SEMI E26 — Radial Cluster Tool: Module Footprint Standard.

SEMI E26-92 (Withdrawn 1104)
RADIAL CLUSTER TOOL FOOTPRINT STANDARD

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Minor editorial changes were made to this document to conform to editorial guidelines.

NOTICE: This document was balloted and approved for withdrawal in 2004.

1 Introduction

1.1 *Scope* — The standard specifies the footprints within which the modules of a radial cluster tool must be accommodated and the restricted areas between such footprints. The standard also applies to those portions of nonradial cluster tools that possess radial elements. The standard is limited to wafers 200 mm (8 in.) in diameter or smaller.

1.2 *Purpose* — The purpose of the standard is to ensure that modules from different suppliers can be integrated into a radial cluster tool. It provides design specifications to equipment manufacturers so that physical interference between adjacent modules in a radial cluster tool is avoided and access to all modules of the cluster tool is guaranteed.

1.3 *Impact* — The standard requires equipment designers to ensure that modules attached to a transport module be confined within a specific footprint and its vertical boundaries.

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

2 Referenced Documents

2.1 *SEMI Documents*

SEMI E21 — Cluster Tool Module Interface: Mechanical Interface and Wafer Transport Standard

SEMI E22 — Cluster Tool Module Interface: Transport Module End Effector Exclusion Volume Standard

SEMI E25 — Cluster Tool Module Interface: Module Access Guideline

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

3 Definitions

3.1 *radial cluster tool* — A cluster tool (as defined in SEMI E21) in which all wafer transport axes (as defined in SEMI E22) intersect at a common point within the transport module (as defined in SEMI E21).

4 Requirements

4.1 *Module Footprint Description* — The footprint within which modules (as defined in SEMI E21) attached to the transport module must be accommodated is illustrated in Figure 1. The variables are given in Table 1 and defined in Table 2 (see Sections R1-1 through R1-6).

4.2 *Restricted Areas* — Modules shall not intrude upon the shaded region between adjoining module footprints in Figure 1 (see Section R1-7). Furthermore, utilities are restricted from entering the module through the vertical planes bordering the module footprint (see SEMI E25).

4.3 *Restriction on Alpha* — The values of alpha (see Table 1) are restricted to $36° \leq \alpha \leq 90°$ (see Section R1-8).

4.4 *Module Connect and Disconnect* — Space for module connect to and disconnect from the transport module and for any related tools must be provided by the module manufacturer within the boundaries of the module footprint and the adjacent restricted areas. Access from any other module footprint, including that of the transport module, is not allowed (see Section R1-9).

LIST OF TABLES AND FIGURES

Table 1 Modular Footprint Variables

L	Transport module side length
α (alpha)	Angle subtended by a side of the transport module at the common point (see Section 3.1)
a_α	Half-minimum separation of adjacent module footprints
A_R	Half-width of reach area within the restricted area
A_M	Half-width of maintenance access area within the restricted area
W1	Module footprint primary width
W2	Module footprint secondary width
X1	Minimum distance to the interface plane for the module footprint primary width
X2	Maximum distance to the interface plane for the module footprint primary width
X3	Minimum distance to the interface plane for the module footprint secondary width
X4	Maximum distance to the interface plane for the module footprint secondary width

Table 2 Definition of Module Footprint Variables (Units are in mm)

$$L \geq 420.0$$

$$A_R = \frac{1}{2}\left[720.0 + (L - 420.0) \times \sin\left(90 - \frac{\alpha}{2}\right)\right] \quad \text{or} \quad 360.0 + \left(\frac{L}{2} - 210.0\right)\cos\frac{\alpha}{2}$$

$$A_M = A_R + \frac{195.0}{2} \quad \text{or} \quad 457.5 + \left(\frac{L}{2} - 210.0\right)\cos\frac{\alpha}{2}$$

$$a_\alpha = \frac{1}{2}(L - 400.0) \times \sin\left(90 - \frac{\alpha}{2}\right) \quad \text{or} \quad \left(\frac{L}{2} - 200.0\right)\cos\frac{\alpha}{2}$$

$$W1 = 2 \times 320.0 \times \cos\left(90 - \frac{\alpha}{2}\right) + 400.0 \quad \text{or} \quad 640.0\sin\frac{\alpha}{2} + 400.0$$

