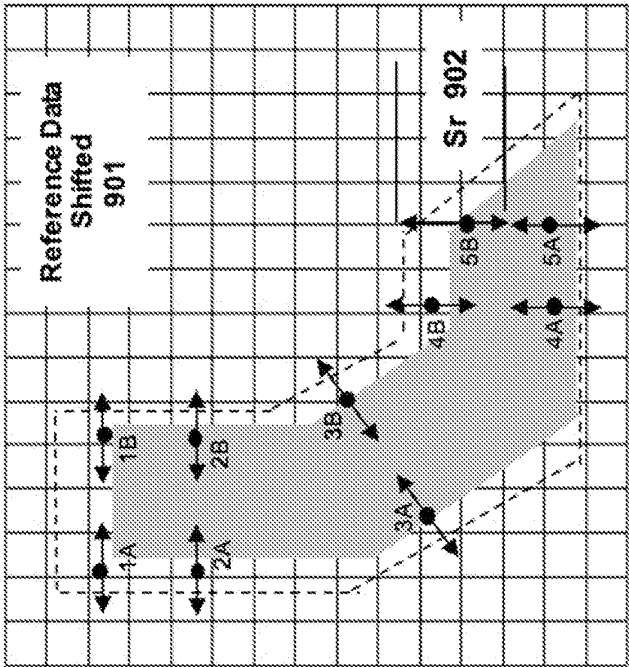
Table 7 List of Measurements Generated From Reference Data				
Vector	Starting Conductor Edge Position	Ending Conductor Edge Position	Measurement Angle	Length
V1	1A	1B	0	R1
V2	2A	2B	0	R2
V3	3A	3B	45	R3
V4	4A	4B	90	R4
V5	5A	5B	90	R5

Figure 7B



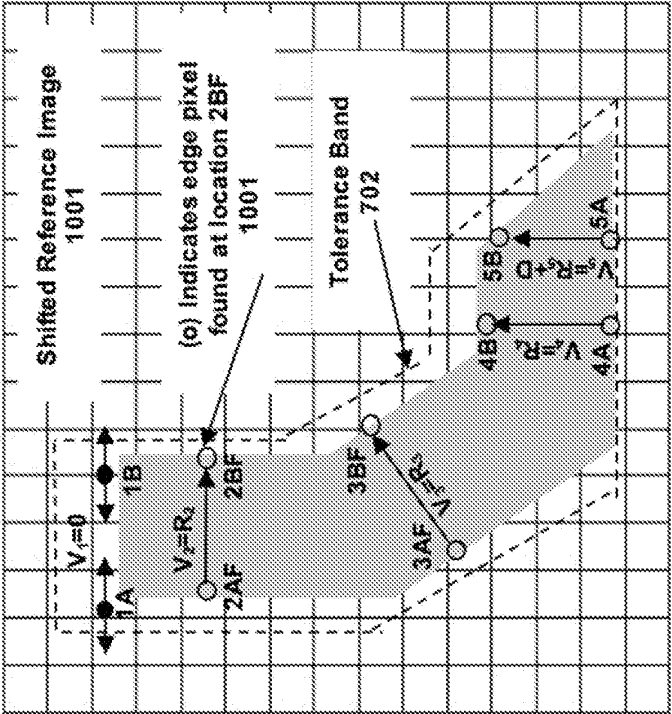
Search Range (Sr ↔) to Find Edges in Scanned Image

Figure 8



Reference Image shifted 1/2 box to the right horizontally and 1/2 box down vertically from nominal center position

Figure 9

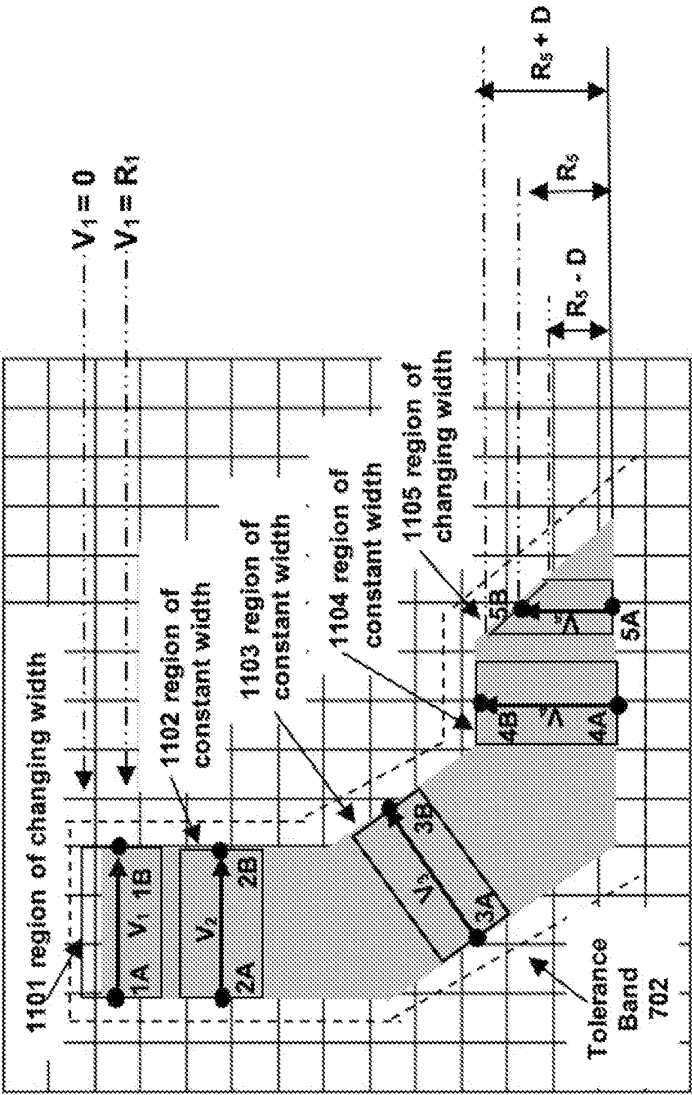


Shifted Reference Showing Feature Edges Found (o) and
Computed Width Vector Measurements →

Figure 10A

Table 10 List of Measurements Generated From Shifted Reference				
Vector	Starting Conductor Edge Position	Ending Conductor Edge Position	Length	Measurement Angle
V1	not found	not found	0	0
V2	2AF	2BF	R2	0
V3	3AF	3BF	R3	45
V4	4AF	4BF	R4	90
V5	5AF	5BF	R5+D	90

Figure 10B

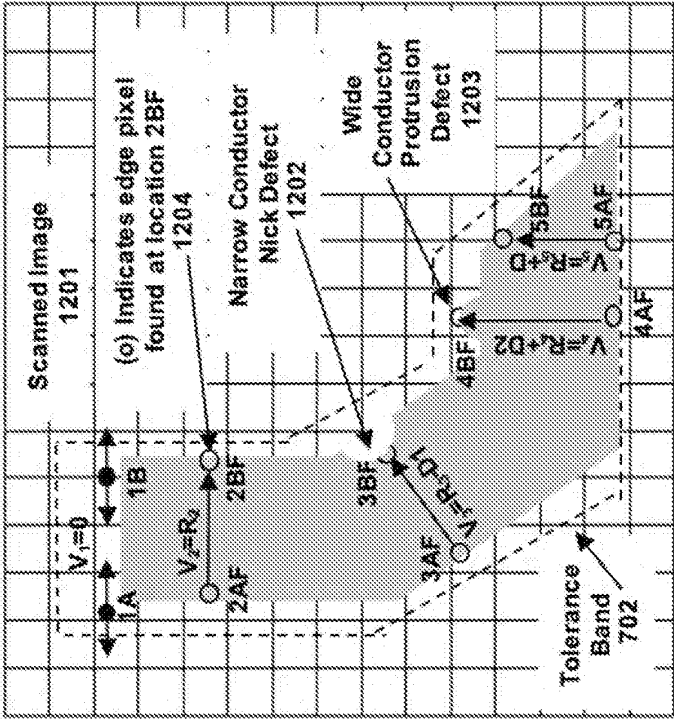


Boundary Box Around Each Vector Indicates Region of
Uncertainty and Shows Range of Valid Vector Values

Figure 11A

Table 11 Inspection Parameter List of Conductor Edge Locations, Measurement Angles and Allowable Vector Lengths						
Vector	Expected Starting Conductor Edge Position	Expected Ending Conductor Edge Position	Measurement Angle	Length of linear search range to find edge	Minimum Allowable Vector length	Maximum Allowable Vector length
V1	1A	1B	0	Sr	0	R1
V2	2A	2B	0	Sr	R2	R2
V3	3A	3B	45	Sr	R3	R3
V4	4A	4B	90	Sr	R4	R4
V5	5A	5B	90	Sr	R5 - D	R5 + D

Figure 11B



Scanned Image Containing Narrow Line Defect (V3) and Wide Line Defect (V4)

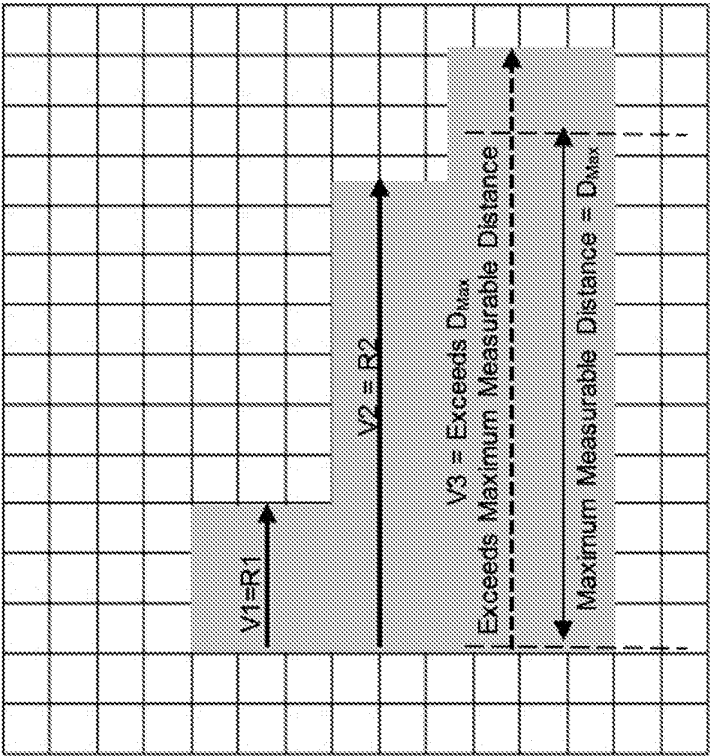
Figure 12A

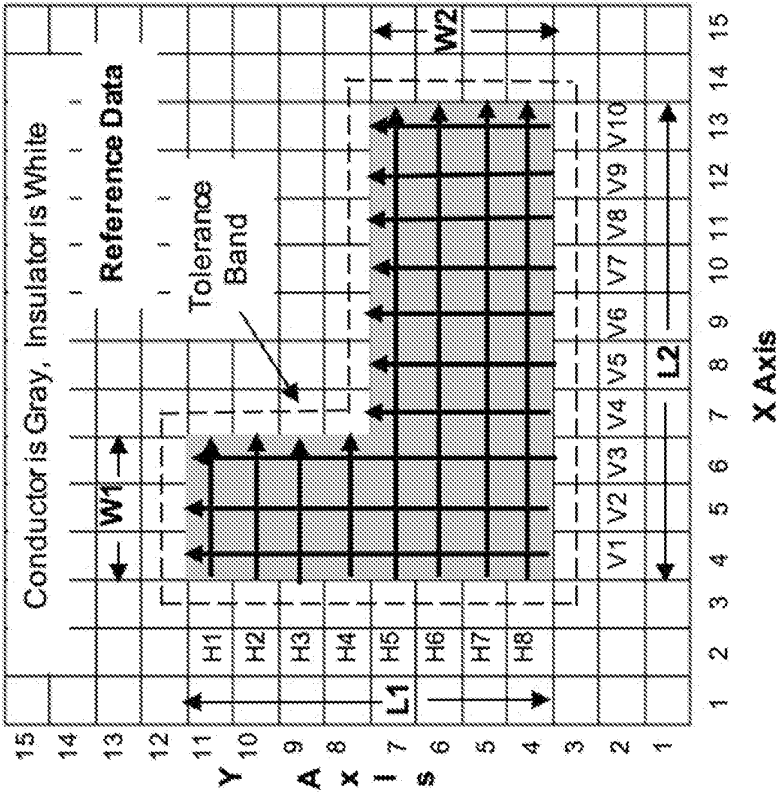
Table 12 Inspection Parameter List and Results of Inspection										
Inspection Parameter List Used to inspect Figure 12A Information Below Generated from Reference Data							Results of Inspection Information Below Generated During Inspection			
Vector	Expected Starting Conductor Edge Position	Expected Ending Conductor Edge Position	Angle of Measurement	Search Range	Minimum Allowable Vector length	Maximum Allowable Vector length	Vector Found	Measured Vector Length	Classification	
V1	1A	1B	0	Sr	0	R1	no	0	OK	
V2	2A	2B	0	Sr	R2	R2	yes	R2	OK	
V3	3A	3B	45	Sr	R3	R3	yes	R3-D1	Defect Narrow Conductor	
V4	4A	4B	90	Sr	R4	R4	yes	R4+D2	Defect Wide Conductor	
V5	5A	5B	90	Sr	R5 - D	R5 + D	yes	R5+D	OK	

