NOTE 2: The bottom of the SEMI E85 exclusion volumes defines the top of the SEMI E84 connector zones. For Option A, the top of the connector zone is defined by dimension H2. For Option B, the top of the connector zone is defined by dimension H0. For Options C, D, and E and F, the top of the connector zone is defined by dimension H4.

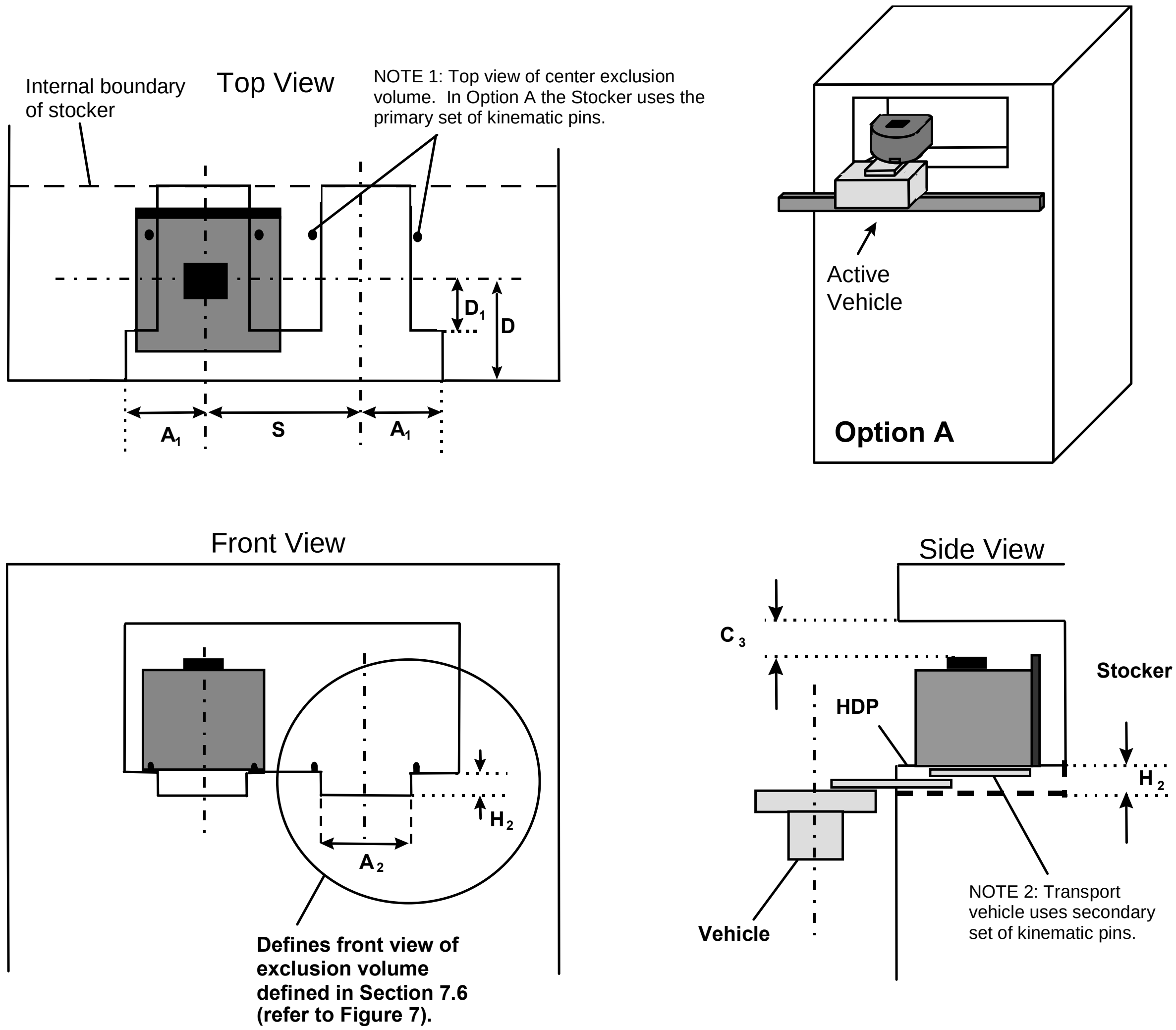
Table 1 Dimensional Requirements for 300 mm AMHS Interbay Load Ports (FOUP ONLY)

Dim	*Definition*	*Option A*	*Option B*	*Option C*	*Option D*	*Option E*	*Option F*
θ (deg)	tilt of the open cassette when placed to the load port	0	SEMI E15.1	0	0	0	N/A
A1	minimum width of the load port cavity or cut-out in the stocker measured from the bilateral datum plane to the nearest obstruction on the stocker	375 mm	N/A	600 mm for HT only (See #1.)	N/A	N/A	N/A
A2	width of the exclusion zone for center pickup using the secondary kinematic coupling pins (symmetric about the bilateral datum plane)	213 +2/-0 mm	N/A	213 +2/-0 mm	213 +2/-0 mm		213 + 2/-0
A3	Minimum width of the exclusion zone (starting at a distance D10 from the FDP) for center pickup using the secondary kinematic coupling pins (symmetric about the bilateral datum plane)	N/A	N/A	225 mm	225 mm	N/A	N/A
A6	maximum protrusion of the interbay transport measured from the bilateral datum plane of the transport (start of the exclusion volume for fork-lift or conveyor rail transfer)	N/A	SEMI E15.1	N/A	N/A	165 mm	N/A
A8	minimum width of the exclusion volume for the fork-lift or conveyor rail transfer mechanism measured from the bilateral datum plane (end of the exclusion volume for fork-lift or conveyor rail transfer)	N/A	N/A	N/A	N/A	245 mm (80 wide)	N/A
C3	height of the nearest stocker obstacle above the carrier during transfer measured from the HDP of the transport—the maximum height of the carrier. This creates an exclusion zone for use of the top robotic flange.	150 mm	SEMI E15.1	N/A	N/A	N/A	N/A
C5	distance from the facial datum plane of the transport to the internal stocker boundary	N/A	SEMI E15.1	250 ± 50 mm	N/A	N/A	250 ± 50 mm
D	distance from the stocker boundary to the facial datum plane on the stocker load port (A,B)	240 mm	SEMI E15.1 250 +0/-10 mm	N/A	N/A	N/A	N/A
D1	maximum distance or protrusion of any load port feature measured from the facial datum plane on the load port (inside the stocker cut-out)	150 mm	SEMI E15.1 200 +10/-4 mm	N/A	N/A	N/A	TBD
D5	distance from the facial datum plane of the interbay transport system to the stocker boundary	N/A	SEMI E15.1	N/A	250 ± 50 mm	250 ± 50 mm	N/A

Dim	*Definition*	*Option A*	*Option B*	*Option C*	*Option D*	*Option E*	*Option F*
D6	minimum distance or length of the center exclusion volume of the interbay transport system measured backwards from the facial datum plane of the interbay transport system to allow for stocker pick up using the secondary kinematic pins	N/A	SEMI E15.1	90 mm	90 mm	TBD	TBD
D10	distance measured from the facial datum plane (FDP) where the depth of the center exclusion zone lowers from H2 to H4 in the interbay transport system (C,D)	N/A	SEMI E15.1	150 mm or 230 mm [#1]	150 mm or 230 mm [#1]	150 mm or 230 mm [#1]	150 mm or 230 mm [#1]
H	Height of the horizontal datum plane of the interbay load port (stocker) or interbay transport system determined by user and supplier	TBD [#1] and must be adjustable by ± 10 mm	TBD [#1] and must be adjustable by ± 10 mm	TBD [#1] and must be adjustable by ± 10 mm	TBD [#1] and must be adjustable by 10 mm	TBD [#1] and must be adjustable by 10 mm	TBD [#1] and must be adjustable by 10 mm
H2	depth of exclusion zone below the horizontal datum plane (HDP) of the stocker load port (A,B) OR the interbay transport system (C,D)	130 mm	SEMI E15.1	100 mm	100 mm	100 mm	100 mm
H4	depth of the exclusion zone below the horizontal datum plane (HDP) of interbay transport system (C,D) starting at a distance D10 from the facial datum plane (FDP)	N/A	N/A	170 mm	170 mm	170 mm	170 mm
S	distance between the bilateral datum plane of two adjacent load ports	450 mm	505 mm	N/A	N/A	N/A	N/A
T3	height of the open volume in that it allows the interbay transport system to enter the stocker the transport. This exclusion zone is occupied by the transport itself, the maximum height of the carrier, a clearance above carrier, and a clearance below the transport.	N/A	N/A	800 mm or 1150 mm [#1]	N/A	N/A	N/A

[#1] User to specify which dimension (see §6).

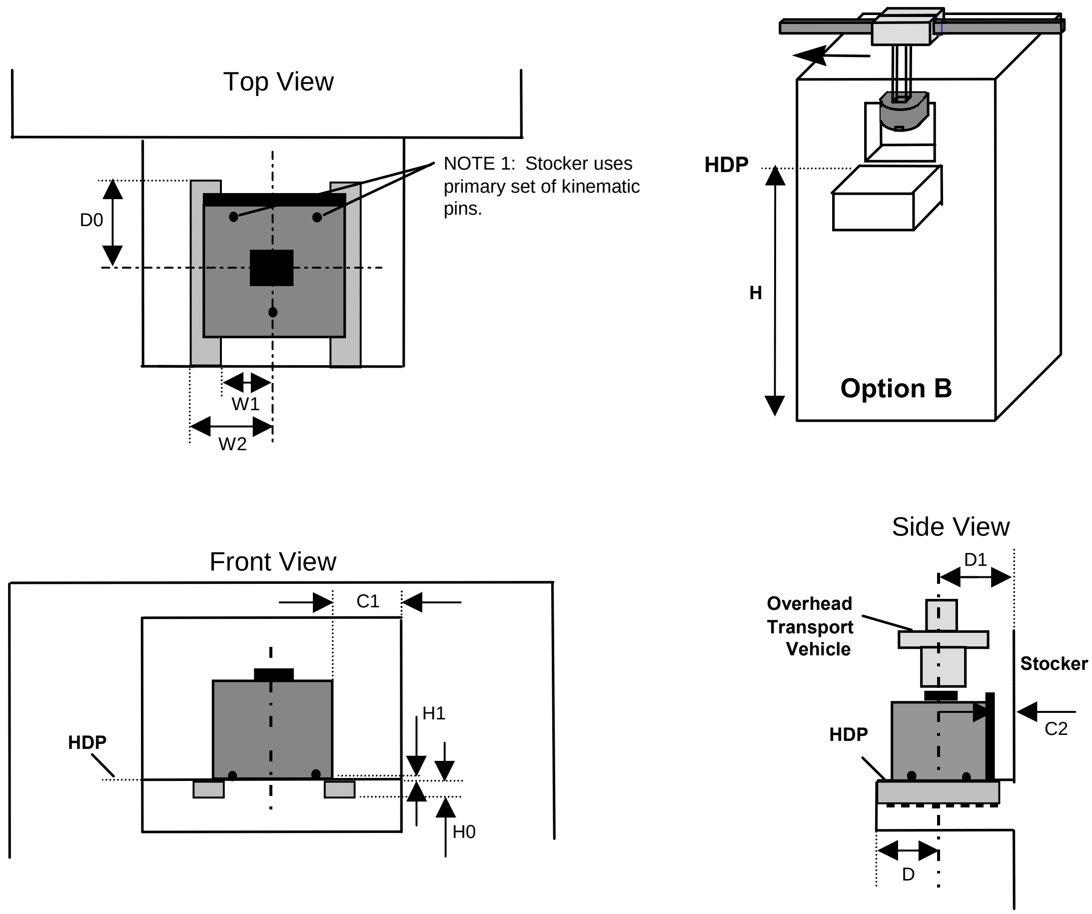
Active Transport Delivers a Carrier to an Internal Stocker Position



Option A	***H2*** *(min)*	***A1*** *(min)*	***A2*** *(range)*	***C3*** *(min)*	***D*** *(max)*	***D1*** *(max)*	***S*** *(min)*	Θ *(deg)*
FOUP	130	375	213 +2/-0	150	240	150	450	0
Open Cassette	140	375	213 +2/-0	100	270	150	450	2

Figure 1
AMHS Interbay Load Port Option A

Active Transport Delivers a Carrier to an Internal Stocker Position

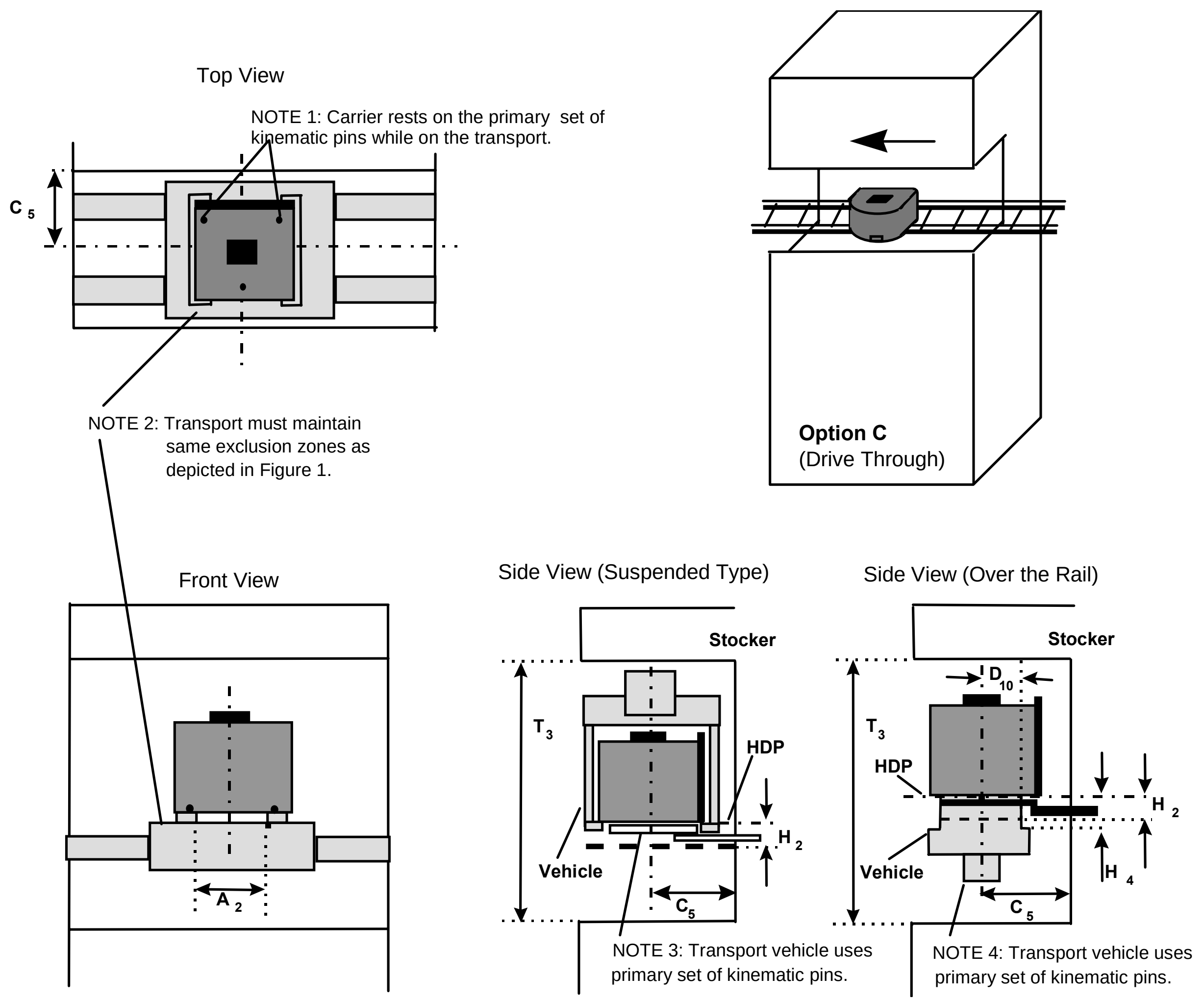


Option B	***H*** *#1*	***H0*** *(min)*	***H1*** *(max)*	***C1*** *(min)*	***C2*** *(min)*	***D0*** *(min)*	***D*** *(range)*	***D1*** *(range)*	***W1*** *(max)*	***W2*** *(min)*
FOUP	TBD	40	25	75	30	110	250 +0/-10	200 +10/-4	130	205
Open Cassette	TBD	50	25	75	30	110	250 +0/-10	200 +10/-4	130	205

#1 User to specify actual dimension (see ¶ 6.2).

Figure 2
AMHS Interbay Load Port Option B

Active Transport Delivers a Carrier to an Internal Stocker Position

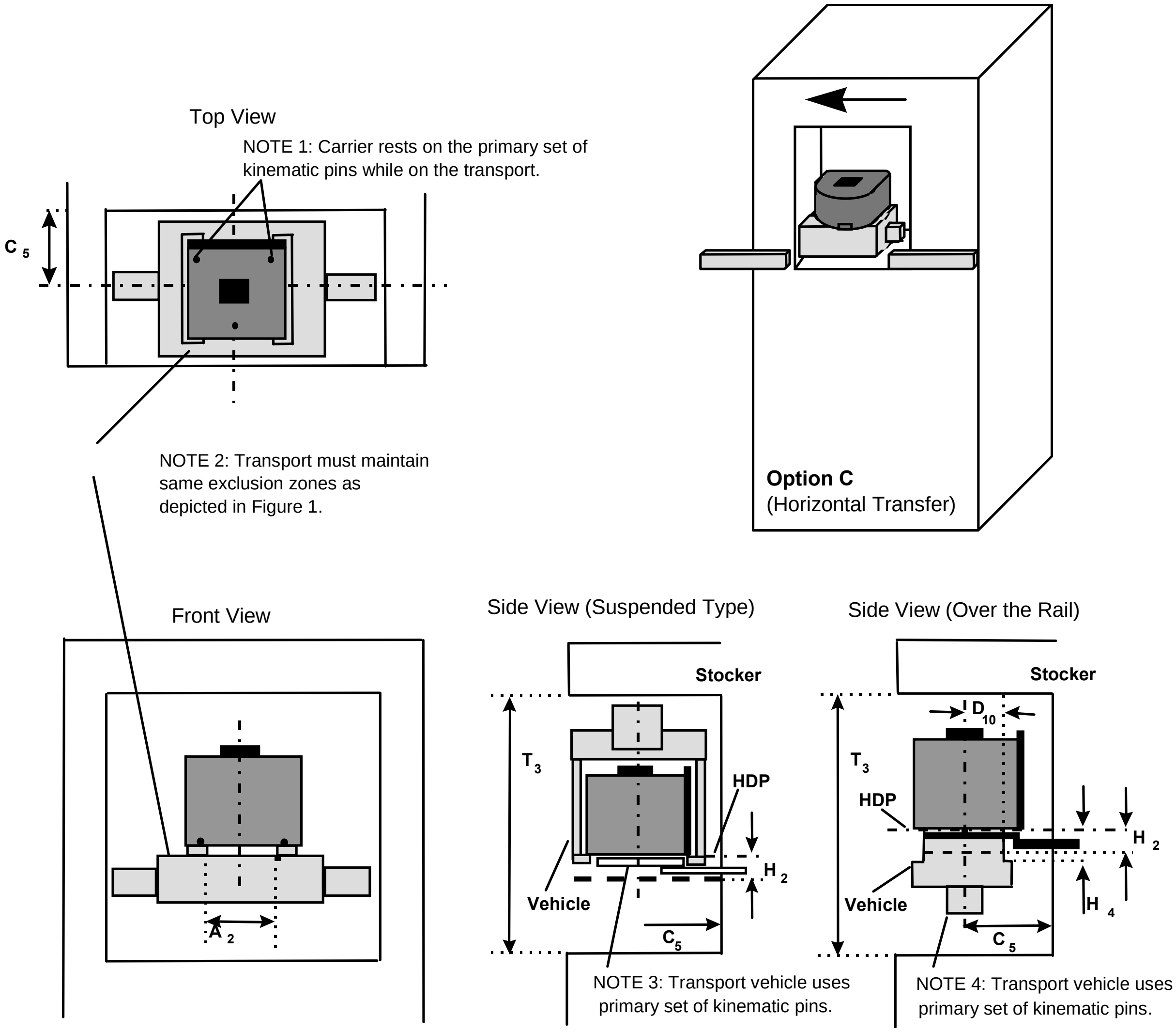


Option C (Drive Through)	***H2*** *(min)*	***H4*** *(min)*	***A1*** *(min)*	***A2*** *(range)*	***A3*** *(min)*	***C5*** *(range)*	***D10*** *(max)* #1	***D6*** *(min)*	***T3*** *(min)* #1	*Θ (deg)*
FOUP	100	170	N/A	213 +2/-0	225	250 ± 50	150 or 230	112	800 or 1150	0
Open Cassette	110 #1	170	N/A	213 +2/-0	225	250 ± 50	150 or 230	112	800 or 1150	2

#1 User to specify which dimension (see ¶6.3.1).