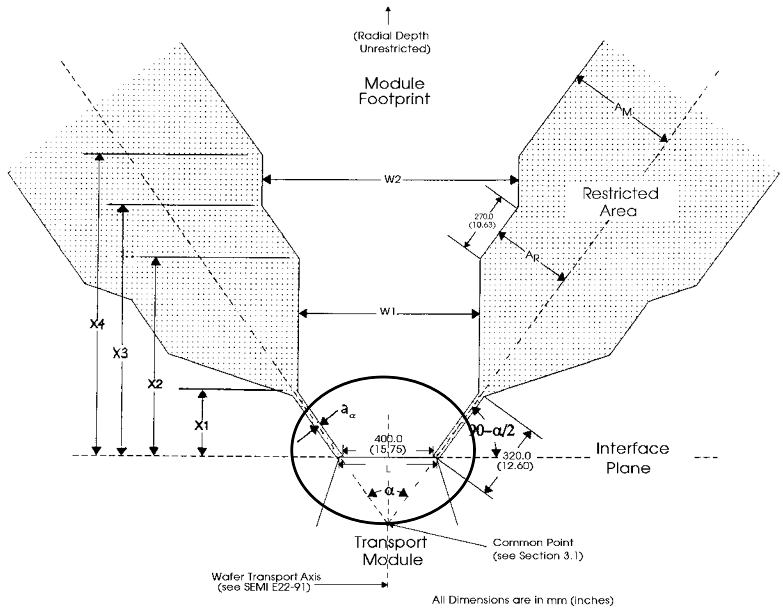
$$W2 = 2 \times 270.0 \times \cos\left(90 - \frac{\alpha}{2}\right) + W1 \quad \text{or} \quad 1180.0\sin\frac{\alpha}{2} + 400.0$$

$$X1 = 320.0 \times \sin\left(90 - \frac{\alpha}{2}\right) \quad \text{or} \quad 320.0\cos\frac{\alpha}{2}$$

$$X2 = \left(\frac{720.0}{2} - a_\alpha\right) \times \sec\left(90 - \frac{\alpha}{2}\right) + X1 \quad \text{or} \quad 360.0\,\mathrm{cosec}\frac{\alpha}{2} - \left(\frac{L}{2} - 200.0\right)\cot\frac{\alpha}{2} + 590.0\cos\frac{\alpha}{2}$$

$$X3 = \frac{1}{2}(W2 - W1) \times \tan\left(90 - \frac{\alpha}{2}\right) + X2 \quad \text{or} \quad 360.0\,\mathrm{cosec}\frac{\alpha}{2} - \left(\frac{L}{2} - 200.0\right)\cot\frac{\alpha}{2} + 590.0\cos\frac{\alpha}{2}$$

$$X4 = \frac{1}{2}(915.0 - 720.0) \times \sec\left(90 - \frac{\alpha}{2}\right) + X5 \quad \text{or} \quad 457.5\,\mathrm{cosec}\frac{\alpha}{2} - \left(\frac{L}{2} - 200.0\right)\cot\frac{\alpha}{2} + 590.0\cos\frac{\alpha}{2}$$



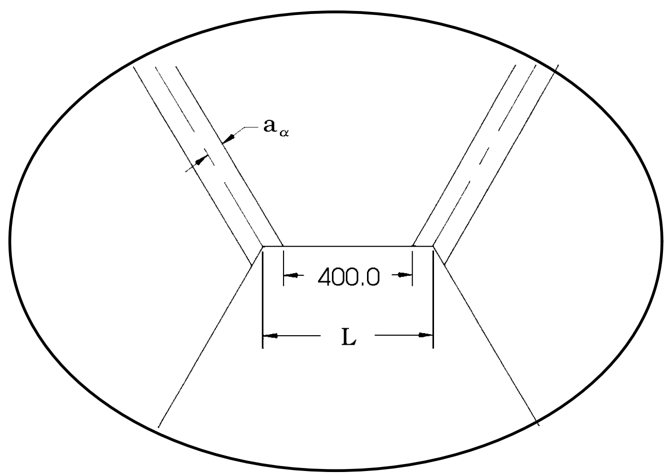


Figure 1
Radial Cluster Tool Module Footprint

RELATED INFORMATION 1

NOTE: This related information is not an official part of SEMI E26 but was reapproved for publication by full letter ballot procedures on February 28, 1999.

R1-1 Alpha Values

R1-1.1 A transport module in the shape of an N-sided regular polygon possesses an alpha value of 360/N (see Section 4.1 and Figure 1).