Figure 12B

Vector Measurements that Exceed the
Maximum Measurable Distance are
Marked as Such in the Measurement List

Figure 13





Measurements are Performed Over
the Entire Perimeter of the Feature
with Measurement Spacing as Close
as One Pixel

Figure 14A

Table 14 Inspection Parameter List List of Measurement Conductor Edge Locations, Measurement Angles and Allowable Vector Lengths For Figure 14a							
Vector	Exp Starting Conductor Edge Position X,Y	Exp Ending Conductor Edge Position X,Y	Mea Angle	Length search range	Min Vector length	Max Vector length	
H1	4,11	6,11	0	+/-1/2	0	W1	
H2	4,10	6,10	0	+/-1/2	W1	W1	
H3	4,9	6,9	0	+/-1/2	W1	W1	
H4	4,8	6,8	0	+/-1/2	W1	L2	
H5	4,7	13,7	0	+/-1/2	W1	L2	
H6	4,6	13,6	0	+/-1/2	L2	L2	
H7	4,5	13,5	0	+/-1/2	L2	L2	
H8	4,4	13,4	0	+/-1/2	0	L2	
V1	4,4	4,11	90	+/-1/2	0	L1	
V2	5,4	5,11	90	+/-1/2	L1	L1	
V3	6,4	6,11	90	+/-1/2	W2	L1	
V4	7,4	7,7	90	+/-1/2	W2	L1	
V5	8,4	8,7	90	+/-1/2	W2	W2	
V6	9,4	9,7	90	+/-1/2	W2	W2	
V7	10,4	10,7	90	+/-1/2	W2	W2	
V8	11,4	11,7	90	+/-1/2	W2	W2	
V9	12,4	12,7	90	+/-1/2	W2	W2	
V10	13,4	13,7	90	+/-1/2	0	W2	

Figure 14B

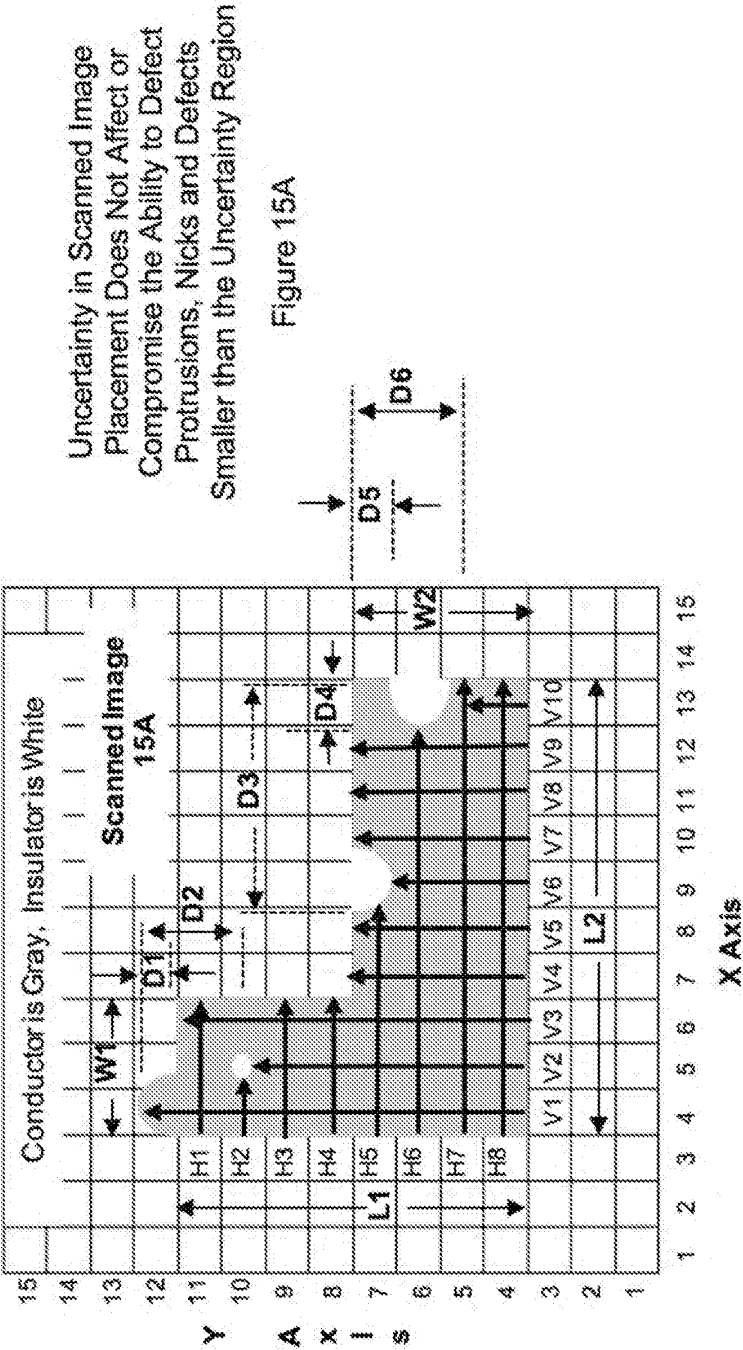
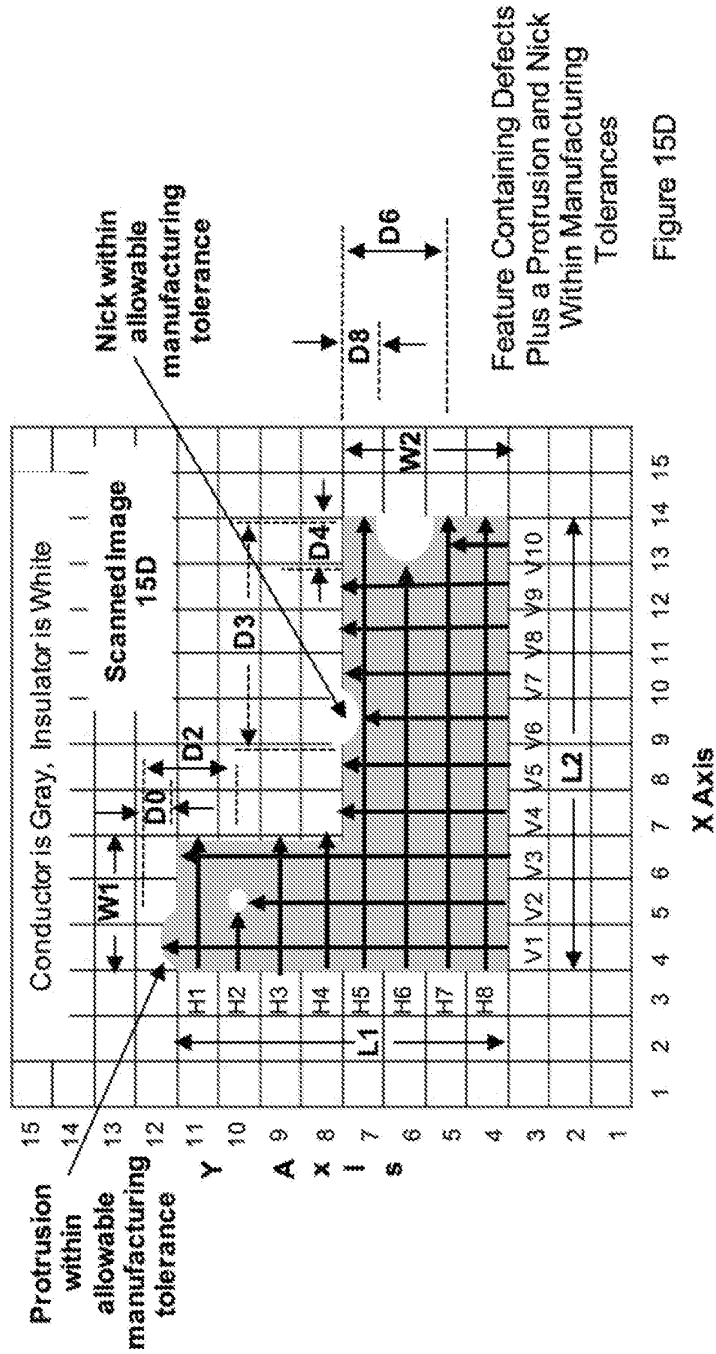


Table 15-1 Inspection Parameter List and Results of Inspection									
Parameter Inspection List Used to Inspect Figure 15A List Generated From Reference Figure 14A Inspection Parameters listed in Table 14, Figure 14B					Results of Inspection Information Below Generated During Inspection of Figure 15A				
Vector	Exp Starting Conductor Edge Position X,Y	Exp Ending Conductor Edge Position X,Y	Mea Angle	Length search range	Min Vector length	Max Vector length	Vector Found	Measured Vector Length	Classification
H1	4,11	6,11	0	+/-1/2	0	W1	yes	W1	OK
H2	4,10	6,10	0	+/-1/2	W1	W1	yes	1/2 W1	Defect Reduced Linewidth
H3	4,9	6,9	0	+/-1/2	W1	W1	yes	W1	OK
H4	4,8	6,8	0	+/-1/2	W1	L2	yes	W1	OK
H5	4,7	13,7	0	+/-1/2	W1	L2	yes	L2-D3 (in range)	OK
H6	4,6	13,6	0	+/-1/2	L2	L2		L2-D4	Defect Reduced Linewidth
H7	4,5	13,5	0	+/-1/2	L2	L2	yes	L2	OK
H8	4,4	13,4	0	+/-1/2	0	L2	yes	L2	OK
V1	4,4	4,11	90	+/-1/2	0	L1	yes	L1+D1	Defect
V2	5,4	5,11	90	+/-1/2	L1	L1	yes	L1-D2	Wide Conductor Defect Reduced Linewidth
V3	6,4	6,11	90	+/-1/2	W2	L1	yes	L1	OK
V4	7,4	7,7	90	+/-1/2	W2	L1	yes	W2	OK
V5	8,4	8,7	90	+/-1/2	W2	W2	yes	W2	OK
V6	9,4	9,7	90	+/-1/2	W2	W2	yes	W2-D5	Defect Reduced Linewidth
V7	10,4	10,7	90	+/-1/2	W2	W2	yes	W2	OK
V8	11,4	11,7	90	+/-1/2	W2	W2	yes	W2	OK
V9	12,4	12,7	90	+/-1/2	W2	W2	yes	W2	OK
V10	13,4	13,7	90	+/-1/2	0	W2	yes	W2-D6	OK