Figure 3
AMHS Interbay Load Port Option C (Drive Through)

Active Transport Delivers a Carrier to an Internal Stocker Position

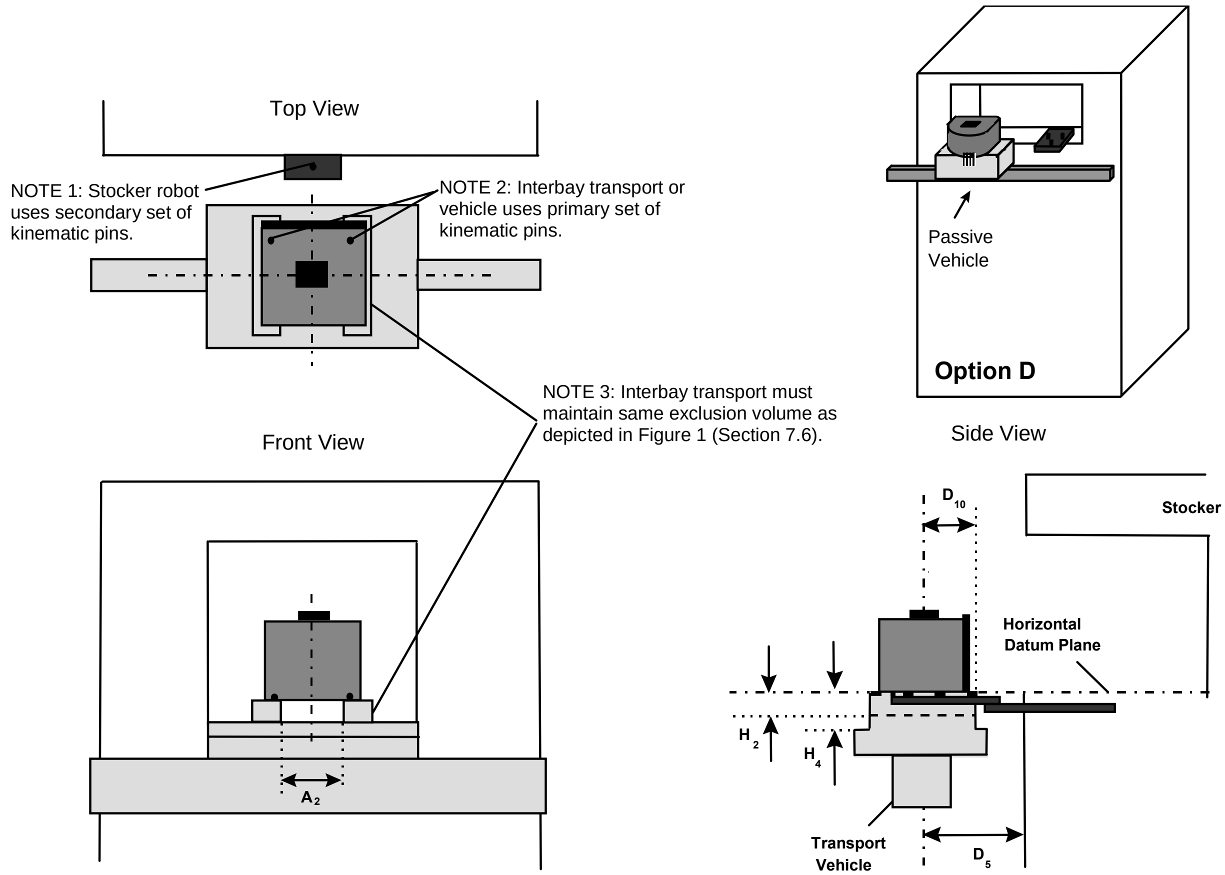


Option C (Horizontal Transfer)	***H2*** *(min)*	***H4*** *(min)*	***A1*** *(min)*	***A2*** *(range)*	***A3*** *(min)*	***C5*** *(range)*	***D10*** *(max)* [#1]	***D6*** *(min)*	***T3*** *(min)* [#1]	*Θ (deg)*
FOUP	100	170	600	213 +2/-0	225	250 ± 50	150 or 230	112	800 or 1150	0
Open Cassette	110 [#1]	170	600	213 +2/-0	225	250 ± 50	150 or 230	112	800 or 1150	2

[#1] User to specify which dimension (see ¶6.3.1.)

Figure 4
AMHS Interbay Load Port Option C (Horizontal Transfer)

Active Transport Delivers a Carrier to an Internal Stocker Position

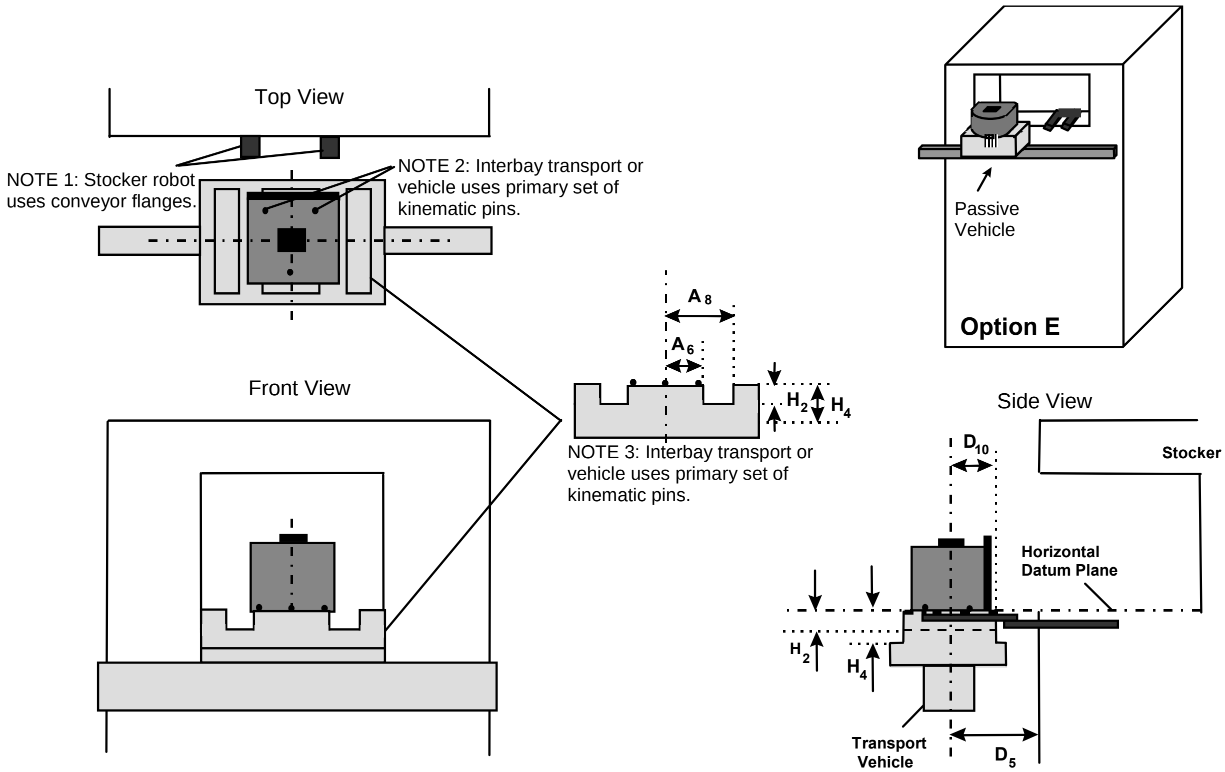


Option D *(Kinematic Coupling Pin Pick-Up)*	***H2*** *(min)*	***H4*** *(min)*	***A2*** *(range)*	***A3*** *(min)*	***D5*** *(range)*	***D10*** *(min)* [#1]	*Θ (deg)*
FOUP	100	170	213 +2/ -0	225	250 ± 50	150 or 230	0
Open Cassette	110	180	213 +2/ -0	225	250 ± 50	150 or 230	2

[#1] User to specify which dimension (see ¶6.3.2).

Figure 5
AMHS Interbay Load Port Option D (Kinematic Coupling Pin Pick-Up)

Active Transport Delivers a Carrier to an Internal Stocker Position



Option E *(Conveyor Flange Pick-Up)*	***H2*** *(min)*	***H4*** *(min)*	***A6*** *(max)*	***A8*** *(min)*	***D5*** *(range)*	***D10*** *(min)* *(See #1.)*	*Θ (deg)*
FOUP	40	170	165	245 (80 wide)	250 ± 50	150 or 230	0
Open Cassette	50	180	123	203 (80 wide)	250 ± 50	150 or 230	2

#1 User to specify which dimension (see ¶6.3.3).

Figure 6
AMHS Interbay Load Port Option E (Conveyor Flange Pick-Up)

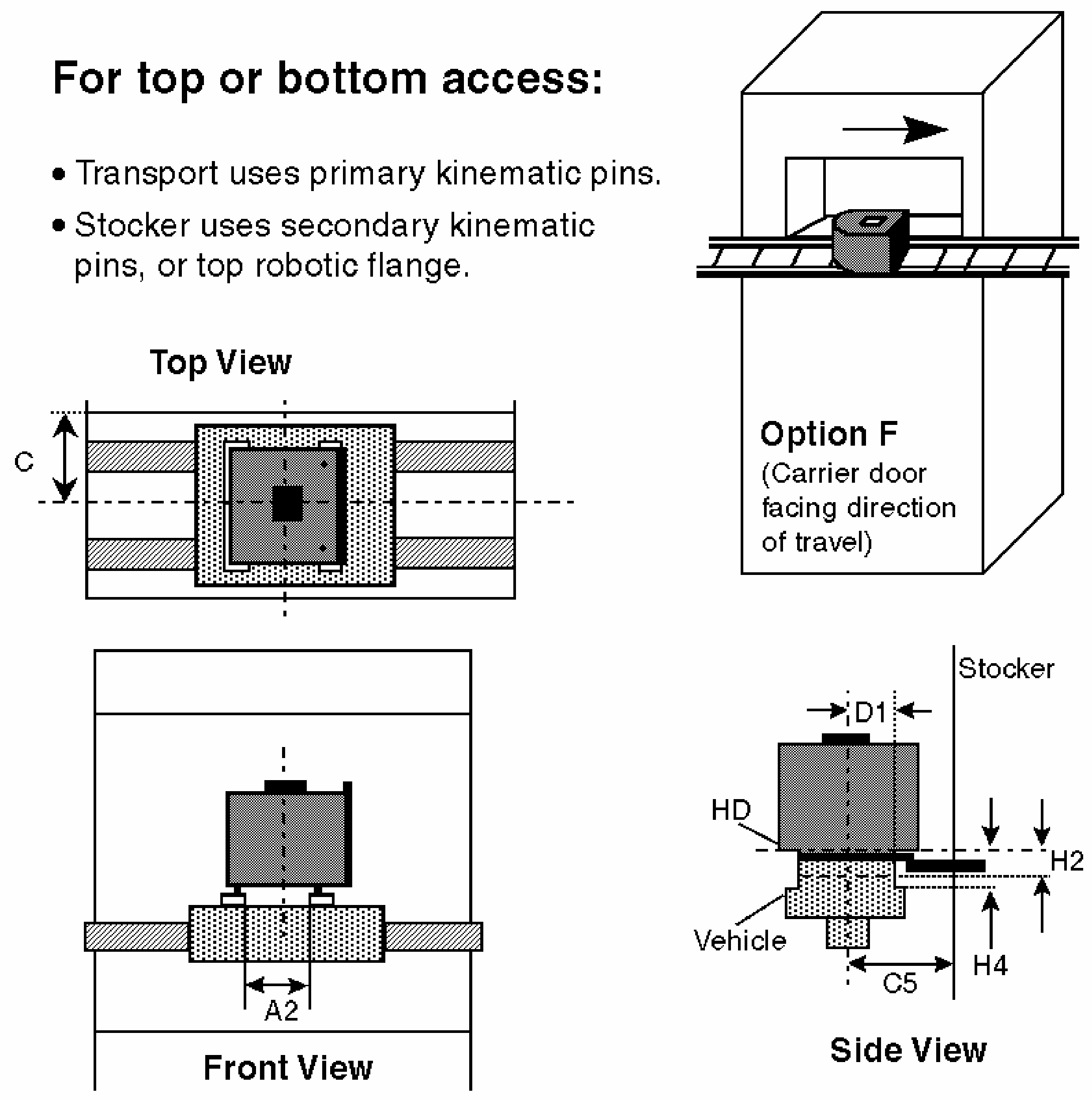


Figure 7
AMHS Interbay Load Port Option F (Carrier Oriented perpendicular to face plane)
(Top and Bottom Access)

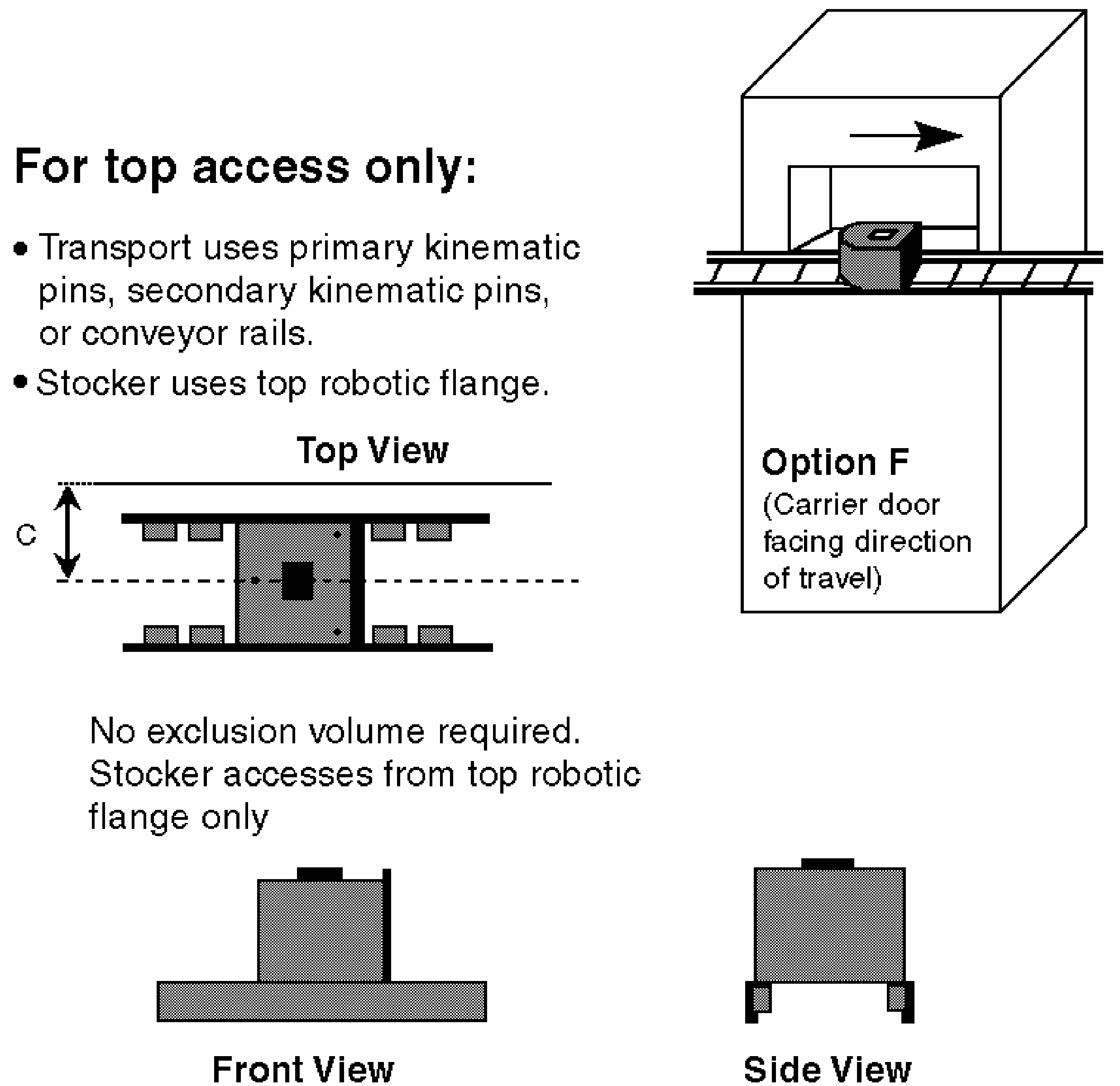


Figure 8
AMHS Interbay Load Port Option F' (Carrier Oriented perpendicular to face plane)
(Top Access Only)

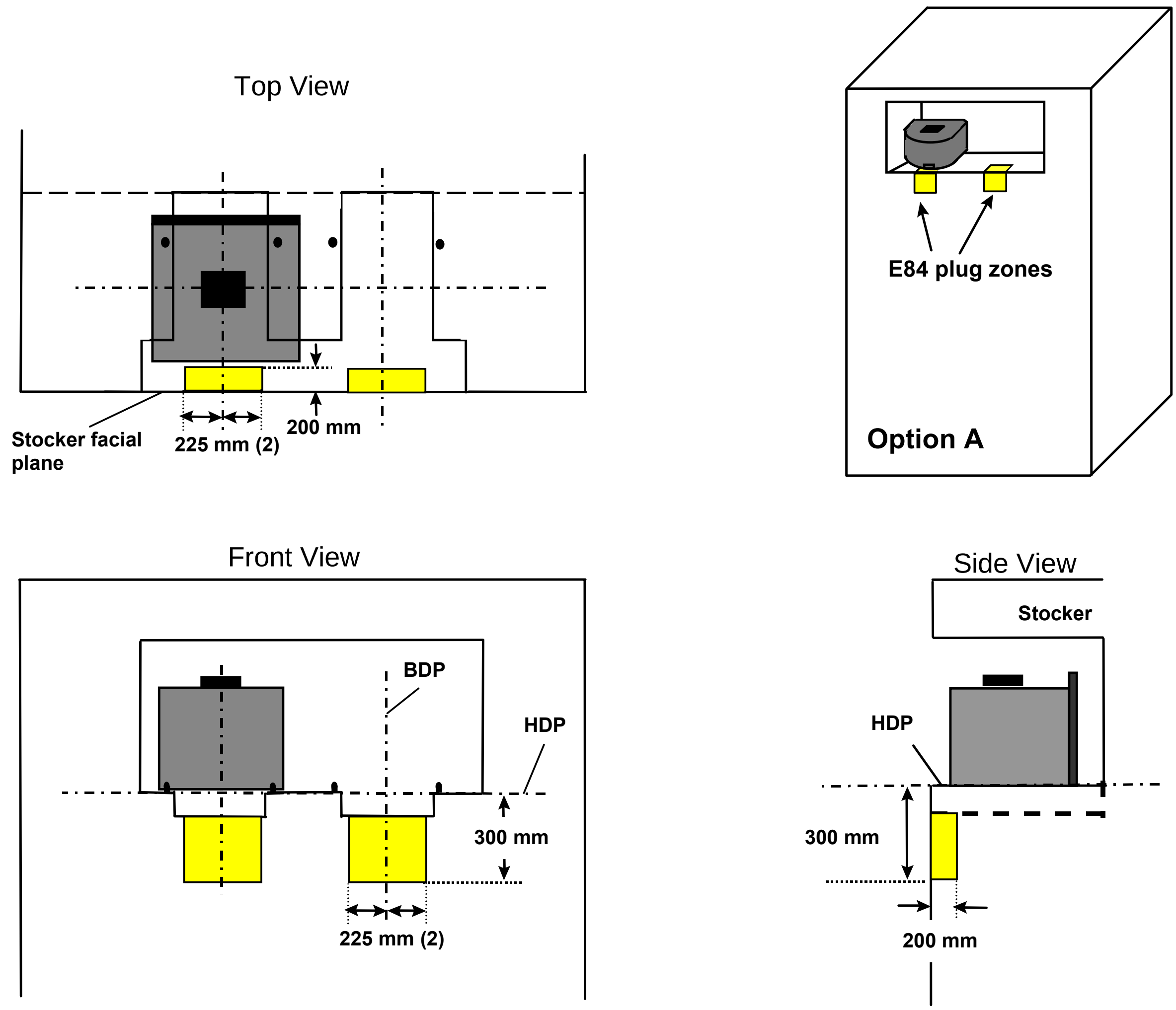
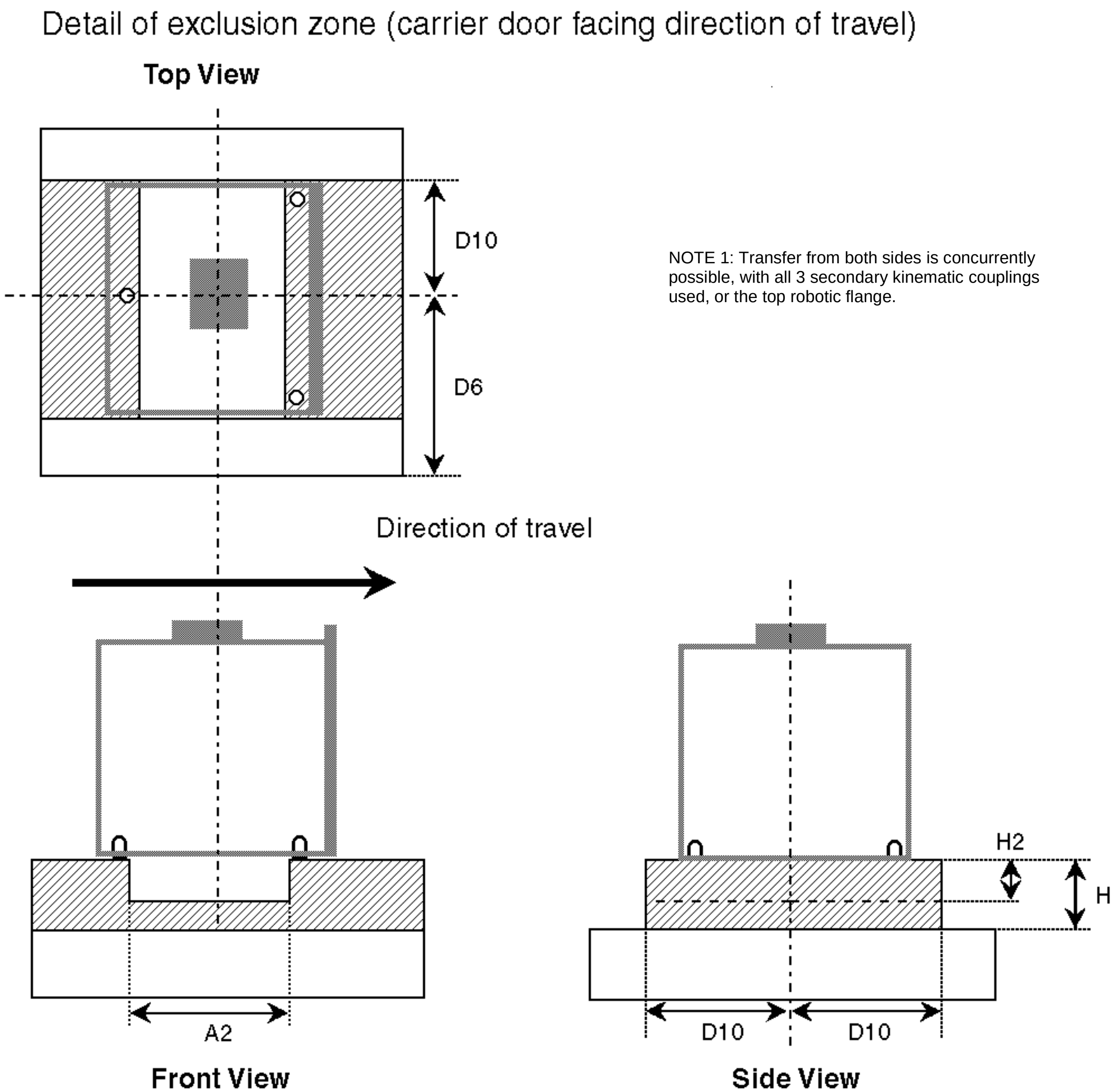