R1-2 Transport Module Side Length

R1-2.1 The specified transport module side length (L) of 420 mm (16.54 in.) given in Table 2 is a minimum value that will ensure clearance at the interface plane valve (see SEMI E21), assuming a 340 mm (13.39 in.) flange width at the interface plane plus additional clearance for side-mounted clamps. The side length is specified as a minimum value since a single transport module could have various side lengths and/or alpha values. Longer side lengths may ease access to the transport module, but will have the negative impact of increasing the transport module handler extension, which is the distance from the common point (in Figure 1) to the wafer transport position (defined in SEMI E22). For a radial cluster tool with the transport module handler having the "home" position at the common point, the maximum extension in millimeters is related to the side length, alpha, and the transport maximum reach, which is specified as 305 mm (12 in.) in SEMI E21 by:

$$\left(\frac{\mathrm{L}}{2}\right) \times \tan\left(90 - \frac{\alpha}{2}\right) + 305$$

R1-3 Evaluation of Footprint Shapes

R1-3.1 Access (see Section 4.1) for a variety of purposes is severely restricted in a radial cluster tool, because all modules converge toward one areR1-Achieving access to clamps at the interface plane and to the module (usually a process module) in proximity to the interface plane is especially difficult. Thus, several footprint shapes were modelled: A radial architecture comprising an N-sided regular polygon transport module with L = 420 mm (see Table 2 and Section R1-2) was used, and the dimensional effects on the module footprint were investigated for $4 \leq N \leq 10$. Anatomical data was used to evaluate access to various parts of the radial cluster tool. The configuration chosen provides a short, fat footprint. It allows maximum freedom for the module designer and accommodates modules near the interface plane without forcing the design of additional wafer transport mechanisms. Guidance in setting W1 and W2 values (see Figure 1) was provided by the need for a single wafer sputter module to be placed directly on an N = 8 regular polygon transport module and a batch processing module with an intermediate "buffer" station on the same transport module.

R1-4 Module Width at Interface Plane

R1-4.1 Although L can be longer than 420 mm (16.54 in.), the module attached to the transport module cannot possess a width greater than 400 mm (15.75 in.) at the interface plane in order to be interchangeable among all transport module interfaces (see Figure 1).

R1-5 Flexibility for Module Suppliers

R1-5.1 Module footprint dimensions (calculated from the expressions in Table 2) and transport module handler extensions (calculated from the expression in Section R1-2) for L = 420 mm and for selected values of alpha are given in Table A1 to provide guidance for weighing design targets. Alpha values corresponding to values of N for an N-sided regular polygon transport module are noted.

R1-5.2 Modules designed for an N = 8 (α = 45º) transport module will fit on any transport module with $N \leq 8$ ($\alpha \leq 45$º), providing for greater flexibility, but possessing a more restrictive footprint, than a module designed for an N = 6 (α = 60º) transport module.

R1-6 Nonradial Cluster Tool Applicability

R1-6.1 An example of a nonradial transport module is shown in Figure R1-1. Sides 1, 3, 4, and 5 of the transport module are equivalent to a radial cluster tool. The standard applies to these four sides (see Section 4.1).

R1-7 Restricted Areas

R1-7.1 Access (see Section 4.2) for maintenance activities that involve the lifting of heavy components or crouching, requires a minimum separation of 2 AM = 915 mm (36 in.) between integrated module hardware (see Table 2). When a width of 915 mm (36 in.) for the entire restricted area was used in the model (see Section R1-3), it became apparent that footprints would comprise narrow corridors. This would force the design of buffer chambers and additional wafer handling mechanisms for many applications. For practical purposes, the concept of a smaller reach area (the hatched region in Figure R1-2), where the module should be detached from the transport module for heavy lifting or crouching tasks, was considered acceptable.

R1-7.2 *Dependence on L* — A transport module side length (L) greater than the minimum value of 420.0 mm will result in a larger restricted area by increasing the half widths A_M, A_R, and a_α beyond their respective minimum values of 457.5 mm, 360.0 mm, and 10×cos[α/2] mm (see Table 2).

R1-7.3 *Restricted Area Temporary Residence* — Equipment such as roll-out drawers or swing-out equipment may temporarily reside in the restricted area (see Section 4.2).

R1-8 Restriction on Alpha

R1-8.1 The maximum value of alpha was based on an N = 4 (α = 90º) regular polygon transport module design (see Section 4.3).

R1-8.2 In order for a module manufacturer to adequately design for access, some knowledge of the adjacent modules must be available. This can be done by setting a minimum value for alpha, which then defines the adjacent footprint leading to the most stringent "half" access area. For the purposes of the standard, the minimum value of alpha was based on an N = 10 (α = 36º) regular polygon transport module (see Figure R1-2).