Figure 15B

Table 15-2 Inspection Parameter List With Manufacturing Tolerances Added to Inspect Feature in Figure 15D and Results of Inspection									
Inspection Parameter List Generated From Reference Figure 14A with Manufacturing Tolerances Added to Table 14 to Inspect Figure 15D					Results of Inspection Information Below Generated During Inspection of Figure 15D				
Vector	Exp Starting Conductor Edge Position X,Y	Exp Ending Conductor Edge Position X,Y	Mea Angle	Length search range	Min Vector length	Max Vector length	Vector Found	Measured Vector Length	Classification
H1	4,11	6,11	0	+/-1/2	0	W1+α	yes	W1	OK
H2	4,10	6,10	0	+/-1/2	W1-α	W1+α	yes	½ W1	Defect Reduced Linewidth
H3	4,9	6,9	0	+/-1/2	W1-α	W1+α	yes	W1	OK
H4	4,8	6,8	0	+/-1/2	W1-α	L2+β	yes	W1	OK
H5	4,7	13,7	0	+/-1/2	W1-α	L2+β	yes	L2	OK
H6	4,6	13,6	0	+/-1/2	L2-β	L2+β		L2-D4	Defect Reduced Linewidth
H7	4,5	13,5	0	+/-1/2	L2-β	L2+β	yes	L2	OK
H8	4,4	13,4	0	+/-1/2	0	L2+β	yes	L2	OK
V1	4,4	4,11	90	+/-1/2	0	L1+β	yes	L1+D0	OK
V2	5,4	5,11	90	+/-1/2	L1-β	L1+β	yes	L1-D2	Defect Reduced Linewidth
V3	6,4	6,11	90	+/-1/2	W2-α	L1+β	yes	L1	OK
V4	7,4	7,7	90	+/-1/2	W2-α	L1+β	yes	W2	OK
V5	8,4	8,7	90	+/-1/2	W2-α	W2+α	yes	W2	OK
V6	9,4	9,7	90	+/-1/2	W2-α	W2+α	yes	W2-D8	OK
V7	10,4	10,7	90	+/-1/2	W2-α	W2+α	yes	W2	Within Tolerance
V8	11,4	11,7	90	+/-1/2	W2-α	W2+α	yes	W2	OK
V9	12,4	12,7	90	+/-1/2	W2-α	W2+α	yes	W2	OK
V10	13,4	13,7	90	+/-1/2	0	W2+α	yes	W2-D6	OK

Figure 15C



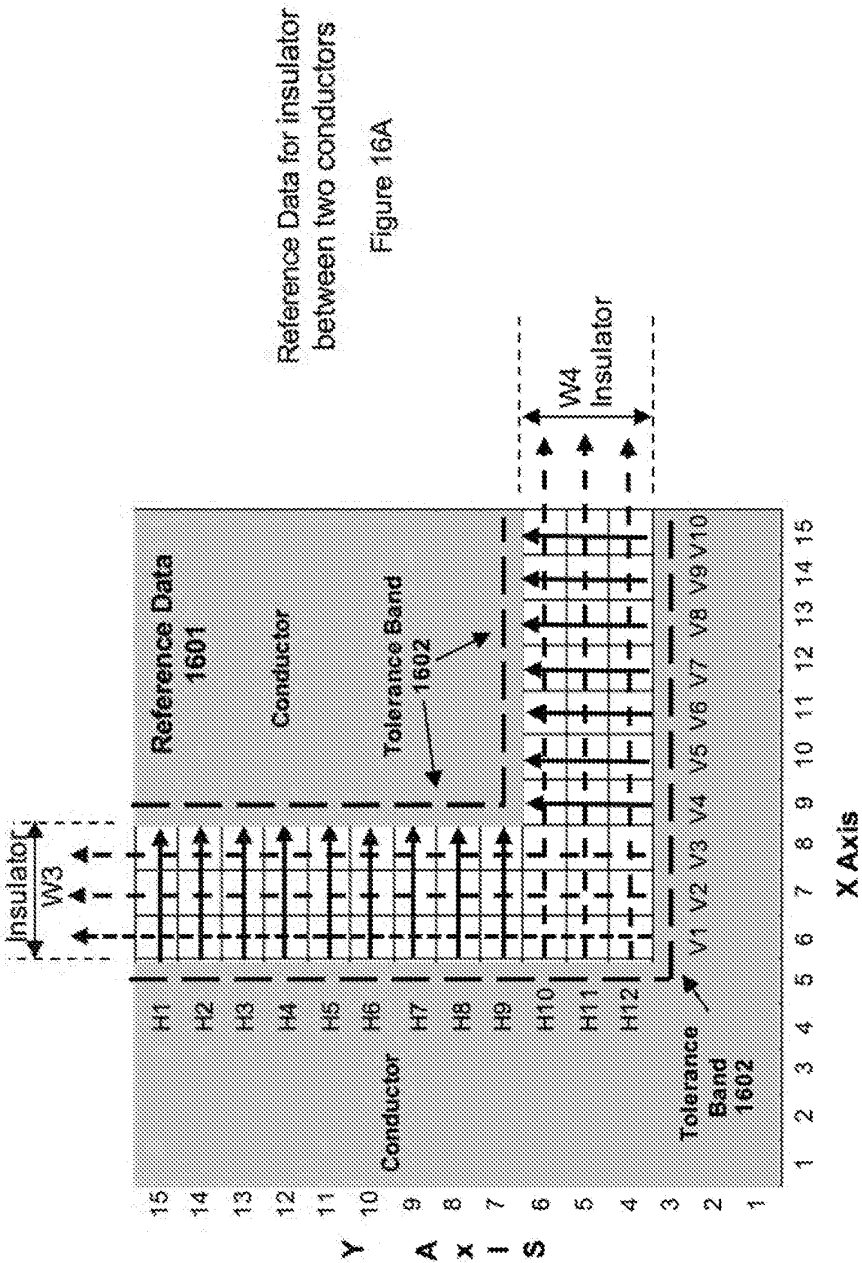


Table 16
**Inspection Parameter List of Measurement Insulator Edge Locations,
Measurement Angles and Allowable Vector Lengths For Figure 16A**

Vector	Exp Insulator Starting Edge Position X,Y	Exp Insulator Ending Edge Position X,Y	Mea Angle	Length search range	Min Vector length	Max Vector length
H1	6,15	8,15	0	+/-1/2	W3	W3
H2	6,14	8,14	0	+/-1/2	W3	W3
H3	6,13	6,13	0	+/-1/2	W3	W3
H4	6,12	8,12	0	+/-1/2	W3	W3
H5	6,11	8,11	0	+/-1/2	W3	W3
H6	6,10	8,10	0	+/-1/2	W3	W3
H7	6,9	8,9	0	+/-1/2	W3	W3
H8	6,8	8,8	0	+/-1/2	W3	W3
H9	6,7	8,7	0	+/-1/2	W3	D _{MAX}
H10	6,6	D _{MAX}	0	+/-1/2	W3	D _{MAX}
H11	6,5	D _{MAX}	0	+/-1/2	D _{MAX}	D _{MAX}
H12	6,4	D _{MAX}	0	+/-1/2	0	D _{MAX}
V1	6,4	D _{MAX}	90	+/-1/2	0	D _{MAX}
V2	7,4	D _{MAX}	90	+/-1/2	D _{MAX}	D _{MAX}
V3	8,4	D _{MAX}	90	+/-1/2	W4	D _{MAX}
V4	9,4	9,6	90	+/-1/2	W4	D _{MAX}
V5	10,4	10,6	90	+/-1/2	W4	W4
V6	11,4	11,6	90	+/-1/2	W4	W4
V7	12,4	12,6	90	+/-1/2	W4	W4
V8	13,4	13,6	90	+/-1/2	W4	W4
V9	12,4	12,7	90	+/-1/2	W4	W4
V10	13,4	13,7	90	+/-1/2	W4	W4

Figure 16B

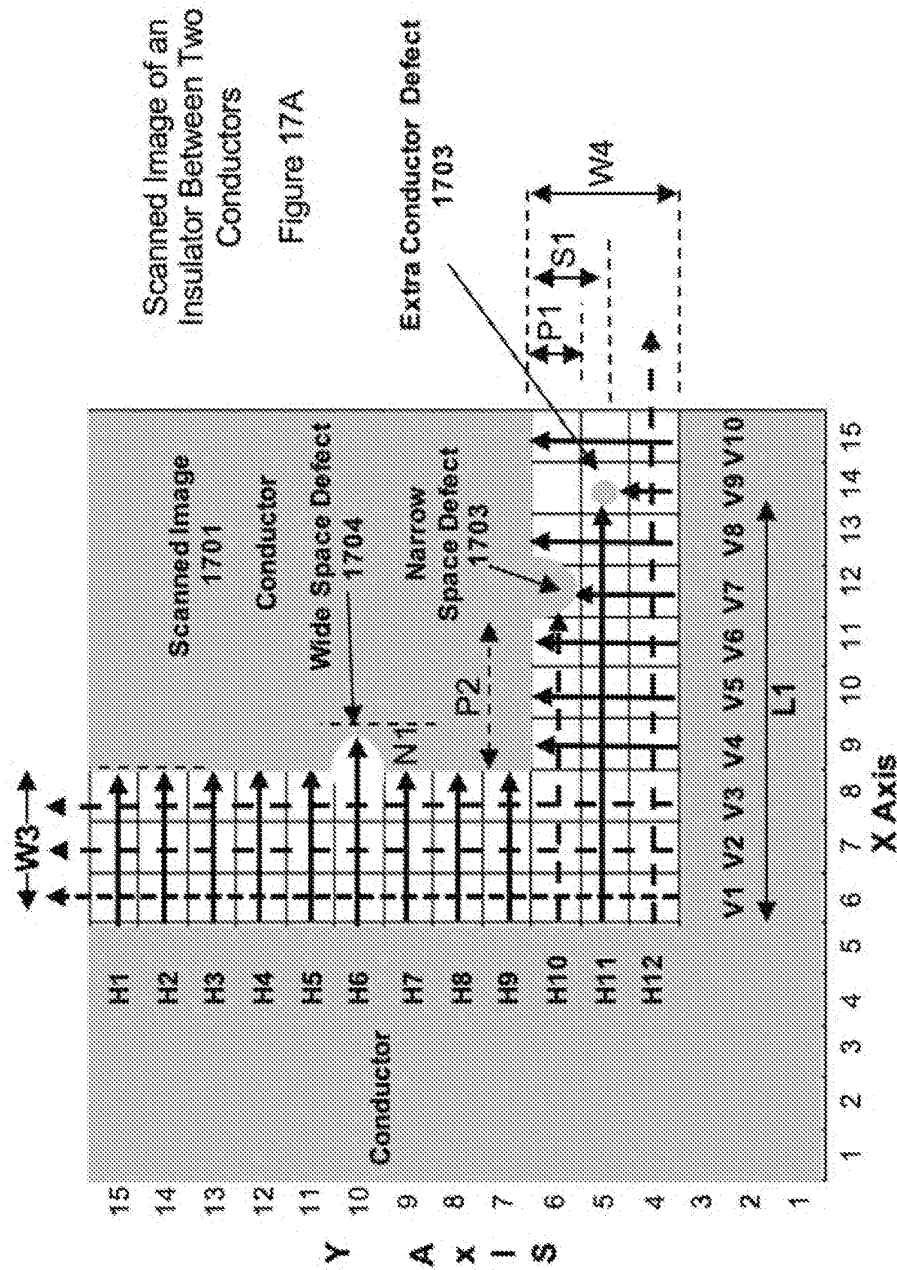
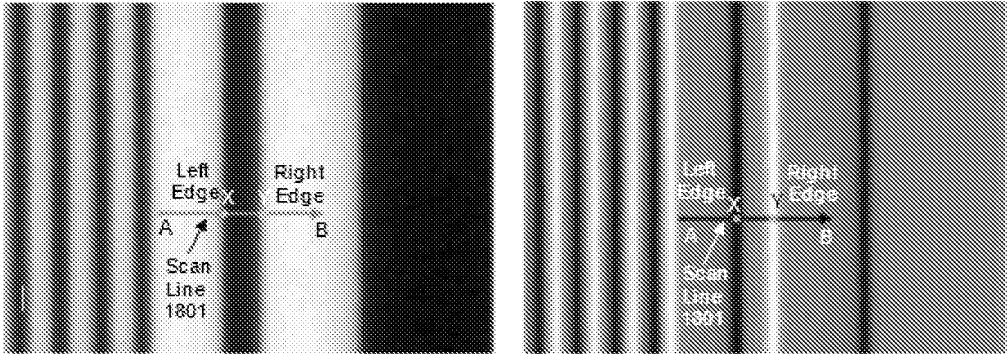