Figure 9
Drawing of Example Available Area for Connector on Stocker for Option A



NOTE 1: Transfer from both sides is concurrently possible, with all 3 secondary kinematic couplings used, or the top robotic flange.

NOTE 2: Figure 8 and all exclusion zone dimensions for Option F only apply if bottom access is required.

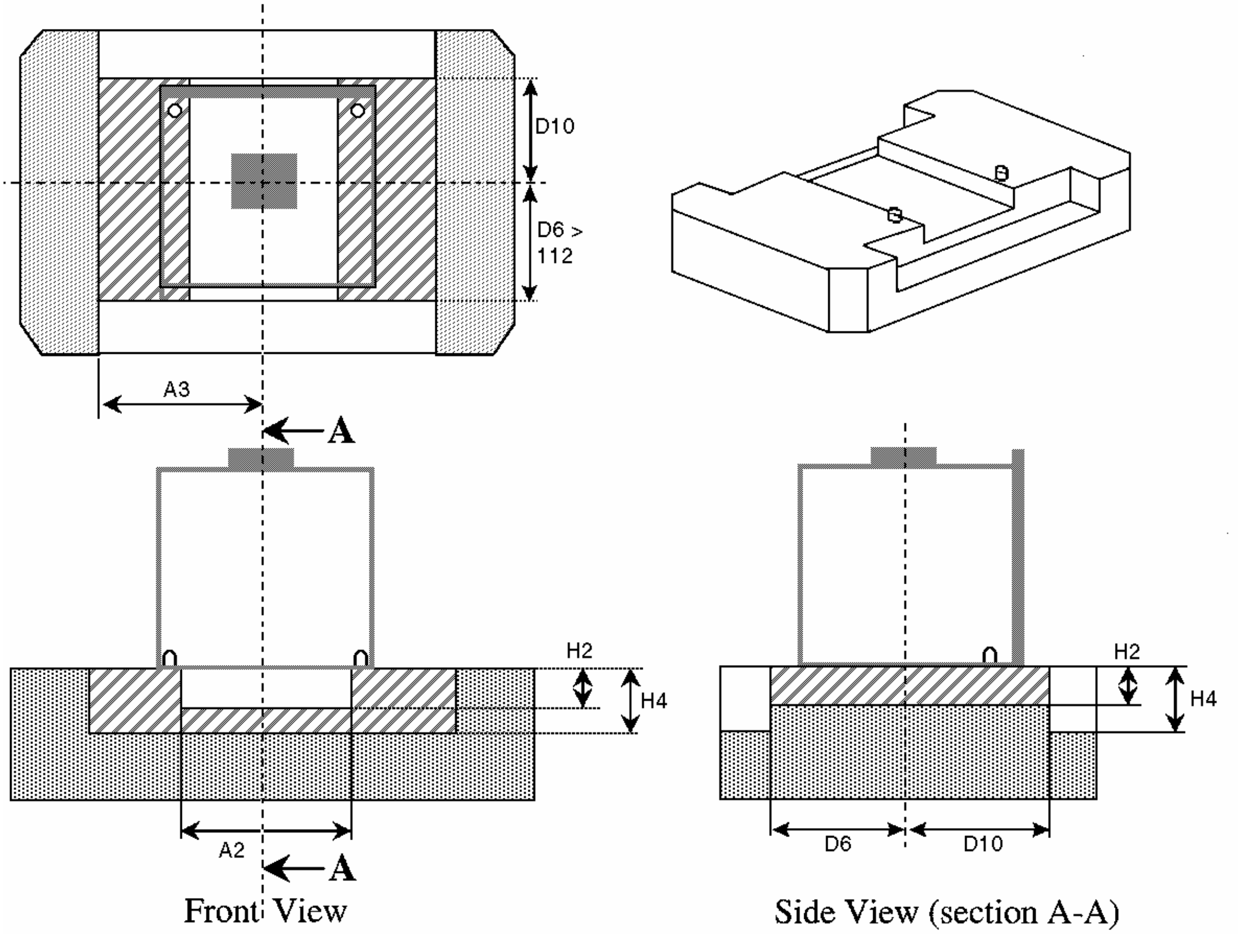
Figure 10
Exclusion Zone Detail – Option F

Table 2 Dimensional Requirements for 300 mm AMHS Interbay Load Ports (Open Cassette Only)

Dim	*Definition*	*Option A*	*Option B*	*Option C*	*Option D*	*Option E*	*Option F*
θ (deg)	tilt of the open cassette when placed to the load port	2	SEMI E15.1	2	2	2	2
A1	minimum width of the load port cavity or cut-out in the stocker measured from the bilateral datum plane to the nearest obstruction on the stocker	375 mm	N/A	600 mm for HT only #1	N/A	N/A	N/A
A2	width of the exclusion zone for center pickup using the secondary kinematic coupling pins (symmetric about the bilateral datum plane)	213 +2/-0 mm	SEMI E15.1	213 +2/-0 mm	213 +2/-0 mm	213 +2/-0 mm	213+2/-0 mm
A3	Minimum width if the exclusion zone (starting at a distance D10 from the FDP) for center pickup using the secondary kinematic coupling pins (symmetric about the bilateral datum plane)	N/A	N/A	225 mm	225 mm	N/A	N/A
A6	maximum protrusion of the interbay transport measured from the bilateral datum plane of the transport (start of the exclusion volume for fork-lift or conveyor rail transfer)	N/A	SEMI E15.1	N/A	N/A	123 mm	N/A
A8	minimum width of the exclusion volume for the fork-lift or conveyor rail transfer mechanism measured from the bilateral datum plane (end of the exclusion volume for fork-lift or conveyor rail transfer)	N/A	N/A	N/A	N/A	203 mm (80 wide)	N/A
C3	height of the nearest stocker obstacle above the carrier during transfer measured from the HDP of the transport— the maximum height of the carrier. This creates an exclusion zone for use of the top robotic flange..	100 mm	SEMI E15.1	N/A	N/A	N/A	N/A
C5	distance from the facial datum plane of the transport to the internal stocker boundary	N/A	SEMI E15.1	250 ± 50 mm	N/A	N/A	250 ± 50 mm
D	distance from the stocker boundary to the facial datum plane on the stocker load port (A,B)	270 mm	250 +0/-10 mm	N/A	N/A	N/A	N/A
D1	maximum distance or protrusion of any load port feature measured from the facial datum plane on the load port (inside the stocker cut-out)	150 mm	SEMI E15.1 200 +10/-4 mm	N/A	N/A	N/A	TBD
D10	distance measured from the facial datum plane (FDP) where the depth of the center exclusion zone lowers from H2 to H4 in the interbay transport system (C,D)	N/A	SEMI E15.1	150 mm or 230 mm #1	150 mm or 230 mm #1	150 mm or 230 mm #1	150 mm or 230 mm #1
D5	distance from the facial datum plane of the interbay transport system (vehicle) to the stocker boundary	N/A	SEMI E15.1	N/A	250 ± 50 mm	250 ± 50 mm	TBD

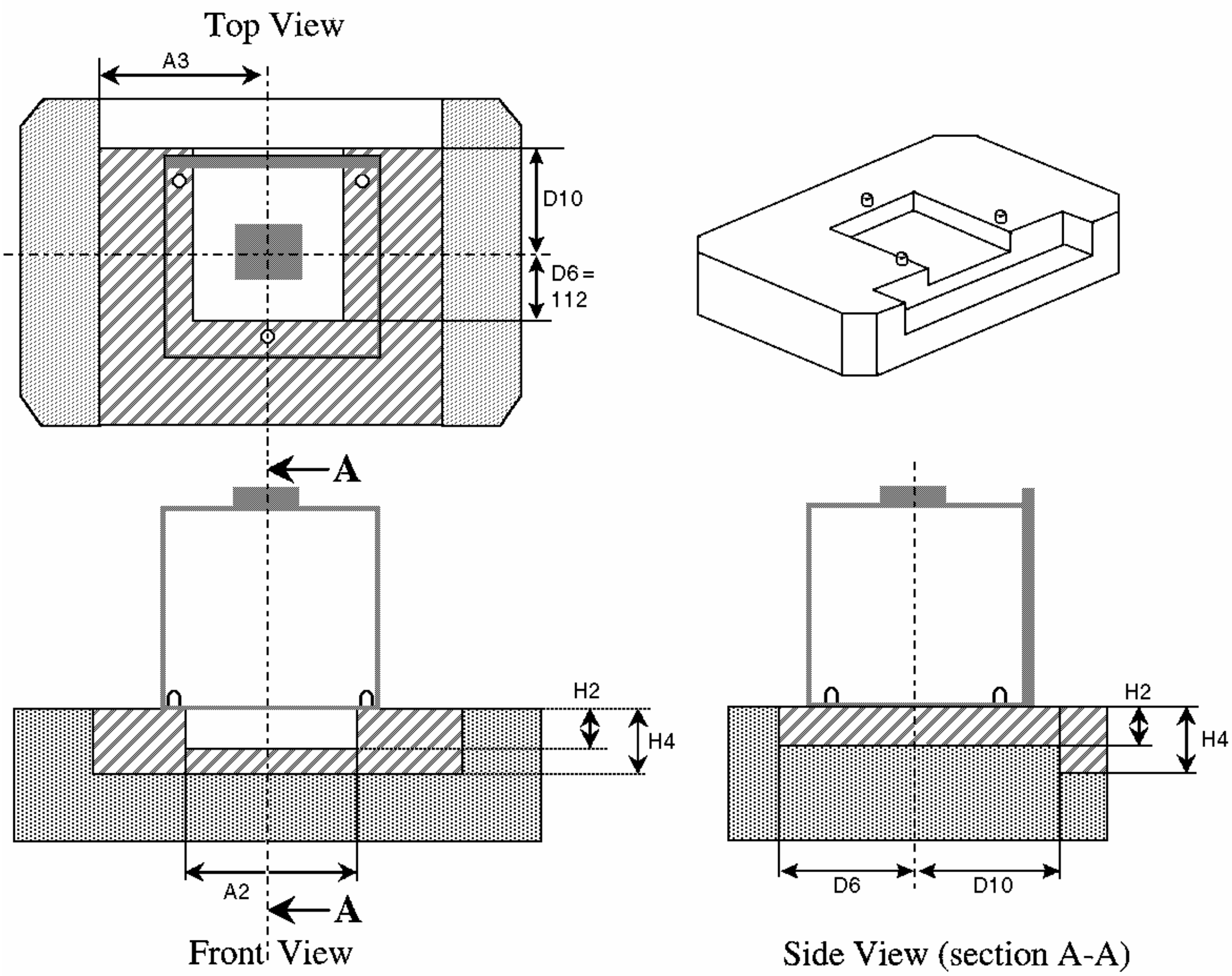
Dim	Definition	Option A	Option B	Option C	Option D	Option E	Option F
D6	distance of the inner cavity or cut-out of the interbay transport system as measured from the facial datum plane of the interbay transport system to allow for stocker pick up using the secondary kinematic pins	N/A	SEMI E15.1	90 mm	TBD	TBD	TBD
H	height of the horizontal datum plane of the interbay load port (stocker) or interbay transport system (vehicle) determined by user and supplier	TBD [#1] and must be adjustable by ± 10 mm	TBD [#1] and must be adjustable by ± 10 mm	TBD [#1] and must be adjustable by ± 10 mm	TBD [#1] and must be adjustable by ± 10 mm	TBD [#1] and must be adjustable by ± 10 mm	TBD [#1] and must be adjustable by ± 10 mm
H2	depth of exclusion zone below the horizontal datum plane (HDP) of the stocker load port (A,B) OR the interbay transport system (C,D)	140 mm	SEMI E15.1	100 mm	110 mm	50 mm	100 mm
H4	depth of the exclusion zone below the horizontal datum plane (HDP) of interbay transport system (C,D) starting at a distance D10 from the facial datum plane (FDP)	N/A	N/A	170 mm	180 mm	180 mm	170 mm
S	distance between the bilateral datum plane of two adjacent load ports	450 mm	SEMI E15.1	N/A	N/A	N/A	N/A
T3	height of the open volume in that it allows the interbay transport system to enter the stocker the transport. This exclusion zone is occupied by the transport itself, the maximum height of the carrier, a clearance above carrier, and a clearance below the transport.	N/A	N/A	800 mm or 1150 mm [#1]	N/A	N/A	N/A

[#1] User to specify which dimension (see §6).



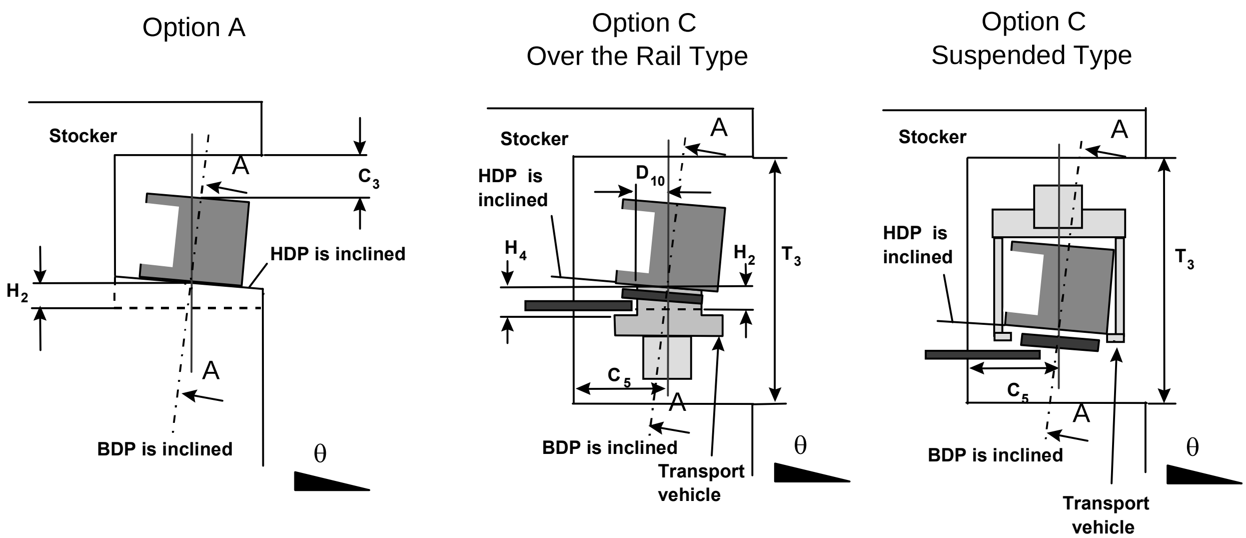
NOTE: Dimension D10 will be 150 mm or 230 mm as specified by the user.

Figure 11
Detailed Views of Center Exclusion Volume
(where D6 > minimum to allow for transfer from both sides)



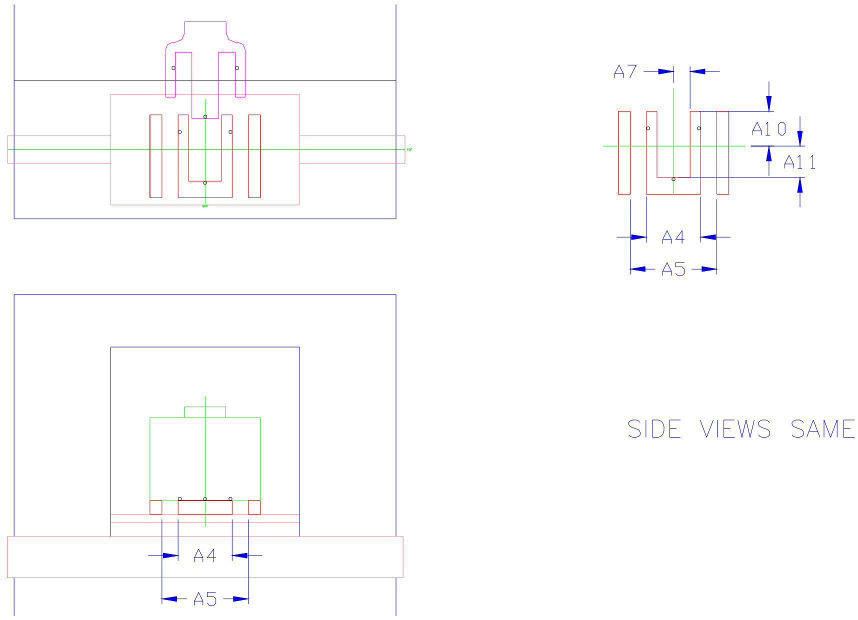
NOTE: Dimension D10 will be 150 mm or 230 mm as specified by the user.