R1-9 Module Connect and Disconnect

R1-9.1 The number of components and the degree of complexity at the interfaces of a radial cluster tool are high. To ensure non-interference between modules, the concept of an impenetrable wall at the interface plane and adjacent module footprints should be used. Within this area, requirements for module connect and disconnect are the responsibility of the module manufacturer (see Section 4.4).

Table R1-1 Module Footprint Dimensions and Transport Module Handler Extensions*

α(degrees)	a_α*(mm)*	*W1(mm)*	*W2(mm)*	*X1(mm)*	*X2(mm)*	*X3(mm)*	*X4(mm)*	*TMHE**(mm)*
90 (N=4)	7.1	852.5	1234.4	226.3	725.4	916.3	1054.2	515.0
84	7.4	828.2	1188.6	237.8	764.7	965.4	1111.1	538.2
78	7.8	802.8	1142.6	248.7	808.4	1018.2	1173.1	564.3
72 (N=5)	8.1	776.2	1093.6	258.9	857.6	1076.0	1241.9	594.0
66	8.4	748.6	1042.7	268.4	914.0	1140.4	1319.4	628.4
60 (N=6)	8.7	720.0	990.0	277.1	979.8	1213.6	1408.6	668.7
56	8.8	700.5	954.0	282.5	1030.6	1269.0	1476.6	700.0
51.428 (N=7)	9.0	677.7	912.0	288.3	1097.3	1340.5	1585.2	741.1
48	9.1	660.3	879.8	292.3	1155.0	1401.6	1641.3	776.7
45 (N=8)	9.2	644.9	851.6	295.6	1212.2	1461.7	1716.5	812.0
42	9.3	629.4	822.9	298.7	1277.2	1529.3	1801.4	852.1
40 (N=9)	9.4	618.9	803.6	300.7	1325.8	1579.5	1864.6	882.0
38	9.5	608.4	794.2	302.6	1379.3	1634.5	1834.0	914.9
36 (N=10)	9.5	597.8	764.6	304.3	1438.5	1695.3	2010.8	951.3

* Calculated for L = 420 mm

** Transport Module Handler Extension

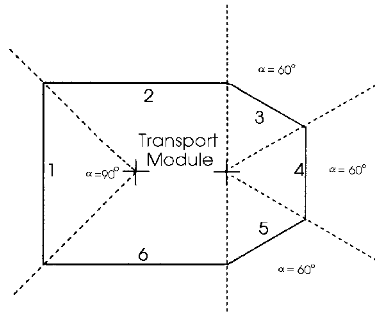


Figure R1-1

Example of Nonradial Cluster Tool Applicability

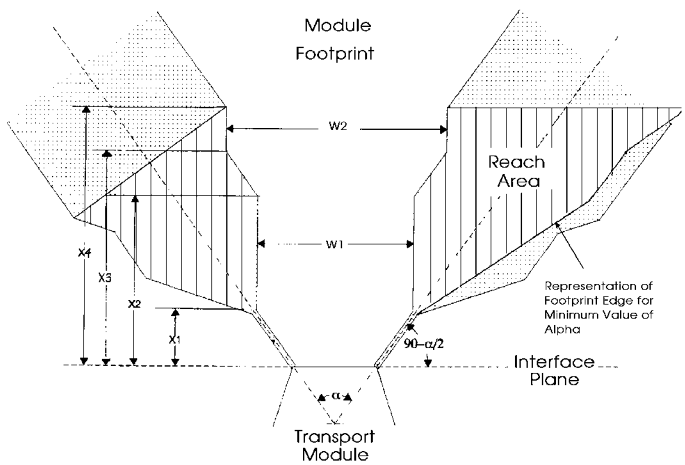


Figure R1-2

Reach Space and Footprint Restrictions

SEMI E26.1-92 (Withdrawn 1104)
RADIAL CLUSTER TOOL FOOTPRINT 300 mm STANDARD

This standard was technically approved by the Global Physical Interfaces & Carriers Committee and is the direct responsibility of the North American Physical Interfaces & Carriers 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 in 1992; last published June 1999.

Minor editorial changes were made to this document to conform to editorial guidelines.

NOTICE: This document was balloted and approved for withdrawal in 2004.

1 Introduction

1.1 The standard provides the requirements to extend the limits of applicability of SEMI E26 from 200 mm diameter wafers or smaller to 300 mm diameter wafers or smaller.