Table 17 Inspection Parameter List Used to Inspect Feature in Figure 16A and Results of Inspection									
Inspection Parameter List Generated From Reference Figure 16A					Results of Inspection Information Below Generated During Inspection of Figure 17a				
Vector	Exp Insulator Starting Edge Position X,Y	Exp Insulator Ending Edge Position X,Y	Mea Angle	Length search range	Min Vector length	Max Vector length	Vector Found	Measured Vector Length	Classification
H1	6,15	8,15	0	+/-1/2	W3	W3	yes	W3	
H2	6,14	8,14	0	+/-1/2	W3	W3	yes	W3	
H3	6,13	6,13	0	+/-1/2	W3	W3	yes	W3	
H4	6,12	8,12	0	+/-1/2	W3	W3	yes	W3	
H5	6,11	8,11	0	+/-1/2	W3	W3	yes	W3	
H6	6,10	8,10	0	+/-1/2	W3	W3	yes	W3+N1	Defect Wide Insulator
H7	6,9	8,9	0	+/-1/2	W3	W3	yes	W3	
H8	6,8	8,8	0	+/-1/2	W3	W3	yes	W3	
H9	6,7	8,7	0	+/-1/2	W3	D _{max}	yes	W3	
H10	6,6	D _{max}	0	+/-1/2	W3	D _{max}	yes	W3+P2	OK (in range)
H11	6,5	D _{max}	0	+/-1/2	D _{max}	D _{max}	yes	L1	Defect Narrow Insulator
H12	6,4	D _{max}	0	+/-1/2	0	D _{max}	yes	D _{max}	
V1	6,4	D _{max}	90	+/-1/2	0	D _{max}	yes	D _{max}	
V2	7,4	D _{max}	90	+/-1/2	D _{max}	D _{max}	yes	D _{max}	
V3	8,4	D _{max}	90	+/-1/2	W4	D _{max}	yes	D _{max}	
V4	9,4	9,6	90	+/-1/2	W4	D _{max}	yes	D _{max}	
V5	10,4	10,6	90	+/-1/2	W4	W4	yes	W4	
V6	11,4	11,6	90	+/-1/2	W4	W4	yes	W4	
V7	12,4	12,6	90	+/-1/2	W4	W4	yes	W4-P1	Defect Narrow Insulator
V8	13,4	13,6	90	+/-1/2	W4	W4	yes	W4	
V9	12,4	12,7	90	+/-1/2	W4	W4	yes	W4-S1	Defect Narrow Insulator
V10	13,4	13,7	90	+/-1/2	W4	W4	yes	W4	

Figure 17B

Signals and Images Used to Find Edges of Conductors and Insulators to Sub-Pixel



Scanned Fluorescent Image
Conductors are Dark, Insulators are Bright
Figure 18A

Output of Edge Filter
Figure 18B

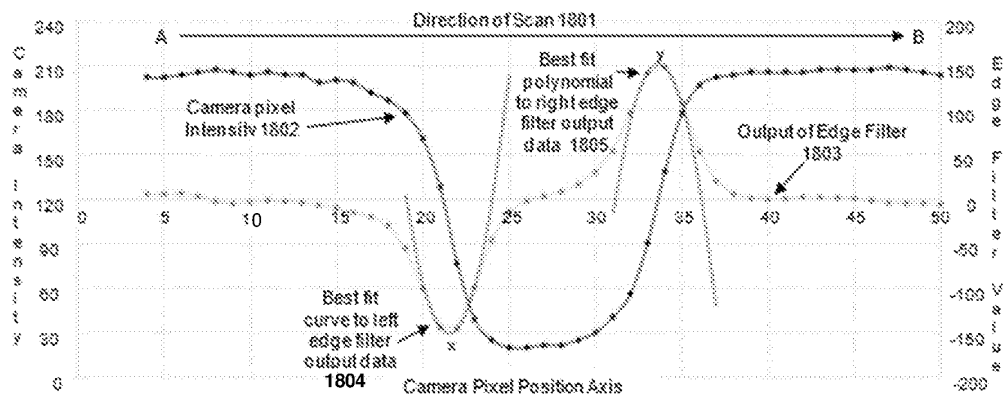


Figure 18C

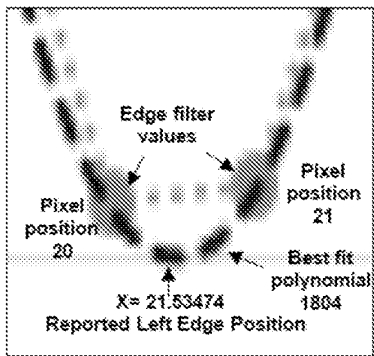


Figure 18D

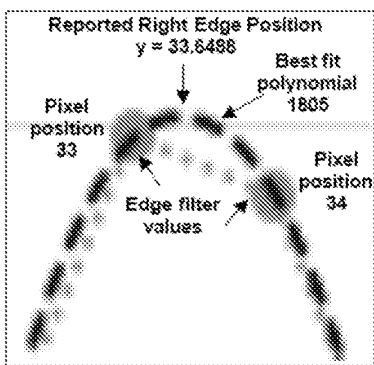
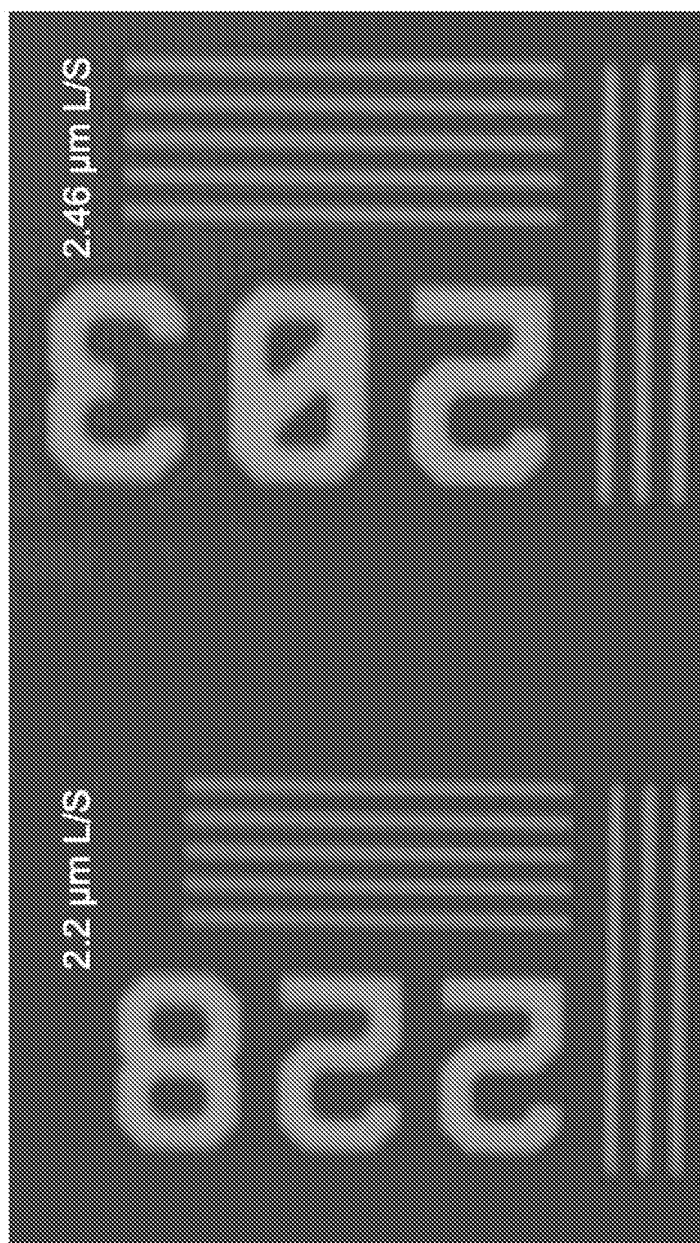


Figure 18E



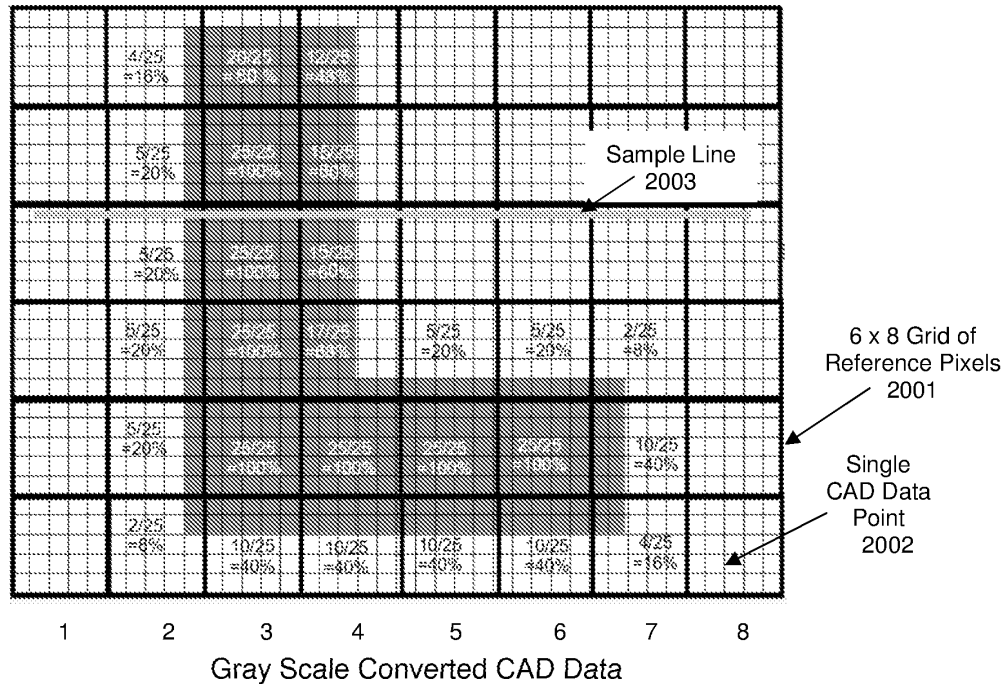
Scanned Chrome on Glass Gray Scale Image of Test Target 1

Figure 19A

Results of Measuring Linewidths on Test Target 1 Using Sobel Gradient Algorithm	
Known Reference Line Width on Target	Measured Line Width Using Sobel Edge Filter and Best Fit Parabolic Curve
2.20 μm (228 lp/mm)	2.20 μm +/- 0.035 μm
2.46 μm (203 lp/mm)	2.46 μm +/- 0.035 μm

Figure 19B

Method 1 for Conversion of CAD Data to Reference Gray Scale Pixels



1. Large Reference Square equals size of camera pixel
2. Small square equals resolution of CAD data
3. Each Reference Pixel contains 25 CAD data points
4. Gray scale intensity value of Reference Pixel (represented by large square) is proportional to percent of Reference Pixel area filled by conductor.