Figure 12
Detailed Views of Center Exclusion Volume
(where D6 = minimum to allow for the carrier to seat on all 3 kinematic pins)



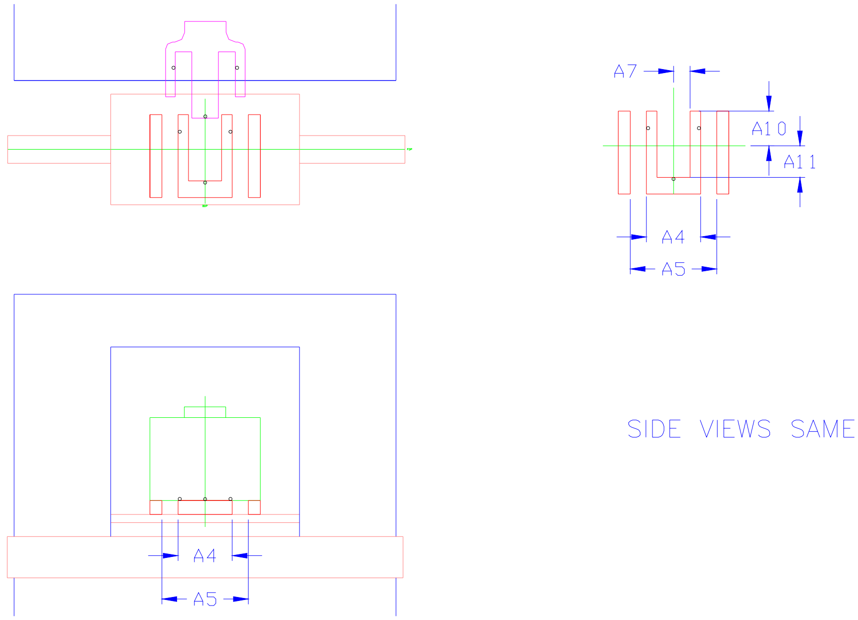
NOTE: The cross section views (A-A) of the exclusion volumes are the same as the views shown in the FOUP Figures 1–9.

Figure 13
Views Illustrating Open Cassette Options



A4	200 mm	A10	130 mm
A5	312 mm	A11	112 mm
A7	60 mm		

Figure 14
AMHS Interbay Loadport Option C'



A4	200 mm	A10	130 mm
A5	312 mm	A11	112 mm
A7	60 mm		

Figure 15
AMHS Interbay Loadport Option D’

RELATED INFORMATION 1

NOTICE: This related information is not an official part of SEMI E85. This related information was approved for publication by full letter ballot procedures on July 19, 2001.

R1-1 Except for Option F and F’, the carrier may only rest on two of the three kinematic pins as defined in SEMI E57 to allow for transfer using the secondary set of kinematic pins. The AMHS supplier must allow the rear of the carrier to rest on a SEMI defined surface defined in SEMI E47.1 (front-opening box) or SEMI E1.9 (open cassette) to ensure the carrier is properly supported. The AMHS supplier should also investigate the stability of the FOUP if it rests on only two pins. One possible solution would be to add a lead-in or retaining feature that interfaces with a SEMI defined outer carrier surface defined in SEMI E47.1 (front-opening box) or SEMI E1.9 (open cassette).

R1-2 To avoid interfering with the lead-in capability (misalignment correction) function of the kinematic couplings, it is recommended that no part of the storage device (other than the kinematic couplings) come horizontally closer than 10 mm (0.39 in.) to the carrier.

R1-3 It is recommended that the systems that deliver carriers to AMHS interbay load ports have a mechanism to correct for misalignment of storage devices and load ports.

R1-4 The dimension H2 which defines the depth of the exclusion zone that allows for carrier transfer using the secondary set of kinematic pins, might be reduced in the future.

R1-5 Dimension C5 (for Option C) and D5 (for Option D) define the range required for stocker reach. Through teaching or adjustment the stocker must be able to transfer carriers from passive interbay transport systems which have a centerline within this range (250 ± 50 mm). This dimension is measured from the center point of the wafers on the interbay transport system.

R1-6 AMHS equipment can be configured with a variety of load ports chosen from the options defined in Section 7.5. Figure R1-1a shows a storage device with two Option A interbay load ports, which may work with an active transport and any carrier.

R1-7 An IC manufacturer or user could also specify the same Option A stocker, but with only one interbay load port. Figure R1-1b shows a storage device with two Option B interbay load ports, which may work with carriers delivered by a passive transport or an overhead transport system. Again, an IC manufacturer or user could also specify the same Option B stocker, but with only one interbay load port.

R1-8 For Example Only: AMHS suppliers may implement lead-in features in various methods which promote registration using any of the SEMI defined dimensions and features of the carrier.

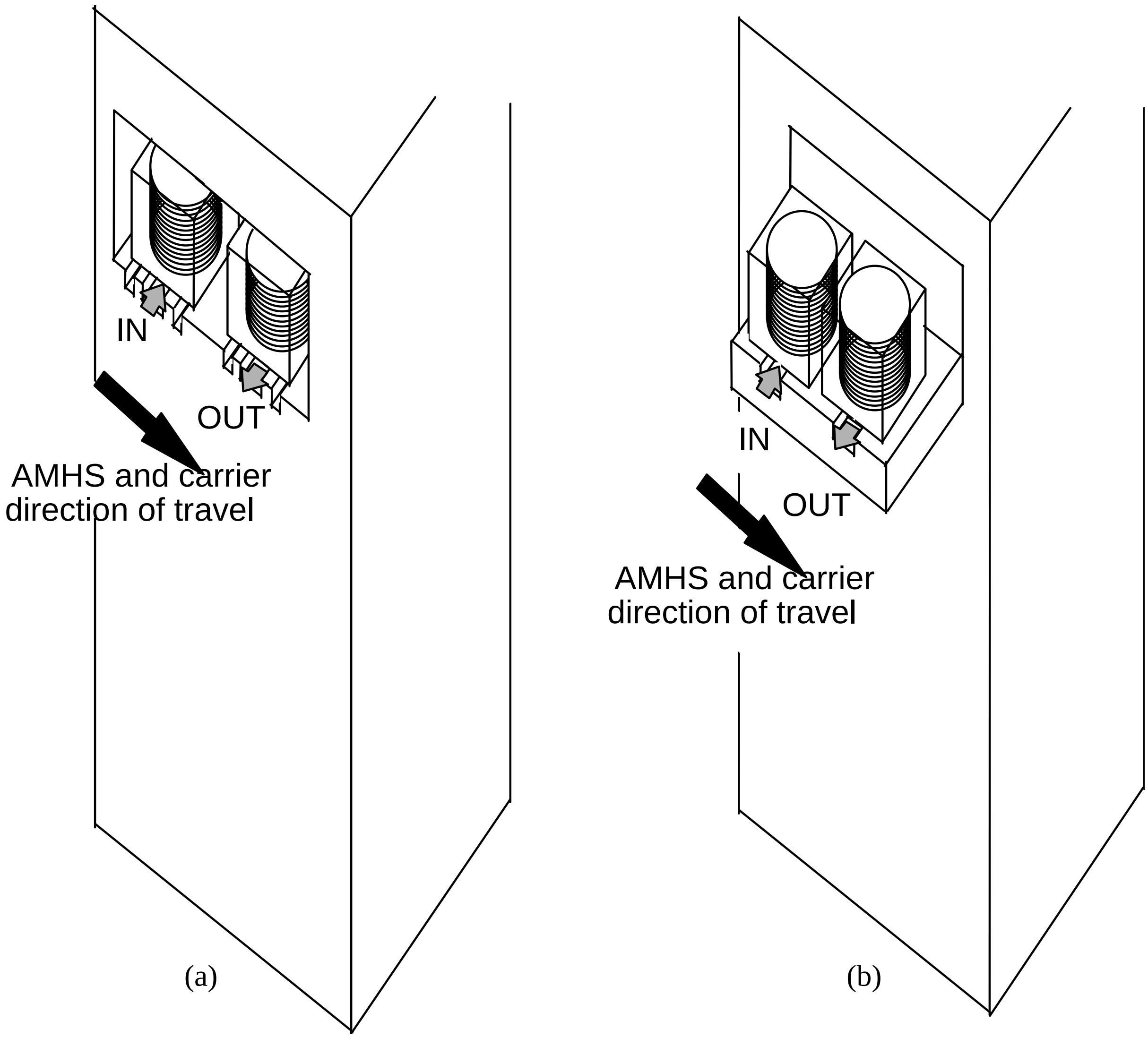


Figure R1-1
Example Combinations of Load Port Options

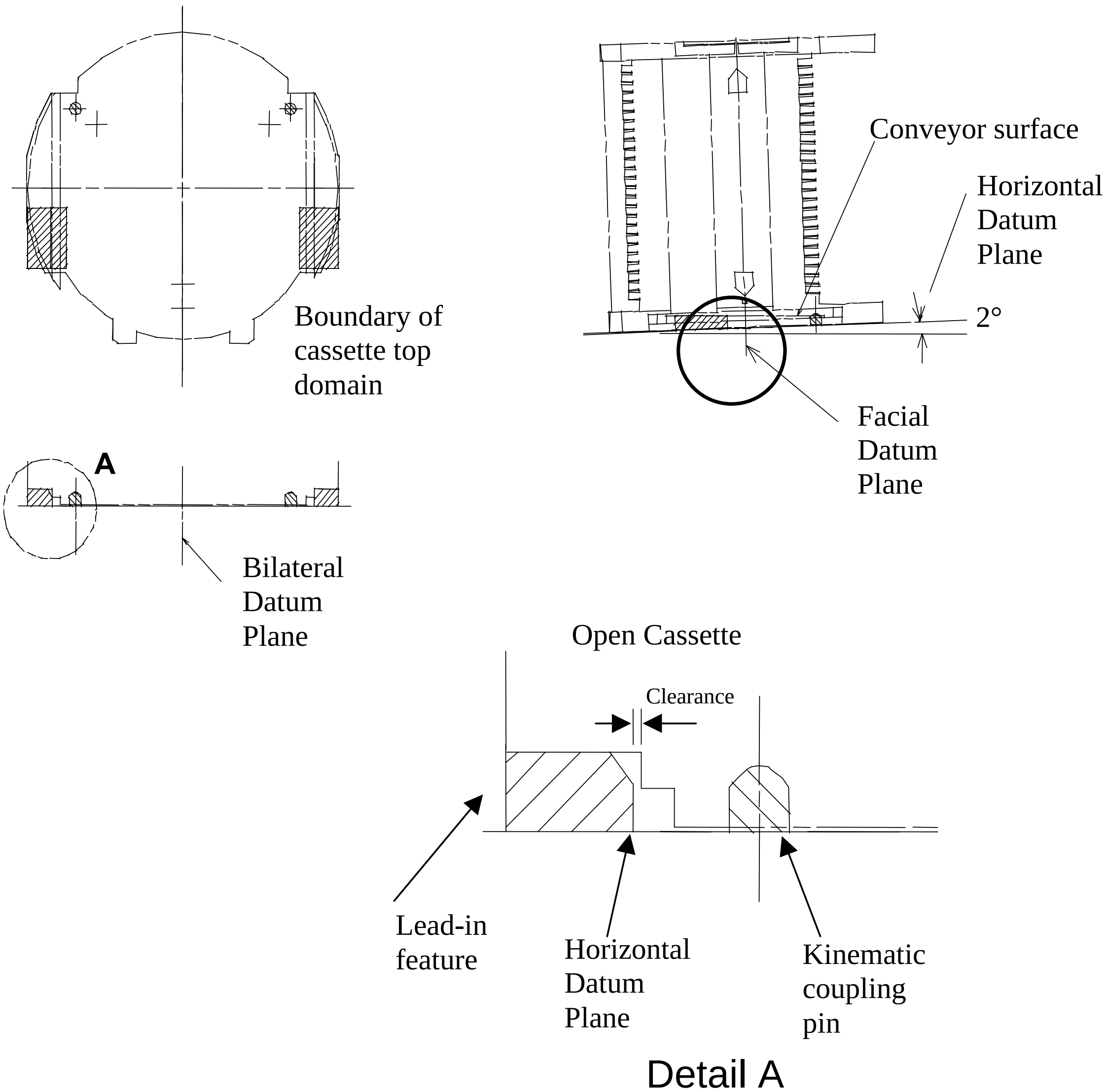


Figure R1-2
An Open Cassette Example of Using Two Kinematic Coupling Pins, Part 1

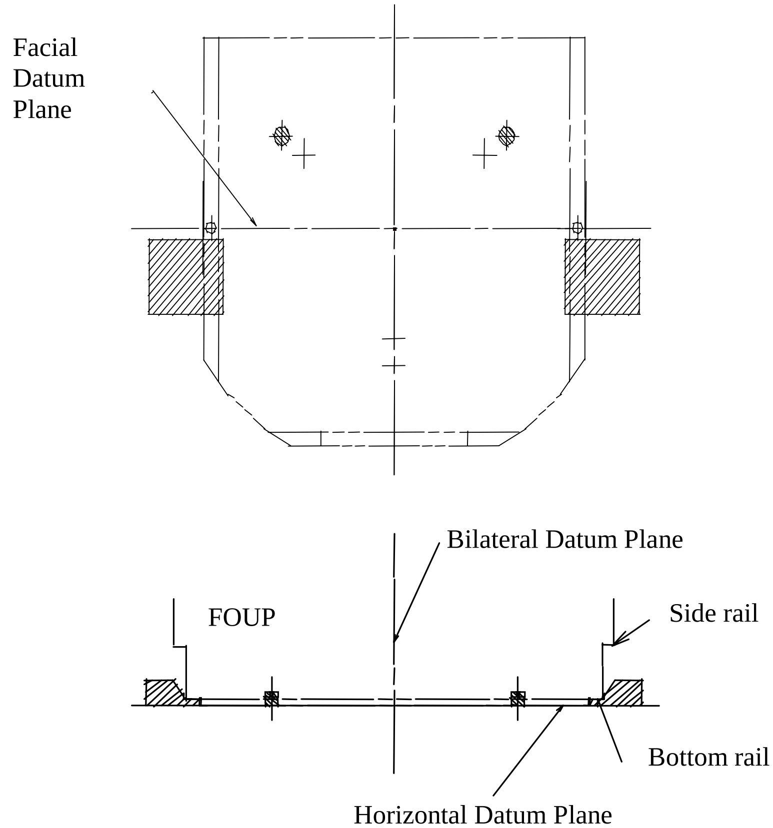


Figure R1-3
A FOUP Example of Using Two Kinematic Coupling Pins, Part 2

SEMI E89-1104[E]
GUIDE FOR MEASUREMENT SYSTEM ANALYSIS (MSA)

This guide was technically approved by the Global Metrics Committee and is the direct responsibility of the North American Metrics Committee. Current edition approved by the North American Regional Standards Committee on August 16, 2004. Initially available at www.semi.org September 2004; to be published November 2004. Originally published September 1999.

[E] This standard was editorially modified in October 2004 to correct an editorial error in the title.

NOTICE: This document was completely rewritten in 2004.

1 Purpose

1.1 The purpose of this guide is to provide a consistent set of terminology and describe a simplified, but constructive, experimental approach to planning and performing a measurement system analysis (MSA).

1.2 The goal of an MSA is to characterize the performance capability of the measurement system (MS) as it is intended to be used in a manufacturing or laboratory setting.

1.2.1 Accurately identifying the MS bias and the size and nature of all sources of variability allows one to determine whether the MS is capable of performing its intended function. Moreover, a well-designed MSA can be used to identify and quantify areas that need the most improvement.

2 Scope

2.1 This guide covers procedures for determining specific measures of MS capability including:

- measurement variability (i.e., reproducibility) under a variety of conditions, including
    - effects of repeatability,
    - load-unload, and
    - time, and
- bias, including bias-related
    - linearity,
    - stability, and
    - matching tolerance.

2.2 This guide also covers secondary metrics such as precision-over-tolerance (P/T) ratio and signal-to-noise ratio (SNR).

2.3 The primary focus of this guide is on determining measurement capability of automated wafer MSs under normal operating conditions, but the definitions and methodologies are extendible to many other measurement situations involving automated measurements on units such as processed dice, packaged devices, flat panel displays, piece parts, etc.

2.4 While there is no universally accepted correct way to conduct an MSA, the approach described in this document is supported in the technical literature (see Section 11) and congruent with practices advocated in ISO 5725-2. The procedures given in this guide represent an approach to the conduct of an MSA and provide basic reference methods that should serve for a variety of applications. Other methods may be appropriate in certain circumstances.

2.5 The procedures in this guide that are intended to separate the various sources of nonsystematic (i.e., random) errors are based on the use of factorial experiments and analysis of variance (ANOVA). Because the primary focus of this guide is on evaluation of automated MSs, the variability introduced by different operators is expected to be minimal.

NOTE 1: Information on measurement uncertainty calculations is provided in Related Information 1. Information on testing measurement distributions for normality and equal repeatability is provided in Related Information 2.

NOTICE: This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the users of this standard to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 Determination of MS capability is meaningless unless the MS is in control. Methodology for establishing and maintaining MS control is beyond the scope of this guide. Such methodology should be a part of a quality management system, such as that mandated by ISO 9000 or similar standards. Additional guidance for laboratories without established procedures may be found in the ASTM *Manual on Presentation of Data and Control Chart Analysis.*[1]

1 *Manual on Presentation of Data and Control Chart Analysis,* 6th edition, MNL 7 (ASTM International, West Conshohocken, PA, 1991)

3.2 This guide does not address those aspects of measurement uncertainty associated with change in the object being measured, either spatially or temporally.

3.3 This guide does not address determination of measurement capability in the case of destructive measurements on samples, or when the MS alters the object being measured as a result of making the measurement.

3.4 This guide does not apply to inter-laboratory experiments designed to measure inter-laboratory precision of test methods.

4 Referenced Standards

4.1 *ISO Standards*[2]

ANSI/ISO Z540-2 — Guide to the Expression of Uncertainty in Measurement

ANSI/ISO/ASQC A3534-1 — Statistics – Vocabulary and Symbols – Part 1: Probability and General Statistical Terms.

ISO 3534-3 — Statistics – Vocabulary and Symbols – Part 3: Design of Experiments.

ISO 5725-2 — Accuracy (trueness and precision) of measurement methods and results – Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method.

ISO 9000 — Quality management systems – Fundamentals and vocabulary, 2000.

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

5 Terminology

5.1 Terminology in this section that is not directly used in this guide, is likely to be encountered while conducting an MSA.

5.2 Definitions of many other terms related to metrology and statistics can be found in VIM,[3] ANSI/ISO/ASQC A3534-1, and ISO 3534-3.

5.3 *Definitions*

5.3.1 *accuracy* — closeness of agreement between a test result or the mean of a group of test results made on an object and its true value.[3]

5.3.1.1 *Discussion* — Accuracy depends on both the precision and bias of the measurement process. Since random components of error (resulting in imprecision) and systematic components of error (resulting in bias) cannot be completely separated in routine use, the reported accuracy must be interpreted as a combination of these two elements.

5.3.2 *bias* — difference between the population mean of the test results from a measurement process and the true (accepted reference) value of the property being measured.

5.3.2.1 *Discussion* — Bias is a systematic component of measurement uncertainty. One or more systematic error components may contribute to the bias. The true value and the population mean are both unknown. The true value may be estimated with the use of a consensus value. If sufficient measurements are made to adequately mitigate the effects of measurement variability, the population mean may be estimated from the sample mean

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (1)$$

where:

$\bar{x}$ = sample mean,
n = number of measurements, and
x_i = i^{th} measurement value.

5.3.3 *calibration* — set of operations that establish the relationship between values of quantities indicated by a measurement system (MS) and the corresponding values assigned to reference materials.

5.3.3.1 *Discussion* — The purpose of calibration is to reduce or eliminate bias in the MS.

5.3.4 *certified reference material (CRM)* — reference material, one or more of whose property values are certified by a technically valid procedure, accompanied by or traceable to a certificate or other documentation issued by a certifying body.

5.3.5 *coefficient of variation* (*CV*) — population standard deviation expressed as a percentage of the mean value.

5.3.5.1 *Discussion* — CV can be estimated from the sample standard deviation, *s*, and the sample mean, $\bar{x}$, of a distribution as follows:

$$CV = \frac{s}{\bar{x}} \times 100 \qquad (2)$$

CV is an appropriate measure of variability only when the sample standard deviation is proportional to the mean; otherwise it varies with the value of the measurand. If the sample standard deviation is

2 ISO Central Secretariat, 1, rue de Varembé, Case postale 56, CH-1211 Genève 20, Switzerland, web site: www.iso.ch; ISO standards are available in the United States through the American National Standards Institute, web site: www.ansi.org, and in most other countries through the ISO member body.

3 International Vocabulary of Basic and General Terms in Metrology, Second Edition [VIM] (ISO, Genève, 1993).

independent of the value of the measurand, it is more appropriate to use it directly rather than CV.

5.3.6 *effect* — change in the expected value of a given response due to the change of a given factor from one level to another. It is a measure of influence that a particular variable level has on the output variable.

5.3.6.1 *fixed effect* — variable for which estimates of the mean are obtained for each level.

5.3.6.2 *random effect* — variable for which estimates of the mean are not obtained for each level; rather the variable is treated as a variance component.

5.3.7 *factor* — predictor variable whose level is changed with the intent of assessing its effect on the response variable (in a designed experiment) [adapted from ISO 3534-3].

5.3.7.1 *crossed factor(s)* — two factors are crossed when every level of one factor appears with every level of the second factor.