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

2 Referenced Documents

2.1 *SEMI Documents*

SEMI E26 — Radial Cluster Tool Footprint Standard

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

3 Requirements

3.1 *Fixed Dimensions* — Two of the fixed dimensions given in SEMI E26 are changed (see Section R1-1): The fixed distance along the interface plane is increased from 400.0 mm (15.75 in.) to 500.0 mm (19.69 in.) and the slant distance separating X2 and X3 (see Section R1-2) is increased from 270.0 mm (10.63 in.) to 420.0 mm (16.54 in.).

3.2 *Variables* — The variables given in SEMI E26 are restated in Table 1 to reflect the increase in fixed dimensions (see Sections 3.1 and R1-3).

3.3 *Restriction on Alpha* — The values of alpha are restricted to $45° \le \alpha \le 90°$ (see Section R1-4).

Table 1 Definitions of Module Footprint 300 mm Variable (Units are in mm)

$$L \geq 520.0$$

$$a_\alpha = \left(\frac{L}{2} - 250.0\right)\cos\frac{\alpha}{2}$$

$$A_R = 360.0 + \left(\frac{L}{2} - 260.0\right)\cos\frac{\alpha}{2}$$

$$A_M = 457.5 + \left(\frac{L}{2} - 260.0\right)\cos\frac{\alpha}{2}$$

$$W1 = 640.0\sin\frac{\alpha}{2} + 500.0$$

$$W2 = 1480.0\sin\frac{\alpha}{2} + 500.0$$

$$X1 = 320.0\cos\frac{\alpha}{2}$$

$$X2 = 360.0\operatorname{cosec}\frac{\alpha}{2} - \left(\frac{L}{2} - 250.0\right)\cot\frac{\alpha}{2} + 320.0\cos\frac{\alpha}{2}$$

$$X3 = 360.0\operatorname{cosec}\frac{\alpha}{2} - \left(\frac{L}{2} - 250.0\right)\cot\frac{\alpha}{2} + 740.0\cos\frac{\alpha}{2}$$

$$X4 = 457.5\operatorname{cosec}\frac{\alpha}{2} - \left(\frac{L}{2} - 250.0\right)\cot\frac{\alpha}{2} + 740.0\cos\frac{\alpha}{2}$$

RELATED INFORMATION 1

NOTE: This related information is not an official part of SEMI E26.1 but was reapproved for publication by full letter ballot procedures on February 28, 1999.

R1-1 Interface Plane Reach Dimension

R1-1.1 The 320.0 mm slant distance adjacent to the interface plane (see Figure 1 in SEMI E26) accommodates the reach of the human arm and therefore applies to the 200 mm standard and to the 300 mm standard (see Section 3.1).

R1-2 Large Modules

R1-2.1 Large modules such as batch process modules can be accommodated in the region of the module footprint defined by the width W2 (see Figure 1 in SEMI E26). An increase in the slant distance between X2 and X3 from 270.0 mm to 420.0 mm leads to an increase in W2 sufficient to accommodate most large modules (see Section 3.1).

R1-3 Selected Design Data

R1-3.1 The transport module handler extension is the distance from the common point (see SEMI E26) to the wafer transport position (defined in SEMI E22, "Cluster Tool Module Interface: Transport Module End Effector Exclusion Volume Standard"). The maximum extension in millimeters is related to L, alpha, and the transport maximum reach (specified as 380.0 mm in SEMI E21.1, "Cluster Tool Module Interface 300 mm: Mechanical Interface and Wafer Transport Standard") by:

$$\frac{L}{2} \times \cot\frac{\alpha}{2} + 380.0$$

R1-3.2 Transport module handler extensions and module footprint dimensions (calculated from the expressions in Table 1) for selected values of alpha are given in Table R1-1. Alpha values corresponding to values of N for an N-sided regular polygon transport module are noted (see Section 3.2).

R1-4 Restriction on Alpha

R1-4.1 If $\alpha < 45^\circ$ ($N > 8$ for an N-sided regular polygon transport module), process modules must be reduced in size or located further from the interface plane than would be the case for $45^\circ \leq \alpha \leq 90^\circ$.