Figure 20A

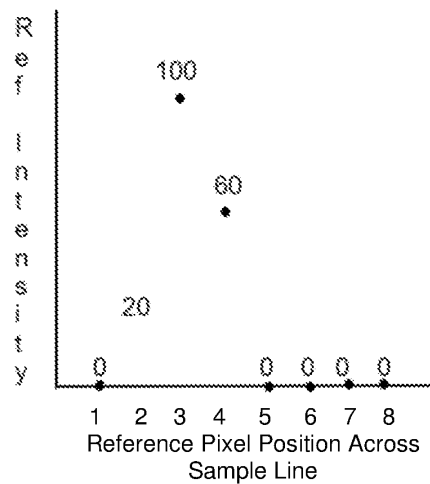


Figure 20B

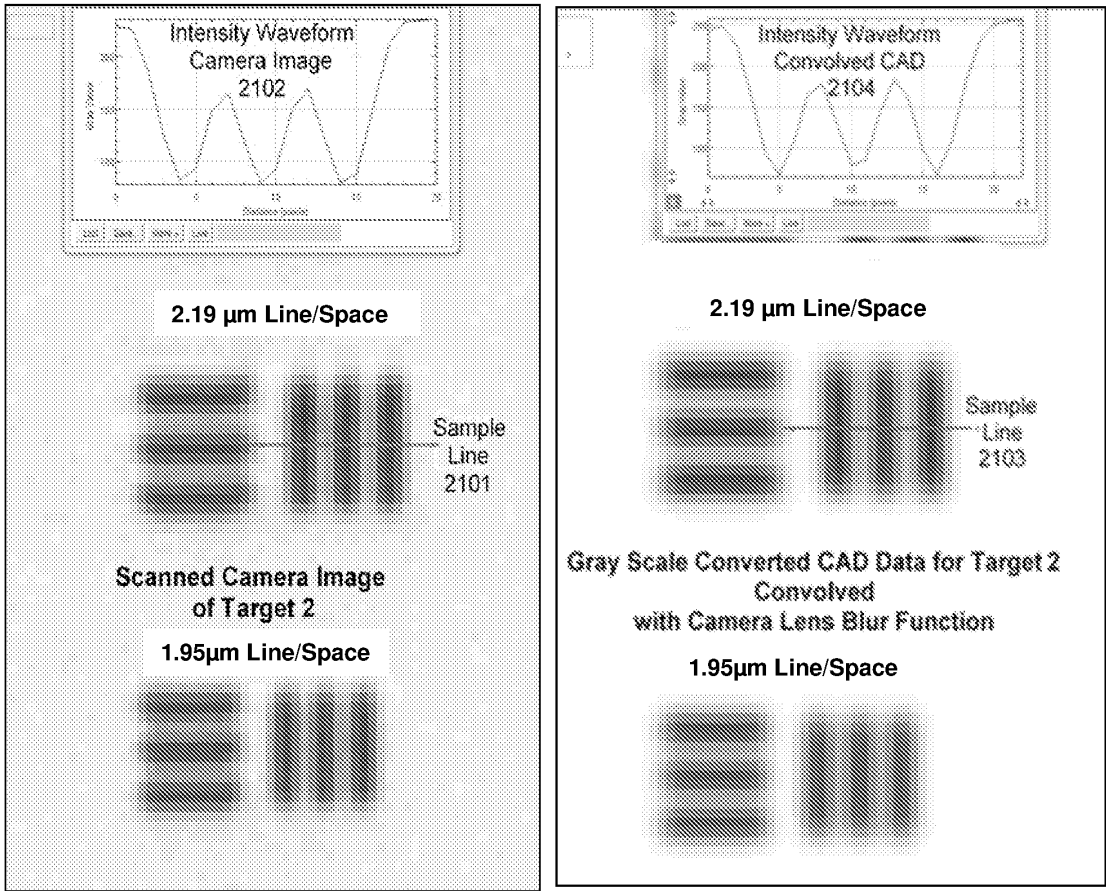
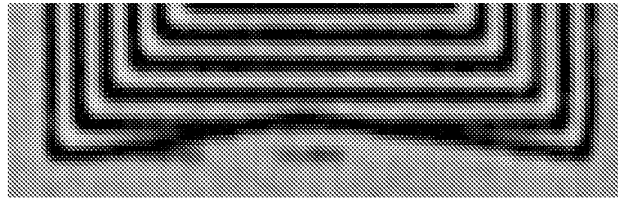


Figure 21A

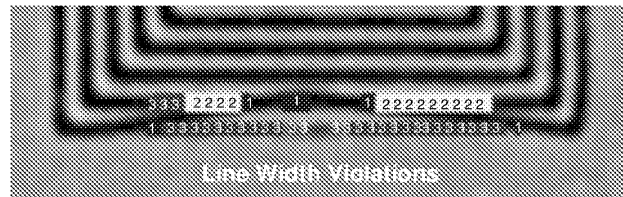
Figure 21B

Table 21C Linewidth Difference Measured Between CAD Data Convolved With Lens Blur Function (Figure 21B) and Scanned Camera Image (Figure 21A)	
Known Line Width /Space From CAD Data	Difference Measured Between CAD Data Convolved With Lens Blur Function (Figure 21A) and Scanned Camera Image (Figure 21B)
2.19 μm	+/- 0.1 μm
1.95 μm	+/- 0.1 μm

Figure 21C



Scanned Fluorescent Image of Metal Conductors, which Appear Black,
on a Bright Fluorescing Substrate
Figure 22A

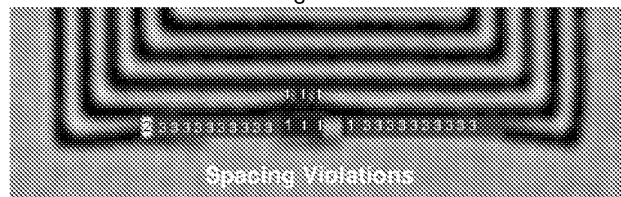


-Tolerance < Good < +Tolerance
Tolerance < number 1 < 2xTolerance
2x Tolerance < number 2
number 3 = Not found in 2.1 um search range

-1.8 um < Good < 2.2 um
1.6 um < number 1 < 1.8 um or
2.2um < number 1 < 2.4um
2 < 1.6 um or 2.4 < number 2
number 3 = Not found in 2.1

Line Width Violations

Figure 22B

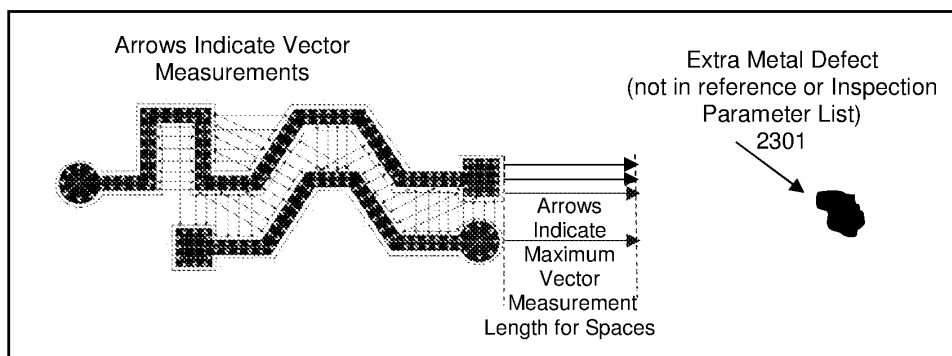


-Tolerance < Good < +Tolerance
Tolerance < number 1 < 2xTolerance
2x Tolerance < number 2
number 3 = Not found in 2.1 um search range

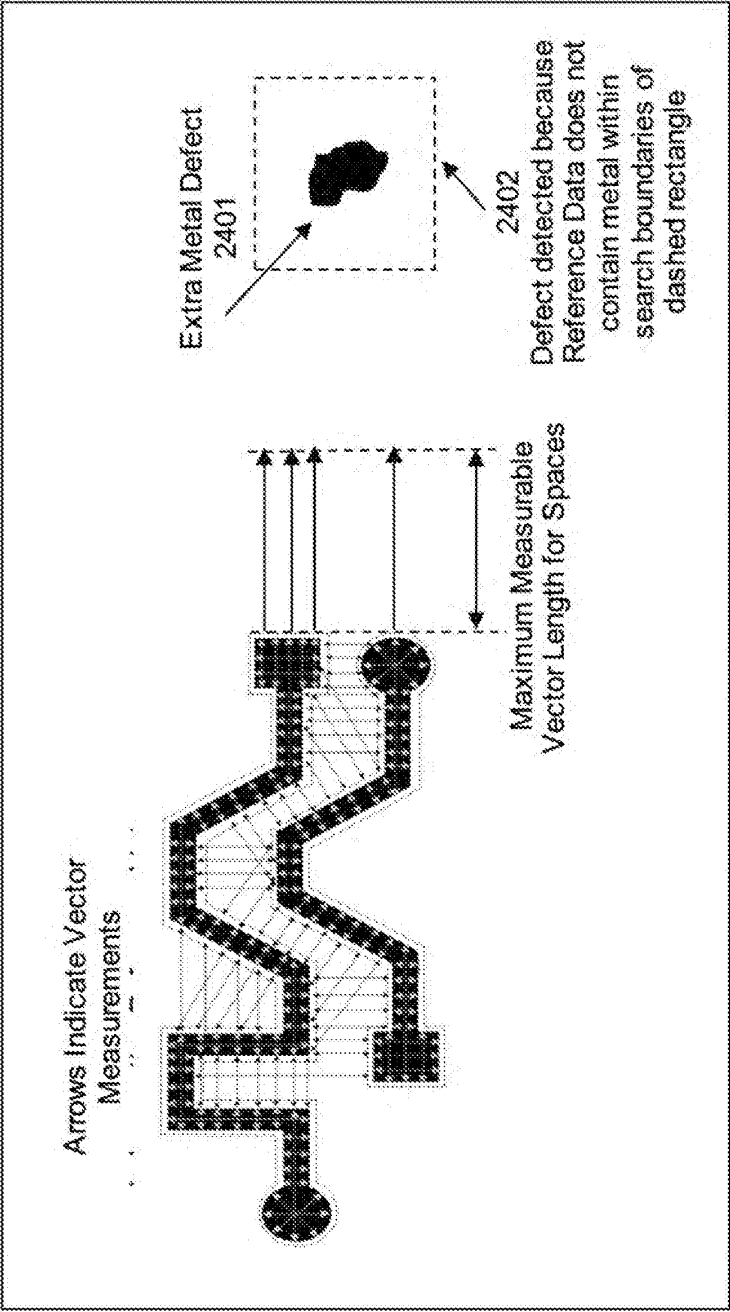
-1.8 um < Good < 2.2 um
1.6 um < number 1 < 1.8 um or
2.2um < number 1 < 2.4um
2 < 1.6 um or 2.4 < number 2
number 3 = Not found in 2.1