5.3.7.2 *fixed factor* — factor that has either all of its levels represented in an experiment or levels selected by a nonrandom process.

5.3.7.3 *nested factor(s)* — factor that has a different set of levels appearing within each level of a second factor. Factor B is nested in factor A when randomization of the levels of factor B is restricted to specific levels of factor A.

5.3.7.4 *random factor* — factor that has randomly sampled levels from a population of levels.

5.3.8 *gage* — alternate spelling of gauge.

5.3.9 *gauge* — instrument used to assign a value to a quantitative or qualitative characteristic of a physical entity or phenomenon.

5.3.10 *interaction* — effect for which the apparent influence of one factor on the response variable depends upon one or more other factors [ISO 3534-3].

5.3.11 *level* — value of a factor (in a designed experiment) [adapted from ISO 3534-3]. Also called "setting of a variable."

5.3.12 *linearity* — absence of changes in variability or bias as measurements are made at different points within the measurement range.

5.3.12.1 *Discussion* — Traditional definitions of linearity ignore the fact that variability can change over the measurement range, as well as bias. The assumption of constant variability over the measurement range should be verified during the MS analysis.

5.3.13 *lower specification limit (LSL)* — value of an attribute below which a product is said to be nonconforming.

5.3.14 *matching tolerance* (Δ_m) — difference in bias for any two measurement systems (MSs) of the same kind made under the conditions of reproducibility.

5.3.15 *measurand* — particular attribute of a phenomenon, body or substance subject to measurement. [VIM]

5.3.16 *measurement resolution, of a gauge* — smallest difference in measurand that can be meaningfully distinguished by the gauge.

5.3.17 *measurement subsystem* — any set of entities, processes, or conditions that share a common purpose in the measurement.

5.3.17.1 *Discussion* — A measurement subsystem may contain one or more of its own subsystems. For example, a wafer handling mechanism may be further composed of wafer loading and wafer positioning subsystems.

5.3.18 *measurement system* (*MS*) — all entities, procedures, and conditions that can influence the test result obtained with a given measurement process.

5.3.18.1 *Discussion* — The MS may include, but is not limited to, the gauge, operators, setup mechanics, wafers, locations on a wafer, environmental conditions, software used by the gauge, measurement method, etc. The MS may be comprised of measurement subsystems.

5.3.19 *measurement system analysis (MSA)* — procedure in which relevant sources of bias and variability associated with a measurement system (MS) are estimated.

NOTE 2: MSA is also sometimes called gauge (or gage) repeatability and reproducibility (GRR or GR&R).

5.3.20 *nested design* — experimental design in which different levels of one factor appear in each level of a second factor.

5.3.21 *population standard deviation* (σ) — square root of the population variance.

5.3.22 *population variance* (σ^2) — measure of dispersion associated with a population distribution.

5.3.22.1 *Discussion* — For continuous distributions, the population variance is the second central moment.

5.3.23 *precision* — general estimator of the variability of a measurement process about the mean value of the test results obtained.

5.3.23.1 *Discussion* — Precision is a random component of measurement uncertainty. Unless the measurement process is in a state of statistical control, the precision of the process has no meaning. Since the precision is poorer for greater dispersion of the test results, specific measures of variability (such as repeatability and reproducibility) are actually direct measures of the imprecision of the measurement process.

5.3.24 *precision-to-tolerance* (*P/T*) *ratio* — ratio of the precision of a measurement system (MS) to the tolerance (i.e., absolute magnitude of the full range of the product specification).

5.3.24.1 *Discussion* — If the variability associated with the measurement of a parameter by an MS is very small compared with the width of the specification range, the probability of obtaining a test result outside the specification limits when the value of the parameter actually lies within the specification limits (or conversely) is quite small. On the other hand, if the ratio is too large, the probability of obtaining a false test result is much greater.

5.3.25 *predictor variable* — variable that can contribute to the explanation of the outcome of a designed experiment. Also called "input variable," "descriptor variable," and "explanatory variable."

5.3.25.1 *Discussion* — The term "independent variable" is not recommended as a synonym due to potential confusion with independence.

5.3.26 *product standard deviation* ($\sigma_{Product}$) — population standard deviation associated with the distribution of values of all possible realizations of a property of an entity manufactured under specified conditions.

5.3.26.1 *Discussion* — The product variability may be estimated by taking a representative sample from the population and calculating its sample standard deviation ($s_{Product}$) taking suitable account of MS variation (see Section 10.2).

5.3.27 *reference material* — material or substance, one or more of whose property values are sufficiently homogeneous and well established to be used for the calibration of a MS, for the assessment of a measurement method or for assigning values to materials.

5.3.28 *repeatability* (σ_r) — variability associated with repeated measurements taken under repeatability conditions.

5.3.29 *repeatability conditions* — test conditions involving acquisition of a series of test results with the same test protocol and MS setup in the same laboratory by the same operator on the same equipment in the shortest practical period of time on the same test wafer without explicit recalibration.

5.3.29.1 *Discussion* — The acquisition of test data under repeatability conditions is intended to avoid influences of long-term drift, operator or MS differences, material variability, and the like. Recalibration of the MS is expected to cause discontinuous differences in test results. However, if recalibration is required by the test protocol or is internal to the MS, it is considered to be an allowable variation in determination of repeatability.

5.3.30 *reproducibility* (σ_R) — variability associated with the measurement system (MS) when measurements are made under different (but typical) conditions.

5.3.30.1 *Discussion* — Changes associated with subsystems or test conditions are potential sources of variation to be estimated. Repeatability is one source of variation. Other relevant sources of variability may include time, operator, setup procedure, wafer (of like variety), measurement location, test instrumentation, environmental conditions, etc. Although the total number of contributors to the variance can be exceedingly large, one typically focuses on a subset that accounts for a significant portion of the expected MS variability. For clarity, the selected subset should be reported together with the reproducibility. If q different conditions introduce variability into the measurement independently from one another, the variances add directly

$$\sigma_R = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \ldots + \sigma_q^2} \qquad (3)$$

and they may be separated by the use of judiciously designed experiments.

5.3.31 *response variable* — variable representing the outcome of a designed experiment. Also called "output variable."

5.3.31.1 *Discussion* — The term "dependent variable" is not recommended as a synonym due to potential confusion with independence.

5.3.32 *root sum of squares (RSS) difference* — square root of the difference of the squares of two numbers.

5.3.33 *root sum of squares (RSS) sum* — square root of the sums of the squares of two or more numbers.

5.3.34 *sample standard deviation (s)* — square root of the sample variance.

5.3.35 *sample variance* (s^2) — measure of dispersion given by the average squared deviation from the mean for a set of numbers.

5.3.35.1 *Discussion* — If x_i is an individual measurement, $\bar{x}$ is the average across all measurements, and n is the number of measurements, then

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2 \qquad (4)$$

The denominator value of $n - 1$ is used instead of n to make the sample variance an unbiased estimator of the population variance.

5.3.36 *signal–to-noise ratio (SNR)* — ratio of the variation in the manufactured product to the precision of the measurement system (MS).

5.3.36.1 *Discussion* — Because it is difficult to directly measure the standard deviation of the product without including variation due to the measurement instrument, SNR is generally defined as:

$$SNR = \sqrt{\frac{\sigma^2_{Total} - \sigma^2_R}{\sigma^2_R}} \qquad (5)$$

where σ^2_{Total} is an estimate of the total population variance obtained from appropriate measurements of a large, representative sample of the product.

5.3.37 *stability* — absence of additional variability due to taking measurements over time (typically several days or longer).

5.3.38 *statistical model* — mathematical function relating one or more variables to known and measurable inputs plus one or more unknown stochastic (error) terms.

5.3.38.1 *Discussion* — A statistical model consists of three parts. The first part is the response variable that is being modeled. The second part is the deterministic or the systematic part of the model that includes predictor variables. Finally, the third part is the random error or stochastic part of the model, which can be quite elaborate. An example of a statistical model is:

$$y_j = \sum_{i=1}^{p} \beta_i x_i + e_j \qquad (6)$$

where:
y_j = j^{th} measurement,
p = number of input variables,
x_i = i^{th} input variable,
β_i = its corresponding coefficient, and
e_j = error associated with the j^{th} measurement.

In many cases the error distribution(s) are specified before the model is fit (e.g., as normal).

5.3.39 *tolerance* — absolute magnitude of the full range of the product specification.

5.3.40 *total variance* (σ^2_{Total}) — sum of the product variance and the square of the reproducibility.

5.3.41 *uncertainty* — parameter, associated with a measurement, that characterizes the dispersion of values that can be reasonably attributed to the object being measured.

5.3.41.1 *Discussion* — Two types of measurement uncertainty are:

- Type A: uncertainty components evaluated by statistical methods and
- Type B: uncertainty components evaluated by other than statistical methods.

5.3.42 *upper specification limit (USL)* — value of an attribute above which a product is said to be nonconforming.

5.3.43 *variable* — quantitative or qualitative characteristic of an object, processes, or state that may take on more than one value.

5.3.43.1 *Discussion* — When the values occur unpredictably, it is a random variable.

5.3.44 *variance* — population variance (see Section 5.3.22).

6 Goals of and Preliminary Steps in Planning an MSA

6.1 One major goal of an MSA is to determine MS reproducibility under the desired operating conditions. This may range from a simple repeatability study, to a complex determination of the relative contributions of many sources of MS variability using factorial experiments and analysis of variance (ANOVA). Some of the typical types of variability-determination goals to be met by an MSA include the following:

6.1.1 Determination of repeatability.

6.1.2 Determination of the effect of loading and unloading the wafer samples between measurements.

6.1.3 Determination of stability.

NOTE 3: Stability may also have a bias component that can be confounded with the variability component of stability (see Section 6.2.3).

6.1.4 Assessment of the multiple factors that affect the MS variability, which requires the use of factorial experiments and ANOVA.

6.1.5 Assessment of the largest sources of variability in order to focus improvement efforts on the most critical sources. This identification can be made from the analysis of a properly designed and executed factorial experiment.

6.1.6 Once the reproducibility is determined over the desired conditions, secondary metrics, such as P/T ratio and SNR can be easily calculated.

6.2 A second major goal of an MSA is to determine bias and bias-related considerations. In general, bias studies require standards or "golden wafers" with "known" true measurement values or agreed-upon consensus values. Corrective actions ranging from simple recalibration to repair of the MS may be required as a result of the bias determinations. Some of the typical elements of a bias study include:

6.2.1 Determination of bias.

6.2.2 Determination of linearity or whether bias is constant over the range of values that the metrology equipment will be used.

NOTE 4: Linearity also may have a variability component.

6.2.3 Determination of the stability or whether the bias is constant over time.

NOTE 5: Stability also may have a variability component (see Section 6.1.3).

6.2.4 Determination of matching tolerance.

NOTE 6: In the absence of certified or other reference materials, as required for a determination of bias, matching tolerance may be determined by measuring the same set of test materials on the two MSs whose matching is being evaluated. Although this alternate method does not provide a measure of the value of bias, the difference between the mean values measured on the two MSs is the same as the difference in bias.

6.3 Before undertaking an MSA, determine and list the specific goals to be attained by the MSA to be performed.

6.4 It must be emphasized that all of the procedures in this guide yield meaningful estimates only on instruments that are in statistical control. Therefore the first step in analyzing the capability of any MS is to establish that it is in statistical control through control charts or other accepted quality control techniques. Detailed discussion of these techniques is outside the scope of this guide (see Section 3.1).

6.5 It is also useful to review prior studies on the MS to be analyzed to determine (1) what sources of variability were significant and (2) previously obtained values for quantities such as bias, repeatability, and reproducibility.

7 Procedure to Determine Reproducibility

7.1 Identify all the factors of interest that contribute to non-negligible sources of variability in the MS. These factors should be made explicit before an experiment can be appropriately designed or accurately analyzed. The most common sources include:

- Repeatability
- Load-unload operation
- Time over intervals of day(s) or week(s)
- Wafer handling hardware, including ability to place the measurement probe at the same location on the wafer
- Measurement software, including type, revision, or both
- Setup procedure
- Environmental conditions, including temperature and humidity
- Shift (may be confounded with environmental conditions or time or both)
- Magnitudes of attribute(s) of test wafer(s) under investigation
- Operator (usually not significant for automated MSs)

NOTE 7: The factors listed are all included under the term "reproducibility." There is no common agreement as to what factors should be included in reproducibility. Therefore the selection and recording of the factors included in a particular MSA are especially critical.

NOTE 8: Variability associated with factors independent of the MS, such as true value differences in the item being measured, should not be included in reproducibility. Given the design of the MS, it may be necessary to estimate these sources of variability before they are removed from total variability. If such factors are included in the MS, as for example, when different sites on a wafer are measured, variability associated with these factors should be estimated and removed from total MS variability. Although variability due to the measurement process physically altering the measurand (i.e., the interaction between MS and wafer) should be included in reproducibility, consideration of this topic is beyond the scope of this guide (see Section 3.3).

7.2 Identify all factors outside of the MS for which an interaction with one or more factors within the MS may exist. Treat these factors as fixed factors and the interactions as random factors.

NOTE 9: Typically, the only fixed factor considered is related to the measured object, where making measurements at different locations, for different true values, or on different wafer types may be influenced by certain aspects of the MS.

7.3 Identify the nested factors and the factors in which they are nested. Several levels of nesting may exist for a given factor.

NOTE 10: Nesting occurs when the measurement procedure causes a natural hierarchy of events to exist. For example, if repeatability is estimated by taking measurements with the wafer fixed in the gauge, and variability due to the load-unload operation is estimated by taking a second set of measurements after the wafer has been removed and reloaded, repeatability is nested in load-unload. The nesting occurs because each set of repeated measurements is unique to the load in which they appear. Nesting may also occur if a physical hierarchy exists, such as when both measurement locations (sites) and wafer type are fixed factors in an MSA (sites being nested in wafer type).

7.4 Select appropriate test wafers for the MSA.

7.4.1 In the most general case, many types of wafers should be used. These should be representative of the types and levels to be measured in practice by the MS under evaluation.

7.4.2 The test wafers should be as uniform as possible to prevent confounding of handling, loading, or positioning factors, if these are chosen to be examined.

7.4.3 It is necessary to use only one test wafer of each type selected.

7.4.4 Use the same test wafers throughout the MSA.

7.5 Prepare a statistical model for the MSA in order to plan and analyze it properly.

NOTE 11: Statistical models are discussed in Related Information 3. Eastman[4] gives some examples of models for reproducibility studies.

7.6 Select the measurement protocol. Include several examples of every factor that was selected in Section 7.1.

7.7 Select and implement the appropriate MS setup.

NOTE 12: Usually, only a single setup is used in an MSA to determine reproducibility. However, if setup procedure has been chosen as a factor to be evaluated, select the various setups to be used in the MSA.

NOTE 13: Examples of MSAs are given in Related Information 4, 5, and 6. Additional examples may be found in the literature.[4]

7.8 Determine if the MS needs to be calibrated.

7.8.1 Calibrate, if necessary, following the manufacturer's recommended procedure.

7.8.2 Do not recalibrate during the MSA unless required by the normal operating procedure.

7.9 Perform the MSA, randomizing both the sample wafers chosen and the order in which measurements are made, whenever possible. Record the actual order in which all measurements are made.

7.10 To correctly estimate the reproducibility and individual sources of variance, conduct a variance components analysis.

7.10.1 If the experiment has been designed to include multiple repeated measurements taken under the same (repeatability) conditions, it is possible to estimate repeatability. Without multiple repeated measurements, repeatability will be confounded with other sources of variability.

7.10.2 Other factors are those from Section 7.1 that have been included in the experiment design.

7.10.3 Reproducibility is the square root of the sum of the individual variance components (see Equation 3 in Section 5.3.30.1).

NOTE 14: The exact nature of the variance components analysis depends on the design of the experiment conducted. For details, see the examples in Related Information 4, 5, and 6, Box, Hunter, and Hunter,[5] or Montgomery.[6] In designing and performing a complete designed experiment and the associated analysis, it is strongly recommended to utilize some form of commercially available statistical analysis software. If such a product is used, it is advisable to confirm that the assumptions made in the software are congruent with those in this guide.

8 Procedure to Determine Bias, Including Linearity, Stability, and Matching Tolerance

8.1 Obtain J appropriate reference materials, preferably CRMs, where J is between 3 and 10 so that the entire range of interest of the parameter is covered. If CRMs are not available, use wafers with well accepted consensus values covering the range of values of the attributes to be measured. The reference materials should have characteristics similar to the wafers to be measured by the MS being evaluated or their values should be transferable to such wafers.

NOTE 15: Bias cannot be determined if suitable reference materials are not available. In such situations, it is necessary to resort to correlation experiments to establish the systematic errors between different MSs. If the bias is not known, these systematic errors may confound the estimated reproducibility.

8.2 Select and implement the appropriate MS setup.

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4 Eastman, S. A., "Evaluating Automated Wafer Measurement Instruments," International SEMATECH technology transfer document 94112638A-XFR (February 28, 1995), Section 5 and case studies in appendices. However, note that neither the terminology nor the nomenclature in this document is identical with that given in this guide. A PDF file of this report can be downloaded from International SEMATECH's public web site at http://www.sematech.org/docubase/wrappers/26.htm.

5 Box, G. E. P., Hunter, W. G., and Hunter, J. S., Statistics for Experimenters (Wiley, New York, 1978).

6 Montgomery, D.C., Design and Analysis of Experiments, 5th Ed. (Wiley, New York, 2000).

8.3 Determine if the MS needs to be calibrated. Calibrate, if necessary, following the manufacturer's recommended procedure. Do not recalibrate during the bias determination unless required by the normal operating procedure.

8.4 Chose the minimum number of measurements to be made on each of the *J* reference materials, *n*, as the smallest integer greater than $(4\sigma/\delta)^2$ where σ is the estimate of reproducibility (σ_R, see Section 7) and δ is the bias shift to be detected.

NOTE 16: In this relationship, the assumption is made that the maximum acceptable probability of calibrating when unnecessary (Type 1 error) is 0.1 and the maximum tolerable probability of not calibrating when necessary (Type 2 error) is 0.01. If use of other values of these errors is desired, the more complete formula for minimum sample size is the smallest integer greater than $[\sigma(z_1 + z_2)/\delta]^2$ where:

z_1 = value above which $p_1/2$ percent of the standard normal distribution falls where p_1 is the largest acceptable risk of calibrating when unnecessary,

z_2 = value above which $p_2/2$ percent of the standard normal distribution falls where p_2 is the largest acceptable risk of not calibrating when necessary,

σ = estimate of the variability as defined in Section 8.4, and

δ = shift (bias) to be detected.

8.4.1 If no information on MS variability is available, use a minimum of 16 measurements on a reference wafer to estimate bias.

8.5 Perform the measurements on one or more days, depending if stability information is desired or not. To minimize systematic errors, randomize the sequence of measurements among the reference wafers for each daily measurement. If the MS is performed over several days, make an approximately equal number of measurements on each day with at least two measurements made per day.

8.6 *Analysis of the Measurement Data*

8.6.1 This analysis can be done with most commercially available statistical analysis software packages. The procedures given in Section 8.7 are intended only for those without access to such software.

8.6.2 The full model to determine the effect of bias over time and measurement range is:

$$E[y_{ij}] = b_i + a_i x_{ij} \tag{7}$$

where

$E[y_{ij}]$ = expected response for reference wafer *j* on day *i*,

b_i = bias on day *i*,

x_{ij} = certified value for reference wafer *j* on day *i*, and

a_i = slope for day *i*.

NOTE 17: If multiple measurements are made for a given reference wafer on a given day, it is assumed that

$$E[y_{ijk}] = E[y_{ij}] \tag{8}$$

where *k* is any one of the multiple measurements made on reference wafer *j* on day *i*.

8.6.3 When bias and slope do not differ significantly over days (i.e., $a_i \approx a$ and $b_i \approx b$ for all *i*), the reduced model is:

$$E[y_j] = b + ax_j \tag{9}$$

8.6.4 *Linearity* — The calibration coefficient *a* is a linear constant that relates the rate at which bias changes for every unit change in the measurement range. This value should not be significantly different from one. Otherwise, the MS exhibits nonlinearity.

8.6.5 *Stability* — Test for a significant difference between the full and reduced models given by Equations 7 and 9, respectively. If there is no significant difference, continue. Otherwise, bias is not stable over time.

8.6.6 Test for model lack of fit. Significant lack of fit indicates a possible nonlinear relationship involving bias that is not captured by the reduced model

8.6.7 If the test for lack of fit is not significant, estimate *a* and *b*.

8.6.7.1 If *a* is not statistically different from one and *b* is statistically different from zero, *b* is an estimate of the bias.

8.6.7.2 If *a* is statistically different from one, bias is not constant. A linear relationship exists between bias and measurement range.

8.6.7.3 If *b* is not statistically different from zero, the estimate of bias is zero.

8.7 *Detailed Analysis Procedures* — If the measurements are made over a single day only, skip Sections 8.7.1 and 8.7.2 and begin the analysis with Section 8.7.3. Also skip Section 8.7.5. In this case, no information about time variation of bias (stability) can be obtained from the MSA. Otherwise begin the analysis with Section 8.7.1.

8.7.1 Estimate the slopes ($\tilde{a}_i$) and biases ($\tilde{b}_i$) for each day's measurements to determine the effect of time and measurement range on the bias:

$$\tilde{a}_i = \frac{\sum_{j=1}^{J}\sum_{k=1}^{n_{ij}}(y_{ijk} - \bar{y}_i)(x_{ijk} - \bar{x}_i)}{\sum_{j=1}^{J}\sum_{k=1}^{n_{ij}}(x_{ijk} - \bar{x}_i)^2} \tag{10}$$

$$\tilde{b}_i = \bar{y}_i - \tilde{a}_i \bar{x}_i \qquad (11)$$

where:

J = number of reference wafers,

n_{ij} = number of measurement results for reference wafer j on day i,

y_{ijk} = result of measurement k on reference wafer j on day i,

$\bar{y}_i$ = mean of the measurement results on day i,

x_{ijk} = value of the reference parameter on day i, and

$\bar{x}_i$ = mean of the values of the reference parameter on day i.

8.7.2 Calculate the expected response on each reference wafer j on each day i, $E[y_{ij}]$:

$$E\left[y_{ij}\right] = \tilde{b}_i + \tilde{a}_i x_{ij} \qquad (12)$$

where:

x_{ij} = value of the reference parameter for wafer j of day i, and

$\tilde{a}_i$ and $\tilde{b}_i$ are the slope and intercept (bias) for day i as found from Equations 10 and 11, respectively, in Section 8.7.1.

NOTE 18: When multiple measurements are made for a given reference wafer on a given day, it is assumed for all k that

$$E\left[y_{ijk}\right] = E\left[y_{ij}\right] \qquad (13)$$

where k is any one of the multiple measurements made on the i day on the j reference wafer.

8.7.3 Estimate the slopes ($\hat{a}_i$) and biases ($\hat{b}_i$) for the entire data set:

$$\hat{a} = \frac{\sum_{i=1}^{D}\sum_{j=1}^{J}\sum_{k=1}^{n_{ij}}(y_{ijk}-\bar{y})(x_{ijk}-\bar{x})}{\sum_{i=1}^{D}\sum_{j=1}^{J}\sum_{k=1}^{n_{ij}}(x_{ijk}-\bar{x})^2} \qquad (14)$$

$$\hat{b} = \bar{y} - \hat{a}\,\bar{x} \qquad (15)$$

where:

D = number of days over which measurements are made,

$\bar{x}$ = grand mean of the values of the reference parameter,

$\bar{y}$ = grand mean of the measurement results, and

the other parameters are defined in Section 8.7.1.

NOTE 19: This procedure makes the assumption that the bias and slope do not differ significantly over days. This assumption is tested in Section 8.7.5.

8.7.4 Calculate the expected response on each wafer j, $E[y_j]$:

$$E\left[y_j\right] = \hat{b} + \hat{a}\,x_j \qquad (16)$$

8.7.5 Determine whether bias and slope differ significantly over days or not as follows:

8.7.5.1 Calculate the Sum of Squares for the difference between the two cases, SS_M:

$$SS_M = \sum_{i=1}^{D}\sum_{j=1}^{J}\left(E\left[y_{ij}\right] - E\left[y_j\right]\right)^2 \qquad (17)$$

8.7.5.2 Calculate the Error Sum of Squares (SS_e):

$$SS_e = SS_Y - SS_\gamma - SS_M \qquad (18)$$

where

$$SS_Y = \sum_{i=1}^{D}\sum_{j=1}^{J}\sum_{k=1}^{n_{ij}}(y_{ijk}-\bar{y})^2 \qquad (19)$$

and

$$SS_\gamma = \sum_{i=1}^{D}\sum_{j=1}^{J}\sum_{k=1}^{n_{ij}}(y_{ijk}-\bar{y})(x_{ijk}-\bar{x}) \qquad (20)$$

8.7.5.3 Calculate probability associated with the function F_M that follows a Fisher's F distribution with $2D - 1$ and $n - 2D$ degrees of freedom under the hypothesis that there is no difference between the two cases:

$$F_M = \frac{(n-2D)SS_M}{(2D-1)SS_e} \qquad (21)$$

NOTE 20: This probability can be calculated using the Excel function, FDIST(F_M,$2D–1$,$n–2D$).

8.7.5.4 Reject the hypothesis that there is no difference between the two cases when the probability associated with F_M is small (e.g., 0.05 or below). In this case, bias is not stable over time and it is not possible to establish a value for it.

8.7.6 Test for lack of fit as follows:

8.7.6.1 Calculate the Sum of Squares for Pure Error (SS_p):

$$SS_p = \sum_{i=1}^{D}\sum_{j=1}^{J}\sum_{k=1}^{n_{ij}}(y_{ijk}-\bar{y}_j)^2 \qquad (22)$$

where all the symbols have been defined previously.

8.7.6.2 Calculate the lack of fit F test

$$F_{LOF} = \frac{(J-2)SS_p}{(n-J)(SS_e - SS_p)} \qquad (23)$$

where, again, all the symbols have been defined previously.

8.7.6.3 Under the assumption of no lack of fit, the ratio F_{LOF} follows Fisher's F distribution. Calculate the probability associated with this ratio.

NOTE 21: This probability can be calculated using the Excel function: FDIST(F_{LOF},$n–J$,$J–2$).

8.7.6.4 Reject the assumption of no lack of fit if this probability is small (e.g., 0.01 or less). In this case, nonlinearity is probably present in the MS.

8.7.7 If there is no evidence of lack of fit, calculate the approximate 95% confidence interval for $\hat{a}$:

$$\hat{a} \pm 2\sqrt{\frac{SS_e/(n-J)}{\sum_{i=1}^{D}\sum_{j=1}^{J}\sum_{k=1}^{n_{ij}}(x_{ijk}-\bar{x}_j)^2}} \qquad (24)$$

where:

$\bar{x}_j$ = (mean) value of the reference parameter from reference wafer j.

8.7.7.1 If the interval contains the number one, $\hat{a}$ is not statistically different from one. If this is the case and also $\hat{b}$ is significantly different from zero, $\hat{b}$ is the estimate of the bias.

8.7.7.2 If the interval does not contain the number one, $\hat{a}$ is significantly different from one and bias is not constant with parameter level.

8.7.7.3 If $\hat{b}$ is not significantly different from zero, the estimate of bias is zero.

8.8 *Matching Tolerance*

8.8.1 Determine the bias of two MSs of the same kind under conditions of reproducibility.

8.8.2 If the results give a stable bias determination for each MS and if each MS has acceptable linearity, subtract the two biases to obtain the matching tolerance, Δ_m:

$$\Delta_m = bias_1 - bias_2 \qquad (25)$$

where:

$bias_1$ = bias of the first MS and
$bias_2$ = bias of the second MS.

9 Procedure to Determine P/T Ratio

9.1 Estimate the precision of the MS, P, as $6s_R$ if the specification is symmetrically two-sided or as $3s_R$ if the specification is asymmetrical or one-sided.

9.2 Take the tolerance, T, as follows:

9.2.1 The difference between the USL and the LSL for a symmetrical two-sided specification,

9.2.2 The smaller difference between the USL (or LSL) and the target value for an asymmetrical two-sided specification, or

9.2.3 The difference between the USL (or LSL) and the median of the expected distribution for a one-sided specification.

NOTE 22: If a symmetrical two-sided specification is given as

Target ± Tolerance,

double the stated tolerance to obtain the correct value.

9.3 Calculate the P/T ratio, in percent, as follows:

$$P/T(\%) = \frac{P}{T} \times 100 \qquad (26)$$

rounding to the nearest percent.

NOTE 23: Generally, a P/T ratio should be 30% or less.

10 Procedure to Determine *SNR*

10.1 Estimate the precision of the MS, P, as $6s_R$ if the process distribution is two-sided or as $3s_R$ if the process distribution is asymmetrical or one-sided.

10.2 Estimate the population standard deviation of the process distribution from process data as $\sigma_{process}$. Because it is difficult to directly measure the standard deviation of the product without including variation due to the MS, $\sigma_{process}$ is generally defined as:

$$\sigma_{process} = \sqrt{\sigma_{Total}^2 - \sigma_R^2} \qquad (27)$$

where:

σ_{Total}^2 = variance obtained by measuring a large representative sample of the product and

σ_R^2 = variance determined from the reproducibility (see Section 7).

NOTE 24: Detailed procedures for obtaining the process distribution and the associated standard deviation are outside the scope of this guide.

10.3 Calculate the *SNR*, in percent, as follows:

$$SNR(\%) = \frac{\sigma_{process}}{\sigma_R} \times 100 \qquad (28)$$

rounding to the nearest percent.

NOTE 25: In general, an *SNR* of 10 or more generally means the MS is suitable for measuring the product, while an *SNR* of less than 3 or 4 may be a concern in a particular measurement process.

11 Related Documents

11.1 The following documents describe MSA methodologies similar to those advocated in this guide.

Ballard, D. H., McCormack, D. W., Jr., Moore, T. L., Pore, M., Prins, J., Tobias, P. A. (1998). "A Comparison of Gauge Study Practices," Proceedings from the 1997 Joint Statistical Meetings of the American Statistical Association, Quality and Productivity Section.

John, Peter, "Alternative Models for Gauge Studies," International SEMATECH technology transfer document 93081755A-TR (February 24, 1994); PDF file can be downloaded from International SEMATECH's public web site at http://www.sematech.org/docubase/wrappers/26.htm.

Montgomery, D.C. and Runger G. C. (1993), "Gauge Capability and Designed Experiments. Part I: Basic Methods," *Quality Engineering* **6**(1), 115–135.

Montgomery, D.C. and Runger G. C. (1993), "Gauge Capability and Designed Experiments. Part II: Experimental Design Models and Variance Component Estimation," *Quality Engineering* **6**(2), 289–305.

Potter, R.W. (1991), "Measurement System Capability Analysis," IEEE/SEMI Advanced Semiconductor Manufacturing Conference, pp. 121–125.

---, Measurement Systems Analysis Reference Manual, Third Edition, (2002); Daimler Chrysler Corp., Ford Motor Co, and General Motors Corp. Automotive Industry Action Group (AIAG); http://www.aiag.org.

---, "NIST/SEMATECH e-Handbook of Statistical Methods," http://www.itl.nist.gov/div898/handbook.

RELATED INFORMATION 1
MEASUREMENT UNCERTAINTY CALCULATIONS

NOTICE: This related information is not an official part of SEMI E89. It was derived from task force deliberations during the revision of SEMI E89-0999 in 2001-2003. This related information was approved by full letter ballot procedures and was approved for publication by the NA RSC on August 16, 2004.

R1-1.1 Measurement uncertainty depends on the repeatability of the MS, the reproducibility of the result over time, the number of measurements in the test result, and all sources of random and systematic error that could contribute to disagreement between the measurement result and its reference value.

R1-1.2 Determine the measurement uncertainty according to the following rules:

- *Expressing Uncertainty* — Each uncertainty component is quantified by a standard deviation.
- *Bias* — All biases are assumed to be corrected and any uncertainty due to bias is the uncertainty of the correction.
- *Standard Uncertainty* — All uncertainty components (standard deviations), whether Type A or Type B (see Section 5.3.41), are combined as an RSS sum to arrive at a "standard uncertainty," u. This standard uncertainty is the standard deviation of the reported value, taking into account all sources of error, both random and systematic, that affect the measurement result.
- *Extended Uncertainty* — If the purpose of the uncertainty statement is to provide coverage with a high level of confidence, an expanded uncertainty is computed as $U = ku$, where $k = 2$ is typically chosen for an approximate 95% coverage.
- *Uncertainty Interval* — If Y is the reported measurement value, then the symmetric interval from $Y - U$ to $Y + U$ is the uncertainty interval associated with the measurement value.

R1-1.3 The measurement result for which an uncertainty is required must be completely specified as to

- the number of repetitions that were averaged,
- the test method,
- the environmental conditions,
- the operating conditions over which the repetitions were made, and
- any calibration uncertainty.

R1-1.4 Obtain Type A uncertainty for a particular measurement from a determination of reproducibility (see Section 7) conducted according to the same specifications as the particular measurement and including all relevant components of reproducibility.

RELATED INFORMATION 2 TESTING MEASUREMENT DISTRIBUTIONS FOR NORMALITY AND EQUAL REPEATABILTY

NOTICE: This related information is not an official part of SEMI E89. It was derived from task force deliberations during the revision of SEMI E89-0999 in 2001-2003. This related information was approved by full letter ballot procedures and was approved for publication by the NA RSC on August 16, 2004.

R2-1 Testing for Normality

R2-1.1 Testing for normality can be achieved by a commonly applied statistical hypothesis test. In this test, the condition under consideration is that the sample being examined comes from the normal distribution. While there are several ways of implementing this procedure, in each case assume that the measurement results come from a normal distribution and then calculate the probability of obtaining the particular observed sample. Before calculating this probability value (*p*-value), an *a priori* decision is made as to how small this *p*-value has to be to warrant the conclusion that the hypothesis is unreasonable and hence it is unlikely that the observed distribution is normal. A level of 0.05 is commonly chosen and the sample is then tested. If the *p*-value is greater than 0.05 (or the chosen test level, if different from 0.05), one accepts that the underlying distribution is normal.

R2-1.2 Statistical tests for normality can be found in most commercial statistical software. Four common tests are Andersen-Darling, Pearson's Chi Square, Kolmogorov-Smirnov, and Shapiro-Wilk.

R2-1.3 As an example, the 25 observations shown in Table R2-1 are a random sample taken from a manufacturing process. A commonly used statistical package was used to generate the statistical tests mentioned above and the results obtained are shown in Table R2-2.

Table R2-1 Measurement Data

481	476	471	477	479
483	477	480	475	479
480	473	479	484	473
481	475	478	472	480
485	480	478	475	481

R2-1.4 Note that if we require a *p*-value is less than or equal to 0.05 as a rejection criterion, none of these statistical procedures would reject normality for the manufacturing process measurements although the calculated *p*-values are all different.

R2-1.5 For some of these tests, software packages may rely on a combination of tabled values and interpolation to arrive at the answer. For that reason, the numbers given for the same test may vary depending on the software used.

Table R2-2 Calculated Normality Statistics

Test	*Test Statistic Value*	*Calculated* p-*Value*
Anderson-Darling	0.28726858	>0.250
Chi-Square	2.86169631	0.239
Kolmogorov-Smirnov	0.11888191	>0.150
Shapiro-Wilk	0.973356	0.731

R2-2 Testing Two Measurement Systems for Equal Repeatability

R2-2.1 When comparing two MSs, it is possible to test if the repeatabilities are equal. To do so, calculate the ratio of the repeatability of each MS. When forming this ratio, place the larger value in the numerator. The hypothesis under consideration is that the repeatabilities are equal. When this is true, the ratio follows an *F* distribution with ν_1 degrees of freedom for the numerator and ν_2 degrees of freedom for the denominator.

R2-2.2 As a simple example, compare MS 1, which demonstrated a repeatability of 9.243 based on 25 observations, and MS 2, which demonstrated a repeatability of 7.658 based on 23 observations. The *F* ratio is 1.207 with $\nu_1 = 24$ degrees of freedom for the numerator and $\nu_2 = 22$ degrees of freedom for the denominator.

R2-2.3 The probability of seeing an *F* value of 1.207 or larger, based on an *F* distribution with these degrees of freedom is 0.330. Because this *p*-value is larger than the usual pre-selected value of 0.05, there is no reason to reject the hypothesis of equal reproducibilities, given the measurement sample data from the two MSs.

R2-2.4 Extension of these calculations to other types of conditions is beyond the scope of this guide, but additional information on this topic can be found in the literature[7].

7 Miliken, G. A., and Johnson, D. E., Analysis of Messy Data: Volume I Designed Experiments (Chapman & Hall, New York, 1992).

RELATED INFORMATION 3
MODELS FOR MEASUREMENT SYSTEM ANALYSIS

NOTICE: This related information is not an official part of SEMI E89. It was derived from task force deliberations during the revision of SEMI E89-0999 in 2001-2003. This related information was approved by full letter ballot procedures and was approved for publication by the NA RSC on August 16, 2004.

R3-1 Introduction

R3-1.1 This related information section provides a more detailed theoretical explanation that extends ideas described earlier in this guide.

R3-1.2 A measurement model expresses each observed measurement value as the sum of a "true value" plus "bias" plus "random error." The "true value" may be the actual value for the object being measured or the average population value if a sample of objects is measured in the MSA. The random error term is further broken up into contributions from all the significant sources of error under investigation. If an MSA is well designed, standard statistical techniques (such as ANOVA) can be used to estimate the standard deviation contribution from each source of error, and from this the repeatability, reproducibility and precision of the MS are determined.

R3-1.3 Note that any MS that is composed of several measurement subsystems (such as spectrometry and ellipsometry), designed for the measurement of different characteristics or types of samples, should be treated as composed of separate MSs that need to be analyzed independently.

R3-1.4 Writing an appropriate measurement model is the starting point, after which many software packages can be used to design the MSA and calculate ANOVA estimates from the resulting measurement data.

R3-1.4.1 The model must indicate whether each source of variation, i.e., factor, is fixed or random. Variance components are only available for random factors.

R3-1.4.2 The model must indicate which factors are crossed and which are nested.

R3-2 Example of a Measurement Model

R3-2.1 A wafer oxide thickness MS is under investigation. A wafer is placed in the gauge, which then automatically positions the wafer and takes a measurement. While the wafer is positioned, the measurement can be repeated as many times as desired. Sources of variability that might affect a measurement include basic repeatability on a positioned wafer, variability due to the automatic positioning process, variability over time and variability from measuring several different wafers (to cover a range of "true" measurement values).

R3-2.2 An MSA that separates out all these possible sources of variability is the following: 10 wafers are chosen at random from normal production. Each wafer is put in the MS in a random order and measured 3 times at a single site (3 repeats) on day 1 (cycle 1). Immediately after the 30 measurements are recorded, the same measurement process is repeated on the 10 wafers (cycle 2). On day 2, the same wafers are again measured using exactly the same procedure. This is repeated for a total of 5 days, yielding $3 \times 10 \times 2 \times 5 = 300$ measurements.

R3-2.3 Assuming the MS has been calibrated (or bias is not a concern at the moment), a model for variability is constructed as follows: let $h = 1, 2, \ldots, 5$, index the days; let $k = 1, 2, \ldots, 10$, index the wafers; let $j = 1, 2$, index the repositions (cycles) each day and let $i = 1, 2, 3$, index the repeat measurements (taken under repeatability conditions) on a positioned wafer.

R3-2.4 The model for the i^{th} measurement at the j^{th} repositioning on the k^{th} wafer on the h^{th} day is:

$$M_{hkji} = \mu + d_h + w_k + p_{hkj} + r_{hkji} \qquad \text{(R3-1)}$$

where:

M_{hkji} = measurement taken on day h, wafer k, cycle j, and repeat i,

μ = true oxide thickness average value for the population of wafers,

d_h = error term associated with the h^{th} day (due to day-to-day stability variation),

w_k = offset from the average due to the true thickness of the film on wafer k,

p_{hkj} = (short term) error due to the j^{th} positioning of the k^{th} wafer on the h^{th} day, and

r_{hkji} = repeatability error term.

R3-2.5 In this model, the quantities d_h, p_{hkj}, and r_{hkji} are random error terms. They are usually assumed to have a normal distribution with zero mean and standard deviations σ_d, σ_p, and σ_r, respectively. The wafer term w_k may be either a random term or a "fixed effect," depending on whether we consider the wafers measured to be a random sample from the entire population of possible wafers or a fixed population used for experimental purposes. In either case, the estimates of repeatability and reproducibility will be the same.

R3-2.6 When error terms are known to have nonnormal distributions, special methods and/or software (beyond the scope of this guide) are needed.

NOTE 1: The model might also include a wafer-by-day random error term wd_{hki}, if it is suspected that measurements made from day to day on some wafers might vary differently than measurements made from day to day on other wafers, and it is desired to obtain an estimate of this component of reproducibility.

R3-2.7 Reproducibility includes everything but wafer-to-wafer true thickness variability, so

$$\sigma_R = \sqrt{\sigma_d^2 + \sigma_p^2 + \sigma_r^2} \qquad \text{(R3-2)}$$

R3-2.8 The ANOVA for this MSA provides all the variance estimates needed to calculate repeatability, reproducibility and precision. If the wafer term w_k is random, the ANOVA will also estimate σ_d, which is useful for characterizing the wafer population variability.