Spacing Violations

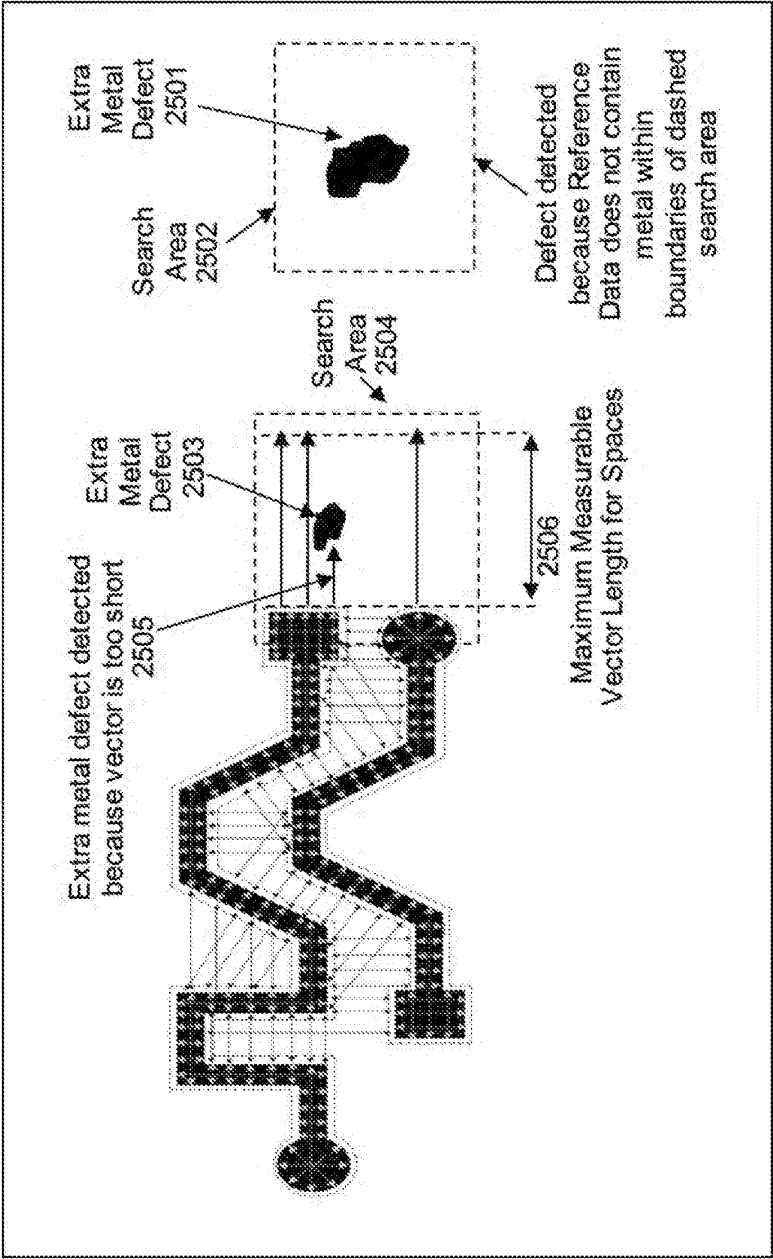
Figure 22C



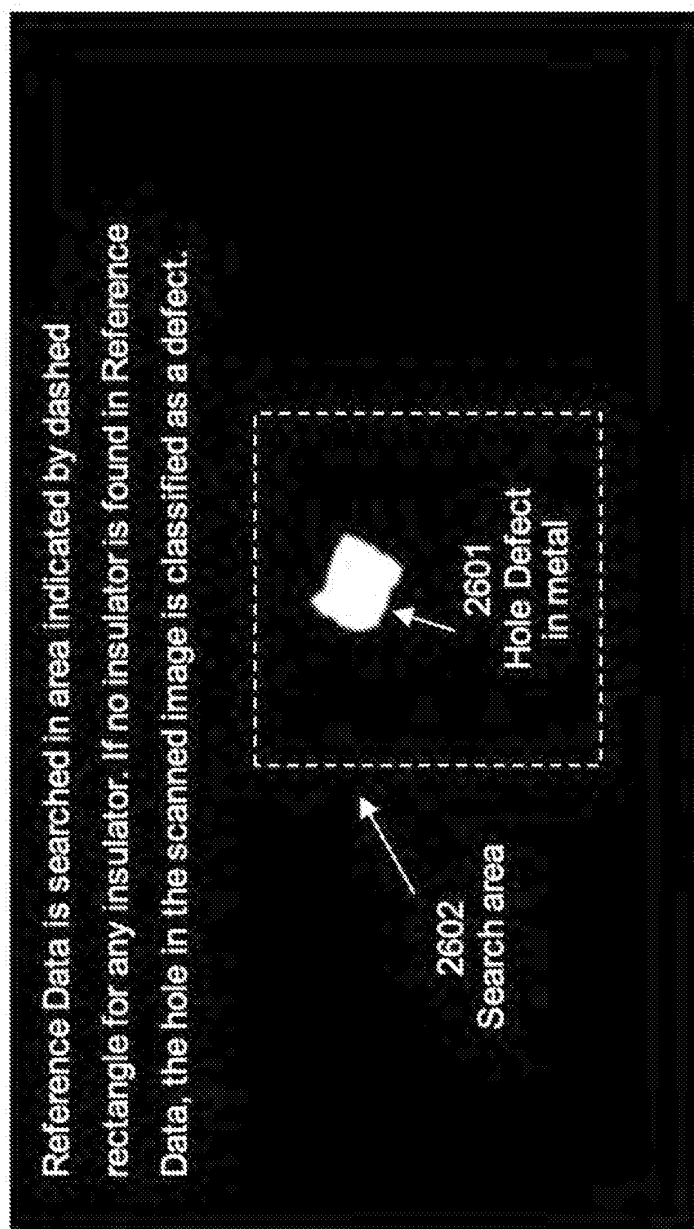
Extra Metal Defect Not in Reference Data
Figure 23



Extra Metal Defect in Large Area of Insulator
Figure 24

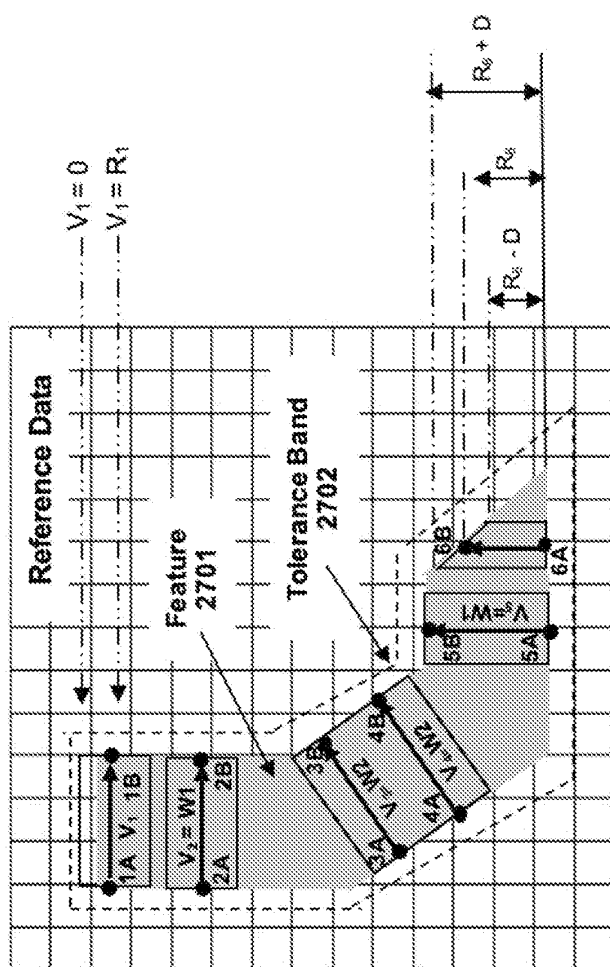


Extra Metal Defects
Figure 25



Hole Defect in Large Area of Metal

Figure 26



Boundary Box Around Each Vector Indicates Region of Uncertainty and Shows Range of Vector Values

Vectors V2, V3, V4, V5 Are Used to Measure Critical Feature Width

Because They Do Not Change Value as Feature Moves Within Region of Uncertainty

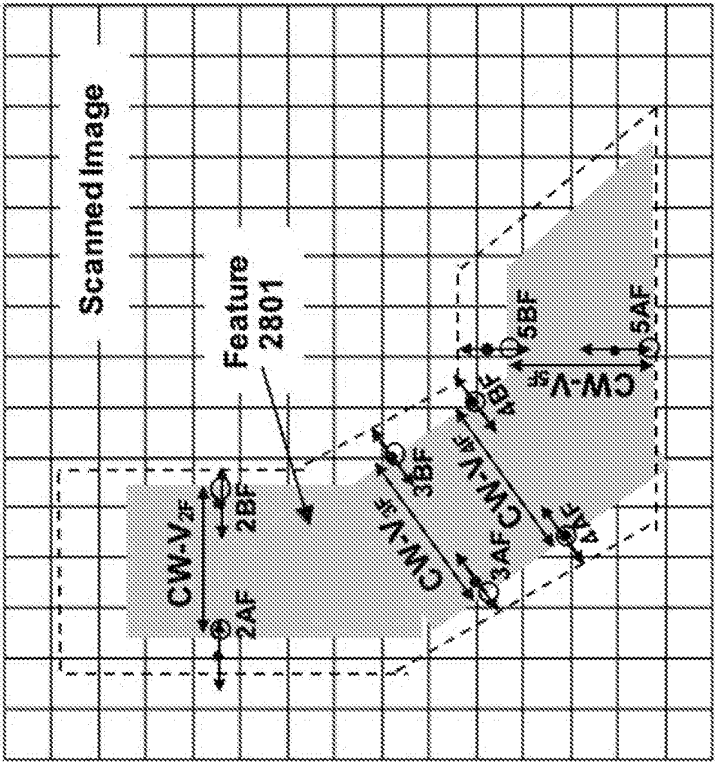
Critical Width Vectors V2 and V5 have the same value = W1

Critical Width Vectors V3 and V4 have the same value = W2

Figure 27A

Table 27 Measurement Parameter List For Feature Shown in Figure 27A Indicating Critical Width Vectors							
List of Conductor Edge Locations, Measurement Angles Vector Lengths and Critical Width Vectors Generated From Reference Data to be used for Statistical Measurements When Inspecting a Scanned Part							
Vector	Expected Starting Conductor Edge Position	Expected Ending Conductor Edge Position	Measurement Angle	Length of linear search range to find edge	Minimum Allowable Vector length	Maximum Allowable Vector length	Critical Width Vector
V1	1A	1B	0	Sr	0	R1	No
V2	2A	2B	0	Sr	W1	W1	Yes
V3	3A	3B	45	Sr	W2	W2	Yes
V4	4A	4B	90	Sr	W2	W2	Yes
V5	5A	5B	90	Sr	W1	W1	Yes
V6	6A	6B	90	Sr	R6 - D	R6 + D	No

Figure 27B



Scanned Image of Part
Showing Feature Edges Found (o)
and Computed Critical Width Vector (CWV)
Measurements