NOTE 2: When inputting this model into a statistical analysis program, the factors “day” and “wafer” are said to be *crossed*, since every wafer is measured on every day. The factor “positioning” is *nested* within wafer and day, and “repeatability” is the residual error term and is *nested* within positioning, wafer and day. A factor “A” is *nested* within another factor “B” if the levels or values of “A” are different for every level or value of “B.”

R3-2.9 This example shows how a fairly complicated MSA can be set up. Each particular situation can lead to a different model and experimental design, depending upon the goals and agreed upon sources of (possibly significant) variation.

RELATED INFORMATION 4
EXAMPLE OF A MEASUREMENT SYSTEM ANALYSIS

NOTICE: This related information is not an official part of SEMI E89. It was derived from task force deliberations during the revision of SEMI E89-0999 in 2001-2003. This related information was approved by full letter ballot procedures and was approved for publication by the NA RSC on August 16, 2004.

R4-1 Introduction

R4-1.1 The following example illustrates how an MSA was performed on an automated wafer film thickness MS for the purpose of determining the reproducibility and variance components. The MS was calibrated prior to the MSA, but the presence of bias would not affect the estimation of variance components as long as the amount of bias does not change over the course of the MSA. Different wafer types were selected to span the range of both possible wafer types and typical thicknesses. Five standard wafers were manufactured with characteristics as shown in Table R4-1.

Table R4-1 Wafers Used for Analysis

Film Type	*Total Nominal Film Thickness (Å)*
Oxide (wafers 1, 2, 3)	50, 980, 7900 (for wafers 1, 2, 3, respectively)
Polysilicon over Oxide (wafer 4)	2,575
Deep UV Resist over ARC over Oxide (wafer 5)	13,000

#1 UV — Ultra Violet, ARC — Anti Reflective Coating.

R4-1.2 Wafers were measured on eight days, evenly spaced over a two-week period. On each day of the MSA each wafer was chosen twice, loaded each time into the gauge and measured twice without unloading. The order of selection was random. Therefore, on a given day, each wafer was measured exactly four times. Measurements were taken at three points on the wafers and averaged. The model (see Related Information 3) used was

$$M_{hkji} = \mu + d_h + w_k + wd_{hk} + c_{hkj} + r_{hkji} + e_{hij} \quad \text{(R4-1)}$$

where:

M_{hkji} = measurement result (average of measurements taken at three points each time) on day h, wafer k, cycle j, and repeat i,

μ = grand mean of film thickness value across all conditions,

d_h = effect or contribution associated with the h^{th} day (due to day-to-day stability variation),

w_k = offset from the average due to the true thickness of the film on wafer k,

wd_{hk}= effect or contribution due to wafer-by-day (wafer × day) interaction,

c_{hkj} = effect or contribution due to cycle j, nested in wafer k and day h,

r_{hkji} = effect or contribution due to repeat i, nested in cycle j, wafer k, and day h, and

e_{hij} = residual effect due to all terms not included in the model.

R4-1.2.1 The variabilities contributed by d_h, wd_{hk}, and c_{hkj} are part of reproducibility. The variability contributed by r_{hkji} is the repeatability.

R4-2 Analysis

R4-2.1 Most statistical analysis software programs report estimates as variances and produce the variance components analysis shown in Table R4-2. (Methods of moments estimates were used. Negative variance components were set to zero). Sources of variation, such as σ_r and σ_R, are standard deviations found by taking the square roots of the appropriate variance component or sum of components.

Table R4-2 Variance Components Estimates — All 5 Wafers

Variance Component	*Estimated Variance*	*Estimated Sigma*
Day	12.1348	3.4835
Cycle	0.1256	0.3544
Repeat	0	0.0000
Wafer × Day	462.9869	21.5171
Residual	0.8446	0.9190

R4-2.2 Wafer variability (σ_{wafer}) was not reported because it is associated with a fixed effect. Variance components are only estimated for random effects. If, for example, the five wafers were randomly selected from a distribution for a single wafer type, wafer variability would be included in the table and could be used to estimate the SNR. However, wafer variability would still not be part of σ_R. For further details, see Related Information 3.

R4-2.3 Reproducibility (σ_R) is calculated as the square root of the sum of the estimates, i.e.,

$$\sigma_R = \sqrt{12.1348 + 0.1256 + 0 + 462.9869 + 0.8446} = 21.82 \qquad \text{(R4-2)}$$

R4-2.4 Repeatability (σ_r) is estimated by the variance component corresponding to repeat and is equal to zero.

R4-2.5 Stability is estimated by the square root of the Day component of the MSA, $\sigma_{stability}$ = 3.4835.

R4-2.6 Figure R4-1 shows a Pareto chart of the sigmas.

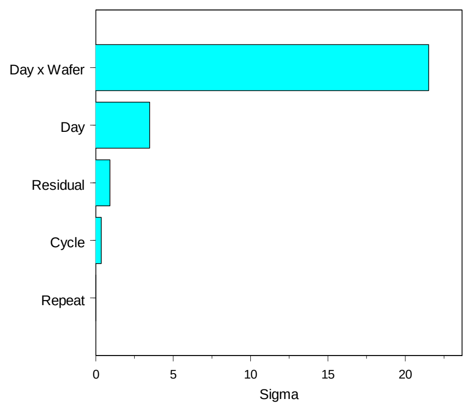

Figure R4-1
Pareto Chart for Effects Sigmas (All Five Wafers)

R4-2.7 Linearity is more difficult to estimate. In general, it is measured by the differences in variability associated with the different wafer types. The large wafer-by-day interaction suggests that there may be a linearity problem. An examination of the standard deviations for each group by day (see Figure R4-2) indicates that Wafer Type 5 (Deep UV Resist) may be responsible. These standard deviations were calculated from the four measurements made on every wafer each day.

R4-2.8 When the variance components analysis was rerun, excluding Wafer Type 5 data, the new estimates obtained confirmed that Wafer Type 5 was problematic. An investigation into the potential cause suggested that the gauge was degrading the resist at the point of measurement, causing the readings to decrease over time.

R4-2.9 If one were interested in measuring only Wafer Types 1 through 4 (employing a different gauge for Wafer Type 5, for example), the improved variance components estimates from Table R4-3 could be used.

R4-2.10 The new estimates for σ_r and σ_R, are 0 and 1.565, respectively. Stability, as measured by day-to-day variability, improves to 0.6450. The new Pareto chart of the effects sigmas is shown in Figure R4-3. The specification range for the product being measured was given as 10 Å, thus the P/T ratio for the MS for Wafer Types 1 to 4 is

$$\frac{P}{T} = \frac{6 \times 1.565}{10} \times 100 = 93.9\% \qquad \text{(R4-3)}$$

Table R4-3 Variance Components Estimates for Wafers 1 – 4

Variance Component	*Estimated Variance*	*Estimated Sigma*
Day	0.4160	0.6450
Cycle	0.0203	0.1426
Repeat	0	0
Day x Wafer	1.4918	1.2214
Residual	0.1937	0.4402

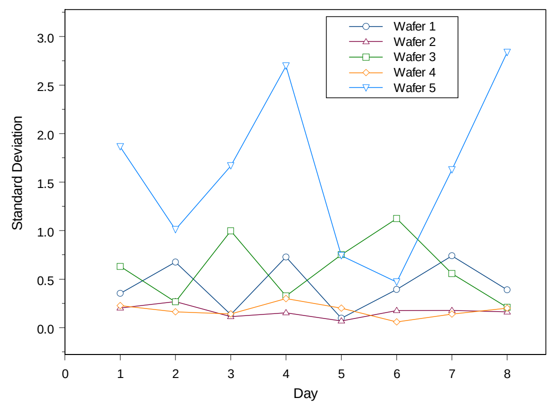

Figure R4-2
Wafer Sigmas by Day

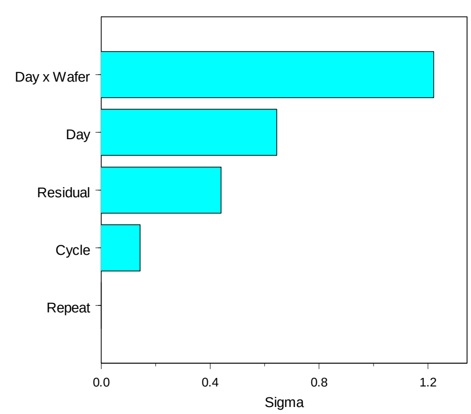

Figure R4-3
Pareto Chart for Effects Sigmas (Wafer Type 5 Removed)

R4-2.10.2 Because this is far above the generally acceptable maximum value of 30% for a suitable MS, it might not be suitable for some applications. Improvement activities would begin with an investigation of why the Wafer × Day sigma is so large. This term indicates differences between the ways certain wafers vary from day to day (stability differences between wafers).

R4-2.11 The actual measurement data obtained in this example MSA is provided in Table R4-4. It may be useful for working through the calculations in this MSA either using statistical analysis software or manually to confirm understanding.

Table R4-4 Measurement Data (Average of Measurements Taken at Three Points Each Time) in Example MSA

Day	*Cycle*	*Repeat*	*Wafer 1*	*Wafer 2*	*Wafer 3*	*Wafer 4*	*Wafer 5*
1	1	1	48.747	980.007	7,907.71	2,576.78	13,061.50
1	1	2	49.603	980.050	7,906.78	2,576.66	13,059.92
1	2	1	49.273	979.623	7,906.18	2,577.14	13,064.28
1	2	2	49.200	979.770	7,906.87	2,577.06	13,062.84
2	1	1	47.187	980.260	7,906.94	2,576.50	13,034.58
2	1	2	47.613	980.303	7,906.60	2,576.59	13,032.42
2	2	1	48.500	980.840	7,906.85	2,576.87	13,033.23
2	2	2	48.560	980.567	7,906.35	2,576.74	13,032.46
3	1	1	47.270	983.120	7,907.46	2,577.35	13,017.89
3	1	2	47.367	983.083	7,909.03	2,577.58	13,016.72
3	2	1	47.550	982.987	7,909.45	2,577.68	13,020.23
3	2	2	47.530	982.870	7,909.67	2,577.48	13,019.89
4	1	1	46.373	982.420	7,909.09	2,576.53	13,000.94
4	1	2	45.913	982.520	7,908.90	2,576.89	12,999.77
4	2	1	47.380	982.210	7,908.35	2,576.84	12,996.04
4	2	2	47.340	982.220	7,908.96	2,577.26	12,995.51
5	1	1	44.457	982.080	7,907.22	2,576.54	12,963.97
5	1	2	44.690	982.020	7,907.36	2,576.21	12,962.29
5	2	1	44.563	981.963	7,907.77	2,576.67	12,963.52
5	2	2	44.613	982.120	7,906.02	2,576.58	12,962.83
6	1	1	45.753	982.200	7,906.16	2,576.42	12,949.45
6	1	2	45.317	982.207	7,904.74	2,576.29	12,948.40
6	2	1	45.030	982.013	7,903.42	2,576.39	12,949.32
6	2	2	45.880	981.837	7,904.56	2,576.33	12,948.96
7	1	1	42.460	981.393	7,904.80	2,575.98	12,938.10
7	1	2	43.350	981.743	7,904.26	2,576.16	12,936.95
7	2	1	44.060	981.770	7,903.59	2,576.05	12,936.02
7	2	2	43.983	981.720	7,903.71	2,576.30	12,934.25
8	1	1	45.783	982.300	7,905.23	2,576.07	12,934.40
8	1	2	46.440	982.420	7,905.62	2,576.56	12,932.71
8	2	1	45.907	982.653	7,905.69	2,576.30	12,930.05
8	2	2	46.573	982.320	7,905.61	2,576.29	12,927.99

RELATED INFORMATION 5
EXAMPLE OF A MEASUREMENT SYSTEM ANALYSIS WITH DAY AND LOAD ONLY

NOTICE: This related information is not an official part of SEMI E89. It was derived from task force deliberations during the revision of SEMI E89-0999 in 2001-2003. This related information was approved by full letter ballot procedures and was approved for publication by the NA RSC on August 16, 2004.

R5-1 Introduction

R5-1.1 The following example illustrates how an MSA is performed for a hypothetical measurement instrument where only day and load are considered. Hand calculations are provided and possible because the data are balanced (i.e., each load has the same number of repeated measurements). Rounding of value may cause results may vary slightly. The data are shown in Table R5-1.

Table R5-1 Data for MSA with Load and Repeat

Repeat	*Load 1*	*Load 2*	*Load 3*
1	593.46	593.43	594.11
2	593.15	594.22	594.03
3	592.87	593.63	593.92
4	593.25	592.73	593.2
5	593.43	592.98	593.16
6	593.21	593.18	593.41
7	593.08	592.74	593.57
8	593.68	592.65	593.46
9	593.06	592.69	592.7
10	592.68	593.38	593.42
11	593.20	593.86	593.5
12	593.00	593.27	593.39

The model for the MSA is

$$Y_{ij} = \mu + l_i + r_{ij} \qquad \text{(R5-1)}$$

Y_{ij} = measurement on the i^{th} load and j^{th} repeat,
μ = true value of the measurand,
l_i = error term associated with the i^{th} load, and
r_{ij} = error term associated with the i^{th} load, j^{th} repeat.

R5-1.2 Load and Repeat are treated as random effects. Repeat is nested within Load.

R5-2 Analysis

R5-2.1 Calculate the mean over all observations (the grand mean, $\overline{Y}_{\bullet\bullet}$) and the mean for each load ($\overline{Y}_{i\bullet}$).

Table R5-2 Mean by Load and Grand Mean

	N Obs	*Mean*
Load 1	12	593.17
Load 2	12	593.23
Load 3	12	593.49
Grand Mean	36	593.30

R5-2.2 Calculate the Sum of Squares for Load (SS_L):

$$SS_L = 12\sum_{i=1}^{3}\left(\overline{Y}_{i\bullet} - \overline{Y}_{\bullet\bullet}\right)^2 = 0.6830 \qquad \text{(R5-2)}$$

R5-2.2.1 In general, the formula for SS_L is

$$SS_L = n\sum_{i=1}^{L}\left(\overline{Y}_{i\bullet} - \overline{Y}_{\bullet\bullet}\right)^2 \qquad \text{(R5-3)}$$

where
n = number of repeats per load and,
L = number of loads.

R5-2.3 Calculate the Sum of Squares for Repeatability (SS_r):

$$SS_r = \sum_{j=1}^{12}\sum_{i=1}^{3}\left(Y_{ij} - \overline{Y}_{i\bullet}\right)^2 = 5.2911 \qquad \text{(R5-4)}$$

where:
Y_{ij} = observation for the i^{th} load, j^{th} repeat.

R5-2.3.1 In general, the formula for SS_r is

$$SS_r = \sum_{j=1}^{n}\sum_{i=1}^{L}\left(Y_{ij} - \overline{Y}_{i\bullet}\right)^2 \qquad \text{(R5-5)}$$

R5-2.4 Calculate the degrees of freedom for Load (df_L) as $L - 1$. Calculate the degrees of freedom for repeatability (df_r) as $L(n - 1)$.

R5-2.5 Calculate the Mean Squares for both Load (MS_L) and Repeat (MS_r) as the Sum of Squares divided by degrees of freedom:

$$MS_L = \frac{SS_L}{df_L} = \frac{0.6830}{2} = 0.3415 \qquad \text{(R5-6)}$$

$$MS_r = \frac{SS_r}{df_r} = \frac{5.2911}{33} = 0.1603 \qquad \text{(R5-7)}$$

R5-2.6 The variance component for Repeatability (VC_r) is MS_r. The variance component for Load is

$$VC_L = \frac{MS_L - VC_r}{12} = 0.01510 \qquad \text{(R5-8)}$$

R5-2.6.1 In general, the formula for VC_L is

$$VC_L = \frac{MS_L - VC_r}{n} \qquad \text{(R5-9)}$$

R5-2.7 Reproducibility is

$$\begin{aligned} \sigma_r &= \sqrt{VC_r + VC_L} \\ &= \sqrt{0.1603 + 0.01510} \\ &= 0.4188 \end{aligned} \qquad \text{(R5-10)}$$

RELATED INFORMATION 6
EXAMPLE ILLUSTRATING THE DIFFERENCES BETWEEN NESTED AND CROSSED EFFECTS

NOTICE: This related information is not an official part of SEMI E89. It was derived from task force deliberations during the revision of SEMI E89-0999 in 2001-2003. This related information was approved by full letter ballot procedures and was approved for publication by the NA RSC on August 16, 2004.

R6-1 Introduction

R6-1.1 The following example illustrates the differences between an MSA where all effects are nested versus the same data when one of the factors is treated as crossed. It is performed on a hypothetical measurement instrument. Hand calculations are provided and possible because the data are balanced. Rounding of value may cause results may vary slightly.

R6-1.2 The data, shown in Table R6-1, consists of seven repeated measurements per load and three loads per sample. There are four samples.

Table R6-1 Data for Example

Sample	*Repeat*	*Load 1*	*Load 2*	*Load 3*
1	1	493.72	493.79	492.92
1	2	492.91	493.77	492.78
1	3	493.08	494.07	492.57
1	4	493.78	491.28	493.52
1	5	492.69	492.19	493.79
1	6	492.57	491.82	493.46
1	7	491.21	492.95	493.33
2	1	516.27	514.21	515.20
2	2	516.26	514.54	515.55
2	3	516.35	514.93	515.28
2	4	515.68	515.14	515.47
2	5	515.46	515.21	515.28
2	6	515.67	515.07	514.87
2	7	514.87	515.00	514.77
3	1	541.30	541.84	541.57
3	2	541.38	541.92	541.59
3	3	541.48	542.33	541.71
3	4	541.53	540.61	541.02
3	5	541.31	541.37	540.76
3	6	541.41	541.21	540.85
3	7	540.85	540.80	541.73
4	1	551.00	551.03	552.02
4	2	550.83	551.02	552.23
4	3	551.01	550.98	551.78
4	4	551.60	551.38	550.12
4	5	550.90	551.13	550.58
4	6	551.29	550.74	550.27
4	7	551.91	549.06	550.98

R6-2 Nested Effects

R6-2.1 Assume that each sample represents measurements made on different days. Load would be nested in day and repeat in Load and Day. Repeats cannot be randomized among Loads or Days. A given Repeat must occur in a specific Load and Day. It is nested in both Load and Day. Likewise, Loads cannot be randomized among Days. Load is nested in Day.

R6-2.2 The model for the MSA is

$$Y_{ijk} = \mu + d_i + l_{ij} + r_{ijk} \qquad \text{(R6-1)}$$

Y_{ijk} = measurement on the i^{th} day, j^{th} load, and k^{th} repeat,

μ = true value of the measurand,

d_i = error term associated with the i^{th} day,

l_{ij} = error term associated with the i^{th} day, j^{th} load, and

r_{ijk} = error term associated with the i^{th} day, j^{th} load, and k^{th} repeat.

R6-2.3 Day, Load, and repeatability are treated as random effects. Load is nested in Day. Repeat is nested within Day and Load.

R6-2.4 Calculate the mean over all observations ($\bar{Y}_{\bullet\bullet\bullet}$), the mean for each day ($\bar{Y}_{i\bullet\bullet}$), and the mean for each load-by-day combination ($\bar{Y}_{ij\bullet}$).

Table R6-2 Means for Each Day

Day 1	*Day 2*	*Day 3*	*Day 4*	*Grand Mean*
492.96	515.29	541.36	551.04	525.16

Table R6-3 Means for Each Load by Day

	Day 1	*Day 2*	*Day 3*	*Day 4*
Load 1	492.85	515.79	541.32	551.22
Load 2	492.84	514.87	541.44	550.76
Load 3	493.20	515.20	541.32	551.14

R6-2.5 Calculate the Sum of Squares for Day (SS_D) as

$$SS_D = 21\sum_{i=1}^{4}\left(\bar{Y}_{i\bullet\bullet} - \bar{Y}_{\bullet\bullet\bullet}\right)^2 = 43395 \qquad \text{(R6-2)}$$

R6-2.5.1 In general, the formula for SS_D is

$$SS_D = n_d\sum_{i=1}^{D}\left(\bar{Y}_{i\bullet\bullet} - \bar{Y}_{\bullet\bullet\bullet}\right)^2 \qquad \text{(R6-3)}$$

where n_d is the number of observations per day and D the number of days.

R6-2.6 Calculate the Sum of Squares for Load (SS_r):

$$SS_L = 7\sum_{j=1}^{3}\sum_{i=1}^{4}\left(\bar{Y}_{ij\bullet} - \bar{Y}_{i\bullet\bullet}\right)^2 = 4.5352 \qquad \text{(R6-4)}$$

R6-2.6.1 In general, the formula for SS_L is

$$SS_L = n\sum_{j=1}^{L}\sum_{i=1}^{D}\left(\bar{Y}_{ij\bullet} - \bar{Y}_{i\bullet\bullet}\right)^2 \qquad \text{(R6-5)}$$

where n is the number of repeats per load and L the number of loads.

R6-2.7 Calculate the Sum of Squares for Repeat (SS_r):

$$SS_r = \sum_{k=1}^{7}\sum_{j=1}^{3}\sum_{i=1}^{4}\left(Y_{ijk} - \bar{Y}_{ij\bullet}\right)^2 = 28.6925 \qquad \text{(R6-6)}$$

R6-2.7.1 In general, the formula for SS_r is

$$SS_r = \sum_{k=1}^{n}\sum_{j=1}^{L}\sum_{i=1}^{D}\left(Y_{ijk} - \bar{Y}_{ij\bullet}\right)^2 \qquad \text{(R6-7)}$$

R6-2.8 Calculate the degrees of freedom for Day (df_D) as $D - 1$. Calculate the degrees of freedom for Load (df_L) as $D(L - 1)$. Calculate the degrees of freedom for Repeat (df_r) as $DL(n - 1)$.

R6-2.9 Calculate the Mean Squares for Day (MS_D), Load (MS_L), and Repeat (MS_r) as the Sum of Squares divided by degrees of freedom

$$MS_D = \frac{SS_D}{df_D} = 14465 \qquad \text{(R6-8)}$$

$$MS_L = \frac{SS_L}{df_L} = 0.5669 \qquad \text{(R6-9)}$$

$$MS_r = \frac{SS_r}{df_r} = 0.3985 \qquad \text{(R6-10)}$$

R6-2.10 The variance component for Repeatability (VC_r) is MS_r.

R6-2.11 The variance component for Load is

$$VC_L = \frac{MS_L - VC_r}{7} = 0.02241 \qquad \text{(R6-11)}$$

R6-2.11.1 In general, the formula for VC_L is

$$VC_L = \frac{MS_L - VC_r}{n} \qquad \text{(R6-12)}$$

R6-2.12 The variance component for Day is

$$\begin{aligned} VC_D &= \frac{MS_D - MS_L}{21} \\ &= \frac{MS_D - 7VC_L - VC_r}{21} \\ &= 688.7806 \end{aligned} \qquad \text{(R6-13)}$$

R6-2.12.1 In general, the formula for VC_D is

$$VC_D = \frac{MS_D - LVC_L - VC_r}{nL} \qquad \text{(R6-14)}$$

R6-2.13 Reproducibility is

$$\sigma_r = \sqrt{VC_r + VC_L + VC_D} = 26.25 \qquad \text{(R6-15)}$$

R6-3 Crossed Effects

R6-3.1 Assume, instead, that each sample represents measurements made on different wafers randomly sampled from a population of wafers.

R6-3.2 The model for the MSA is

$$Y_{ijk} = \mu + w_i + l_{ij} + r_{ijk} + w_i{*}l_{ij} + w_i{*}r_{ijk} \qquad \text{(R6-16)}$$

Y_{ijk} = measurement on the i^{th} wafer, j^{th} load, and k^{th} repeat,
μ = true value of the measurand,
w_i = error term associated with the i^{th} wafer,
l_{ij} = error term associated with the i^{th} wafer, j^{th} load,
r_{ijk} = error term associated with the i^{th} wafer, j^{th} load, k^{th} repeat,
$w_i{*}l_{ij}$ = interaction between wafer and load, and
$w_i{*}r_{ijk}$ = interaction between wafer and repeat.

R6-3.3 In this case, Load would be crossed with Wafer because it is possible to randomize the wafer in which a load is observed. Repeat (when treated as nested in Load) is also crossed with Wafer for the same reason.

R6-3.4 Calculate the Sum of Squares for Wafer (SS_W), Load (SS_L), Repeat (SS_r), Load by Wafer (SS_{LxW}), and Repeat by Wafer (SS_{rxW})

R6-3.4.1 The calculation of SS_W is identical to the calculation of SS_D shown in Equation 2.

R6-3.4.2 The calculation for SS_L is

$$SS_L = 28\sum_{j=1}^{3}\left(\bar{Y}_{\bullet j\bullet} - \bar{Y}_{\bullet\bullet\bullet}\right)^2 = 1.5336 \quad \text{(R6-17)}$$

where $\bar{Y}_{\bullet j\bullet}$ is the mean for the j^{th} load and $\bar{Y}_{\bullet\bullet\bullet}$ the grand mean.

R6-3.4.2.1 In general, the formula for SS_L is

$$SS_L = wn\sum_{j=1}^{L}\left(\bar{Y}_{\bullet j\bullet} - \bar{Y}_{\bullet\bullet\bullet}\right)^2 \quad \text{(R6-18)}$$

where w is the number of wafers, n the number of repeats per load, and L the number of loads on each wafer.

R6-3.4.3 The calculation for SS_r is

$$SS_r = 4\sum_{j=1}^{3}\sum_{k=1}^{7}\left(\bar{Y}_{\bullet jk} - \bar{Y}_{\bullet j\bullet}\right)^2 = 7.9095 \quad \text{(R6-19)}$$

Where $\bar{Y}_{\bullet jk}$ is the mean for the j^{th} load, k^{th} repeat.

R6-3.4.3.1 In general, the formula for SS_r is

$$SS_r = w\sum_{j=1}^{L}\sum_{k=1}^{n}\left(\bar{Y}_{\bullet jk} - \bar{Y}_{\bullet j\bullet}\right)^2 \quad \text{(R6-20)}$$

where $\bar{Y}_{\bullet jk}$ is the mean for each load-by-repeat combination.

R6-3.4.4 Sum of Squares for Load by Wafer (SS_{LxW}) is the difference between SS_L calculations in Equations R6-4 and R6-15

$$SS_{LxW} = 7\sum_{j=1}^{3}\sum_{i=1}^{4}\left(\bar{Y}_{ij\bullet} - \bar{Y}_{i\bullet\bullet}\right)^2 - 28\sum_{j=1}^{3}\left(\bar{Y}_{\bullet j\bullet} - \bar{Y}_{\bullet\bullet\bullet}\right)^2 = 3.0016 \quad \text{(R6-21)}$$

where $\bar{Y}_{ij\bullet}$ is the mean for each load-by-wafer combination and $\bar{Y}_{i\bullet\bullet}$ is the mean for each wafer.

R6-3.4.5 Sum of Squares for Repeat by Wafer (SS_{rxW}) is the difference between SS_L calculations in Equations R6-6 and R6-17

$$SS_{rxW} = \sum_{k=1}^{7}\sum_{j=1}^{3}\sum_{i=1}^{4}\left(Y_{ijk} - \bar{Y}_{ij\bullet}\right)^2 - 4\sum_{j=1}^{3}\sum_{k=1}^{7}\left(\bar{Y}_{\bullet jk} - \bar{Y}_{\bullet j\bullet}\right)^2 = 20.783 \quad \text{(R6-22)}$$

R6-3.5 Calculate the degrees of freedom for Wafer (df_W), $w - 1$, Load (df_L), $L - 1$, Repeat (df_r), $L(n - 1)$, Load by Wafer (df_{LxW}), $(L - 1)(w - 1)$, and Repeat by Wafer (df_{rxW}), $L(n - 1)\ (w - 1)$.

R6-3.6 Calculate the Mean Squares for Wafer (MS_W), Load (MS_L), Repeat (MS_r), Load by Wafer (MS_{LxW}), and Repeat by Wafer (MS_{rxW}) as the Sum of Squares divided by degrees of freedom.

R6-3.7 The variance component for Repeat by Wafer (VC_{rxW}) is equal to MS_{rxW}

$$VC_{rxW} = \frac{SS_{rxW}}{df_{rxW}} = 0.3849 \quad \text{(R6-23)}$$

R6-3.8 The variance component for Repeat (VC_r) is

$$VC_r = \frac{MS_r - VC_{rxW}}{4} = 0.01364 \quad \text{(R6-24)}$$

R6-3.8.1 In general, the equation for VC_r is

$$VC_r = \frac{MS_r - VC_{rxW}}{w} \quad \text{(R6-25)}$$

If N is the total number of observations, then the denominator is derived from

$$w = \frac{N}{nL} \quad \text{(R6-26)}$$

R6-3.9 The variance component for Repeat (VC_{LxW}) is

$$VC_{LxW} = \frac{MS_{LxW} - VC_{rxW}}{7} = 0.01649 \quad \text{(R6-27)}$$

R6-3.9.1 In general, the equation for VC_{LxW} is

$$VC_{LxW} = \frac{MS_{LxW} - VC_{rxW}}{n} \quad \text{(R6-28)}$$

The denominator is derived from

$$n = \frac{N}{Lw} \quad \text{(R6-29)}$$

R6-3.10 The variance component for Load (VC_L) is

$$VC_L = \frac{MS_L - 7VC_{LxW} - 4VC_r - VC_{rxW}}{28} = 0.00757 \quad \text{(R6-30)}$$

R6-3.10.1 In general, the equation for VC_L is

$$VC_L = \frac{MS_L - nVC_{LxW} - wVC_r - VC_{rxW}}{nw} \quad \text{(R6-31)}$$

R6-3.11 The variance component for Wafer (VC_W) is

$$VC_W = \frac{MS_W - 7VC_{LxW} - VC_{rxW}}{21} = 688.78 \quad \text{(R6-32)}$$

R6-3.11.1 In general, the equation for VC_W is

$$VC_W = \frac{MS_W - nVC_{LxW} - VC_{rxW}}{nL} \quad \text{(R6-33)}$$

R6-3.12 Reproducibility is

$$\begin{aligned} \sigma_r &= \sqrt{VC_r + VC_L + VC_{rxW} + VC_{LxW}} \\ &= \sqrt{0.4225} \quad \text{(R6-34)} \\ &= 0.65 \end{aligned}$$

R6-3.12.1 Typically, VC_W is not included in reproducibility because it is a function of true differences on the measurand. If, however, the measurands are known to be the same value, and differences are associated with measurement variability, it should be included in reproducibility.

SEMI E92-0302^E
SPECIFICATION FOR 300 mm LIGHT WEIGHT AND COMPACT BOX OPENER/LOADER TO TOOL-INTEROPERABILITY STANDARD (BOLTS/LIGHT)

This provisional specification was technically approved by the Global Physical Interfaces & Carriers Committee and is the direct responsibility of the Japanese Physical Interfaces & Carriers Committee. Current edition approved by the Japanese Regional Standards Committee on December 3, 2001. Initially available at www.semi.org January 2002; to be published March 2002. Originally published September 1999.

E This document was editorially modified in January 2003 to reflect the withdrawal of SEMI E44. Changes were made to Sections 4.1, 5.2.5, 5.2.9, 5.2.18, and 5.2.19.

1 Purpose

1.1 *Provide Standard for Box Opener/Loader Interoperability* — This standard is intended to provide standard specifications such as interfaces between the component that opens the boxes and presents the boxes to the equipment wafer handler for unloading and loading 300 mm wafers (BOLTS/Light unit) and higher level part of equipment and its functions to provide: (see Figure 1)

- High level of interchangeability/ interoperability,
- Quick attachment/detachment capability with high mechanical repeatability,
- Light weight, and
- Compactness.

1.1.1 In order to provide a high level of interchangeability and interoperability, this standard specifies not only interfaces but also some of the box opener/loader's functions that affect interoperability.

1.2 *Usage of This Standard* — Interoperability specifications defined by this standard are intended to be used as interfaces and functionality between BOLTS/Light compliant box opener/loader and:

- A BOLTS/M compliant loadport unit (that would conform to SEMI E63).
- An integrated loadport such as four box opener/loader in one chassis.
- High-densely packaged equipment that uses the space under the box opener/loader.

1.3 *SEMI Standards Compatibility* — This standard is compatible with 300 mm SEMI standards including SEMI E15.1, E47.1, E1.9, E62, E63 and E64.

1.4 *Open Cassette Application* — The BOLTS/Light unit might be configured to handle boxes that would conform to SEMI E47.1 and SEMI E62.

1.5 A similar unit may be compatibly designed which does not have box opener capability, but facilitates placement of an open cassette (that would conform to SEMI E1.9).

1.6 *Carrier Capacities* — This standard defines one interface for 13 or 25 carrier capacity box opener/ loaders.

1.7 The interface specified in this standard is designed for equipment with a sealed mini-environment, but it is not limited to such.

2 Scope

2.1 *Items Specified* — This standard is intended to set an appropriate level of specification that places minimal limits on innovation while ensuring modularity, interchange-ability, and interoperability including:

- Box opener/loader functions that affect interoperability.
- Mechanical interface features between the box opener/loader and equipment.

2.2 This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the users of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

3 Limitations

3.1 This specification does not apply to the following application:

- Direct insertion of open cassettes into load-lock chambers.

4 Referenced Standards

4.1 *SEMI Standards*

SEMI E1.9 — Mechanical Specification for Cassettes Used to Transport and Store 300 mm Wafers

SEMI E15 — Specification for Tool Load Port

SEMI E15.1 — Specification for 300 mm Tool Load Port

SEMI E47.1 — Provisional Mechanical Specification for Boxes and Pods Used to Transport and Store 300 mm Wafers

SEMI E57 — Mechanical Specification for Kinematic Couplings Used to Align and Support 300 mm Wafer Carriers

SEMI E62 — Provisional Specification for 300 mm Front-Opening Interface Mechanical Standard (FIMS)

SEMI E63 — Mechanical Specification for 300 mm Box Opener/Loader to Tool Standard (BOLTS-M) Interface

SEMI E64 — Specification for 300 mm Cart to SEMI E15.1 Docking Interface Port

4.2 *Other Standard*

I300I/J300 GJG — I300I/J300 Global Joint Guidance for 300 mm Semiconductor Factories

NOTE 1: As listed or revised, all documents cited shall be the latest publications of adopted standards.

5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 *AMHS* — Automated Material Handling System

5.2 *Definitions*

5.2.1 *bilateral datum plane* — a vertical plane that bisects the wafers and that is perpendicular to both the horizontal and facial datum planes (as defined in SEMI E57).

5.2.2 *BOLTS/Light exclusion volume* — a volume reserved by equipment or loadport unit to put BOLTS/Light compliant box opener/loader.

5.2.3 *BOLTS/Light plane* — a vertical plane that interfaces BOLTS/Light compliant box opener/loader and equipment.

5.2.4 *bottom interface plane*— an interface means between the equipment and box opener/loader.

5.2.5 *box* — a protective portable container for a cassette and/or substrate(s).

5.2.6 *box opener/loader* — the equipment component that opens wafer carriers (if needed) and presents the carriers to the equipment's wafer handler for unloading and loading wafers.

5.2.7 *carrier* — any cassette, box, pod, or boat that contains wafers (as defined in SEMI E1.9). Also known as wafer carrier.

5.2.8 *carrier capacity* — the number of substrates that a carrier holds (as defined in SEMI E1.9).

5.2.9 *cassette* — an open structure that holds one or more substrates.

5.2.10 *control connection area* — an area to be used for placement of connectors for electrical signals, power supplies, and other inlets/outlets.

5.2.11 *docked facial datum plane* — a vertical plane that bisects the wafers at the carrier docked position. It is also parallel to the load face plane specified in SEMI E15.

5.2.12 *docking stroke* — the travel distance of the carrier center between its load position (facial datum plane) and the position where the door opening/closing is done.

5.2.13 *facial datum plane* — a vertical plane that bisects the wafers and that is parallel to the front side of the carrier (where wafers are removed or inserted). On equipment load ports, it is also parallel to the load face plane specified in SEMI E15 on the side of the equipment where the carrier is loaded and unloaded (as defined in SEMI E57).

5.2.14 *front-opening unified pod (FOUP)* — a box (that complies with SEMI E47.1) with a nonremovable cassette (so that its interior complies with SEMI E1.9) and with a front-opening interface (that mates with a FIMS port that complies with SEMI E62) (as defined in SEMI E47.1).

5.2.15 *horizontal datum plane* — a horizontal plane from which projects the kinematic-coupling pins on which the carrier sits. On equipment load ports, it is at the load height specified in SEMI E15 and might not be physically realized as a surface (as defined in SEMI E57).

5.2.16 *load face plane* — the furthest physical vertical boundary plane from the cassette centroid or carrier centroid on the side (or sides) of the equipment where loading of the equipment is intended (as defined in SEMI E15).

5.2.17 *loading slider area* — two flat surfaces on equipment which may be used by a maintenance supporting mechanism (not defined in this standard) to support the box opener/loader during attachment and detachment.

5.2.18 *minienvironment* — a localized environment created by an enclosure to isolate the product from contamination and people.

5.2.19 *pod* — a box having a Standard Mechanical Interface (SMIF) per SEMI E19.

5.2.20 *seal zone* — a surface on the equipment at the BOLTS/Light plane for sealing to the box opener/loader.

5.2.21 *side interface feature* — an interface means to perform a seal between the mini-environment of the equipment and box opener/loader.

5.2.22 *wafer carrier* — any cassette, box, pod, or boat that contains wafers (as defined in SEMI E15).

6 Functional Requirements

6.1 This standard does not define actual implementation but requires functional compliance with the following standards for interchangeability and interoperability of box opener/loader.

6.2 The box opener/loader of this standard should be compliant with related sections of factory interface standards such as SEMI E15.1, SEMI E57, SEMI E47.1 and SEMI E62.

6.3 *Outer Dimensions and Physical Factory Material Delivery Interface Compatibility* — Physical dimensions, such as clearances and trenches required for factory delivery systems (human or automated), should be compliant with SEMI E15.1.

6.3.1 *Carrier Registration* — The physical alignment mechanism for the box consists of features (not specified in this standard) on the box that mate with three pins underneath as defined in SEMI E57. Primary kinematic coupling pins should be used.

6.3.2 *Loadport Pitch* — The loadport pitch which conforms to this standard is $S \geq 475$ mm (minimum value for FOUP without handles as defined in SEMI E15.1).

6.4 *Carrier ID Reader/Writer Head Exclusion Volume* — The box opener/loader compliant with this standard should have a carrier ID reader/writer head exclusion volume defined in SEMI E15.1 for automated units that read or write to an ID tag. Regarding the box opener/loader, the front end of this exclusion volume is limited by *y111*. And the rear end of this exclusion volume is defined in SEMI E15.1 D3. The difference between *y111* and SEMI E15.1 D4 should be supplied by the equipment.

6.5 *Carrier Sensing* — The box opener/loader compliant with this standard has to have the following capabilities:

6.5.1 *Carrier Presence Sensor* — Carrier sensing capability which detects carrier presence regardless of its correct placement.

6.5.2 *Carrier Placement Sensor* — Carrier sensing capability which detects correct carrier placement on the kinematic coupling.

6.6 *Info-pad Interfaces* — Optional info-pad sensing/detecting capability as defined in SEMI E1.9 and SEMI E15.1.

6.6.1 *Info-pad A, B Sensors* — Optional carrier sensing capability which detects carrier type as defined in SEMI E1.9 and SEMI E15.1.

6.6.2 *FEOL/BEOL Lockout Pin* — Optional pin that physically detects/rejects a misplaced carrier by using info-pads C and D to distinguish a FEOL carrier vs. a BEOL carrier. This pin should be capable of being installed easily after the equipment is delivered.

6.7 *Box to Equipment Sealing Interface and Door Lock/Unlock Interface* — This standard requires a box to equipment seal interface and door lock/unlock interface compliant with SEMI E47.1 and SEMI E62. This standard does not specify any of the actual design.

7 Mechanical Requirements

7.1 *Datum Planes and Dimensioning Rules* — Dimensions defined in this standard are determined with respect to the following datum planes and default dimensioning rules.

NOTE 2: Unless otherwise stated, perpendicularity and parallelism are implicitly defined in the geometric tolerances.

7.1.1 *Three Common Datum Planes* — Many of the dimensions of the BOLTS/Light interface are determined with respect to the three orthogonal datum planes defined in SEMI E57: the horizontal datum plane, the facial datum plane, and the bilateral datum plane.

7.1.2 *Symmetry* — All of the dimensions for the interface are bilaterally symmetric about the bilateral datum plane unless otherwise noted. These dimensions are shown in Figures 2 and 3 and specified in Table 1.

7.1.3 *Inner and Outer Radii* — All required concave features may have a radius of up to *r100* to allow cleaning and to prevent contaminant build-up. All required convex features may also have a radius of up to *r101* to prevent small contact patches with large stresses that might cause wear and particles. Note that these limits on the radius of all required features are specified as a maximum (not a minimum) to ensure that the required features are not rounded off too much. The lower bound on the radius is up to the equipment supplier. Note also that this radius applies to every required feature unless another radius is called out specifically.