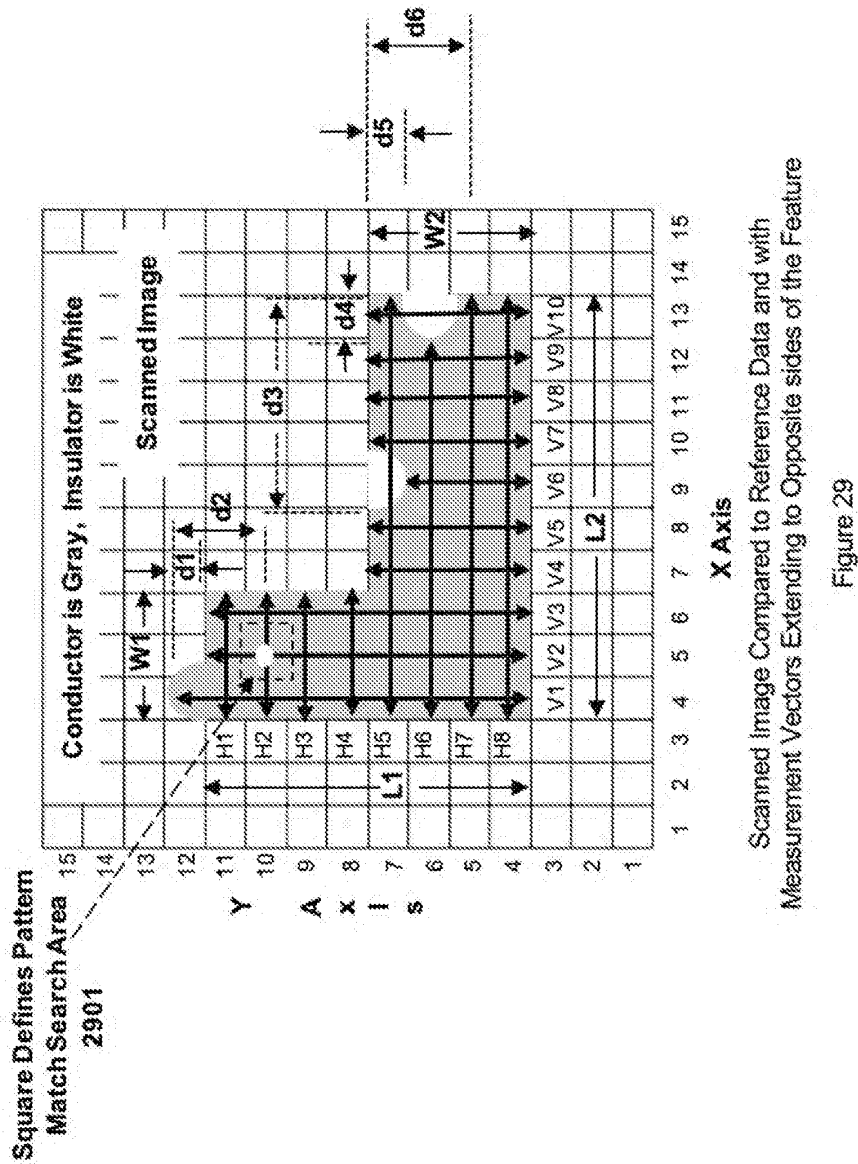
Figure 28A

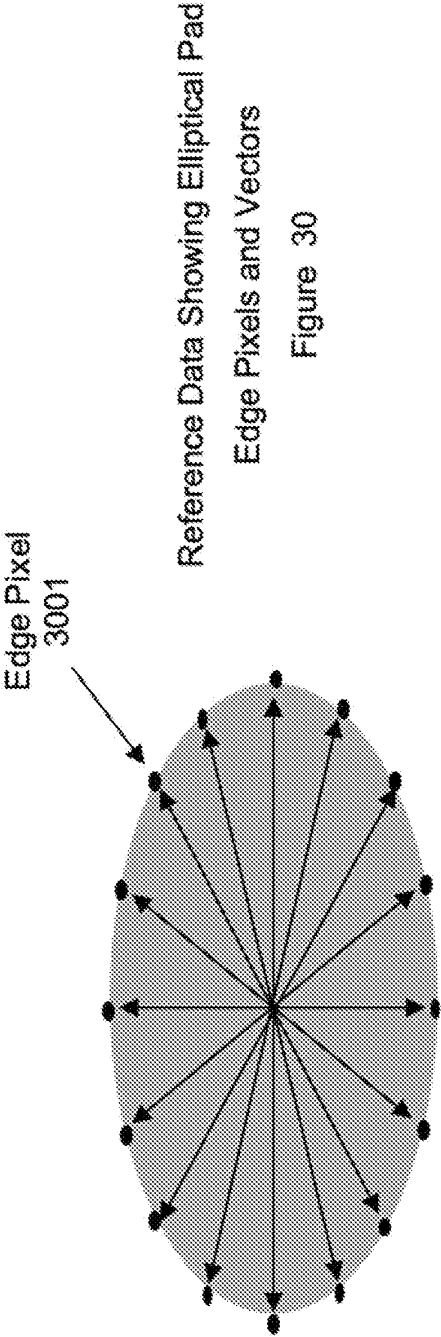
Table 28-1 Critical Width Vector Measurements Computed From Feature in Scanned Image of Figure 28A					
Vector	Starting Conductor Edge Position Found	Ending Conductor Edge Position Found	Measurement Angle	Width Measured in Scanned Image and Used to Compute Statistical Data	Design Width from Reference Data
CW-V _{2F}	2AF (2 _{AX} , 2 _{AY})	2BF (2 _{BX} , 2 _{BY})	0	$CW-V_{2F} = \sqrt{(2_{AX}-2_{BX})^2 + (2_{AY}-2_{BY})^2}$	W1
CW-V _{3F}	3AF (3 _{AX} , 3 _{AY})	3BF (3 _{BX} , 3 _{BY})	45	$CW-V_{3F} = \sqrt{(3_{AX}-3_{BX})^2 + (3_{AY}-3_{BY})^2}$	W2
CW-V _{4F}	4AF (4 _{AX} , 4 _{AY})	4BF (4 _{BX} , 4 _{BY})	90	$CW-V_{4F} = \sqrt{(4_{AX}-4_{BX})^2 + (4_{AY}-4_{BY})^2}$	W2
CW-V _{5F}	5AF (5 _{AX} , 5 _{AY})	5BF (5 _{BX} , 5 _{BY})	90	$CW-V_{5F} = \sqrt{(5_{AX}-5_{BX})^2 + (5_{AY}-5_{BY})^2}$	W1

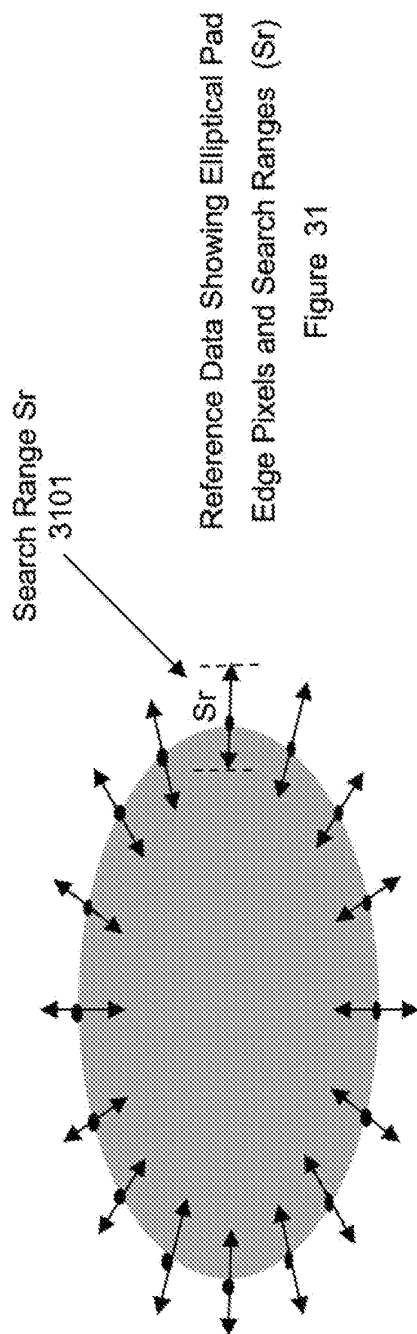
Figure 28B

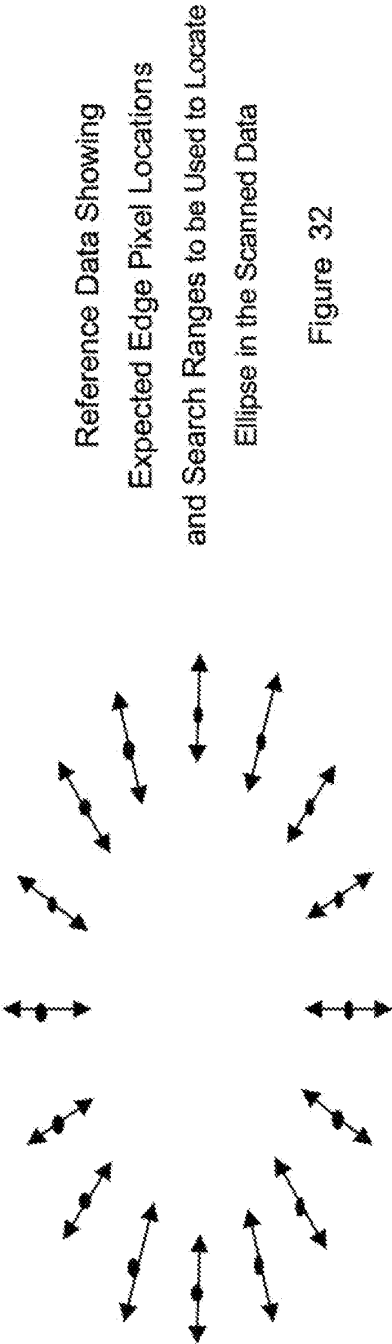
Table 28-2				
Statistical Data Computed From Critical Width Vector Measurements for the Feature in Figure 28A				
Design Width Reference Data	Minimum	Average	Maximum	Standard Deviation STD
W1	Minimum value of all Critical Width Vectors measured whose design width in the Reference Data is supposed to be W1	Average value of all Critical Width Vectors measured whose design width in the Reference Data is supposed to be W1	Minimum value of all Critical Width Vectors measured whose design width in the Reference Data is supposed to be W1	Standard Deviation of all Critical Width Vectors measured whose design width in the Reference Data is supposed to be W1
W2	Minimum value of all Critical Width Vectors measured whose design width in the Reference Data is supposed to be W2	Average value of all Critical Width Vectors measured whose design width in the Reference Data is supposed to be W2	Minimum value of all Critical Width Vectors measured whose design width in the Reference Data is supposed to be W2	Standard Deviation of all Critical Width Vectors measured whose design width in the Reference Data is supposed to be W2

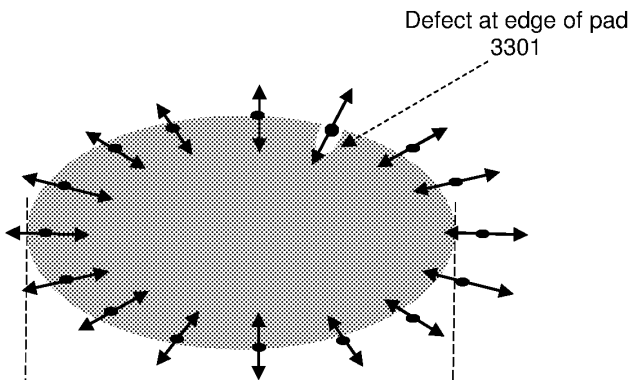
Figure 28C











Scanned Image of Defective Pad
Superimposed On
Expected Edge Pixel Locations
With Search Ranges

Figure 33

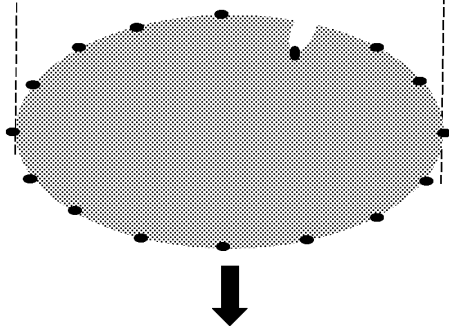


Figure 34

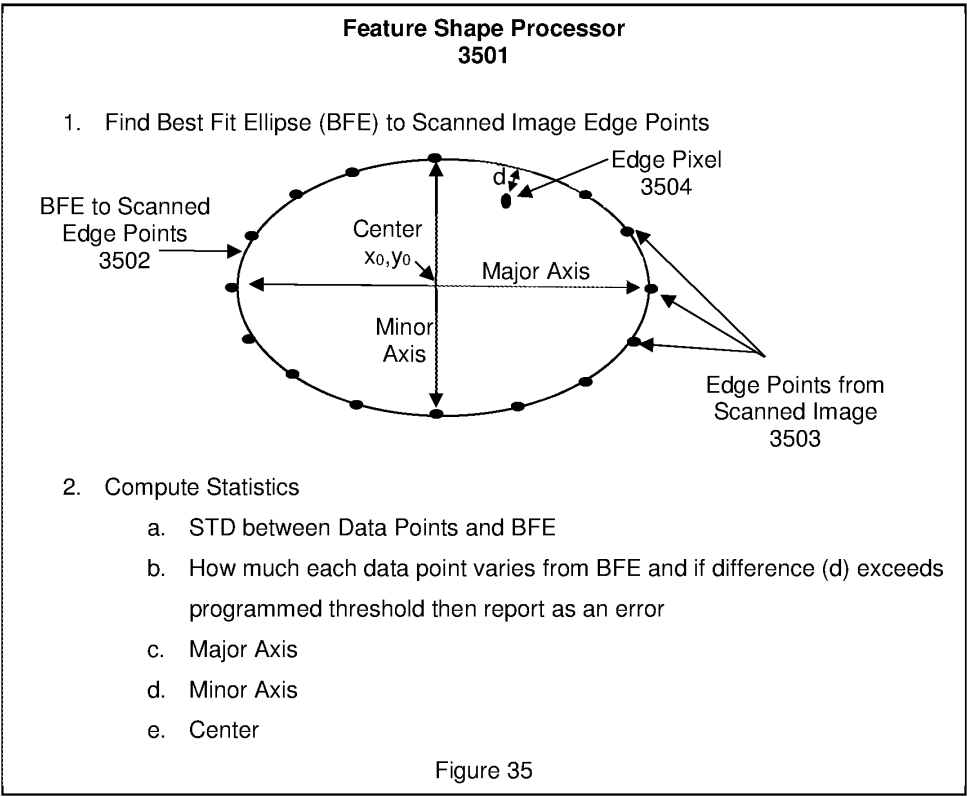
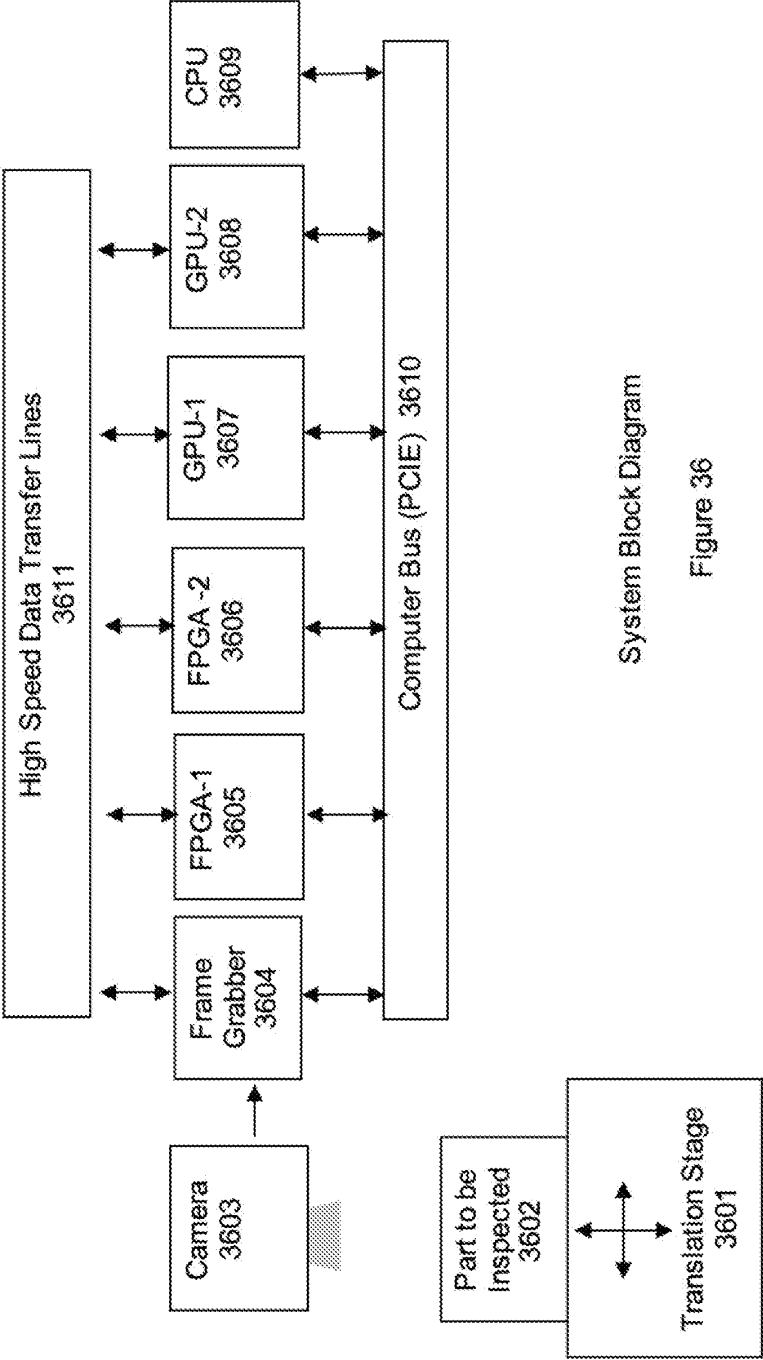


Figure 35



System Block Diagram

Figure 36

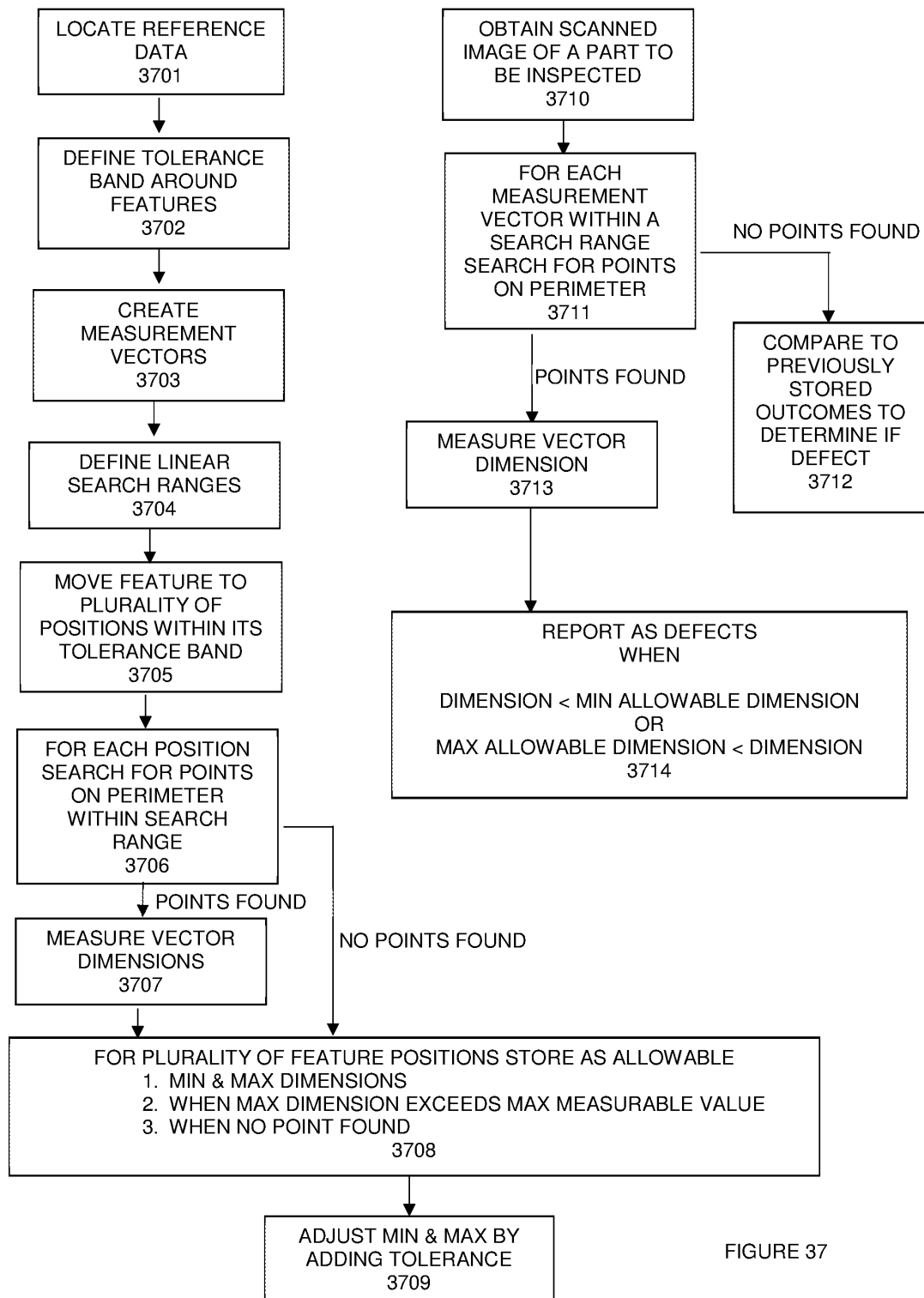


FIGURE 37

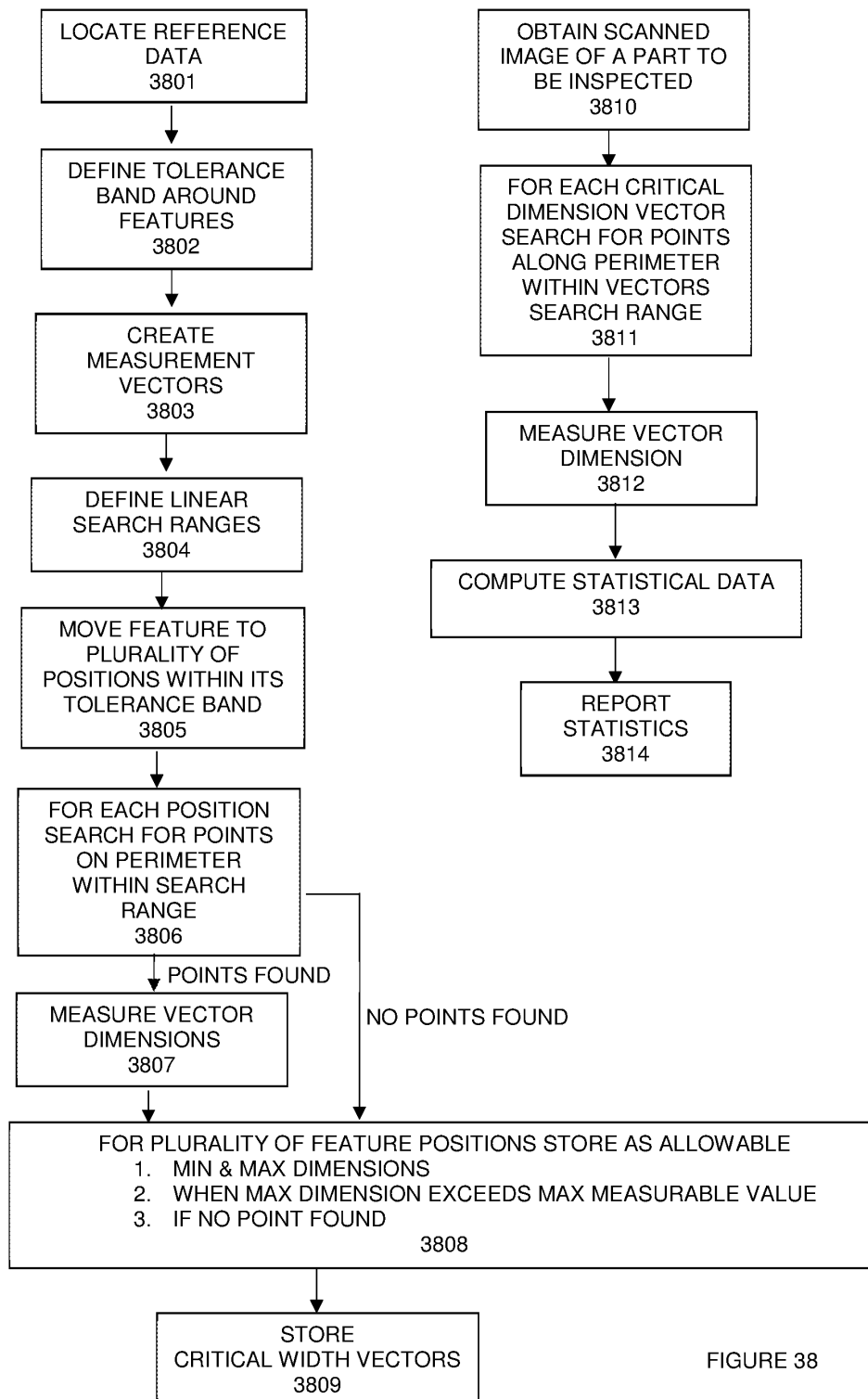


FIGURE 38