Table R1-1 Module Footprint Dimensions and Transport Module Handler Extensions*

α(degrees)	a_α	*W1(mm)*	*W2(mm)*	*X1(mm)*	*X2(mm)*	*X3(mm)*	*X4(mm)*	*TMHE**(mm)*
90 (N=4)	7.1	952.5	1546.5	226.3	725.4	1022.4	1160.3	640.0
84	7.4	928.2	1490.3	237.8	764.7	1076.8	1222.5	668.8
78	7.8	902.8	1431.4	248.7	808.4	1134.8	1289.7	701.1
72 (N=5)	8.1	876.2	1369.9	258.9	857.6	1197.4	1363.3	737.9
66	8.4	848.6	1306.1	268.4	914.0	1266.2	1445.2	780.4
60 (N=6)	8.7	820.0	1240.0	277.1	979.8	1343.5	1538.5	830.3
56	8.8	800.5	1194.8	282.5	1030.6	1401.4	1609.1	869.0
51.428 (N=7)	9.0	777.7	1142.1	288.3	1097.3	1475.7	1700.4	919.9
48	9.1	760.3	1102.0	292.3	1155.0	1538.7	1778.4	964.0
45 (N=8)	9.2	744.9	1066.4	295.6	1212.2	1600.3	1855.0	1007.7

* Calculated for L = 520.0 mm

** Transport Module Handler Extension

NOTICE: SEMI makes no warranties or representations as to the suitability of the standards set forth herein for any particular application. The determination of the suitability of the standard is solely the responsibility of the user. Users are cautioned to refer to manufacturer's instructions, product labels, product data sheets, and other relevant literature, respecting any materials or equipment mentioned herein. These standards are subject to change without notice.

By publication of this standard, Semiconductor Equipment and Materials International (SEMI) takes no position respecting the validity of any patent rights or copyrights asserted in connection with any items mentioned in this standard. Users of this standard are expressly advised that determination of any such patent rights or copyrights, and the risk of infringement of such rights are entirely their own responsibility.

SEMI E27-92 (Reapproved 1104)
STANDARD FOR MASS FLOW CONTROLLER AND MASS FLOW METER LINEARITY

This standard was technically reapproved by the Facilities Committee and is the direct responsibility of the North American Facilities Committee. Current edition approved by the North American Regional Standards Committee in July 11, 2004. Initially available at www.semi.org September 2004; to be published November 2004. Originally published in 1992.

1 Purpose

1.1 The purpose of this standard is to establish a uniform, worldwide definition of linearity in order to prevent confusion and misunderstanding between manufacturers and users of mass flow devices. A linearity specification is used to allow prediction to a known level of uncertainty, the output of an MFC at points other than those at which its output is known.

2 Scope

2.1 The scope is to define the linearity of the mass flow controller (controller with integral flow transducer and control valve) and the mass flow meter (flow transducer only). Terminal-based linearity is used to describe the linearity of MFCs and MFMs.

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 Background

3.1 There are three commonly-used methods of describing linearity: independent, zero-referenced, and terminal-based linearity. Terminal-based linearity best describes the performance requirements for MFCs and MFMs because of its ease of application. In addition, it also yields the maximum expression of deviation. See reference documents regarding independent and zero-referenced linearity.

4 Referenced Standards

4.1 *IEC Standard*[1]

TC-65 — Industrial Process Measurement and Control Terms and Definitions

4.2 *ISA Standard*[2]

S51.1 — Process Instrumentation Terminology

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

5 Terminology

5.1 *Definitions* (See Figures 1 and 2)

5.1.1 *actual flow* — the gas flow as measured by an external standard, not the electrical output of a mass flow meter (see Section 4.2).

5.1.2 *linearity* — the closeness to which a curve approximates a straight line. It is measured as a non-linearity and expressed as a linearity (see Section 4.2).

5.1.3 *lower range input value* — lowest value of input at which the instrument is specified to operate. In mass flow controllers this is zero or the lowest set point at which the instrument is specified. In mass flow meters this is no flow or the lowest actual flow value at which the instrument is specified.

5.1.4 *range* — the region between the limits within which a quantity is measured, expressed by stating the lower and upper range values (see Section 4.2).

5.1.5 *span* — the algebraic difference between the upper and lower range values.

e.g.,

Range = 4% to 100%, Span = 96%

Range = 0% to 100%, Span = 100%

5.1.6 *terminal-Based linearity* — maximum deviation of the calibration curve from a straight line which intercepts the calibration curve at upper and lower input range values.

5.1.7 *upper range input value* — Highest value of input at which the instrument is specified to operate. In mass flow controllers this is full scale or the highest set point at which the instrument is specified. In mass flow

1 International Electrotechnical Commission, 3 rue de Varembe P.O. Box 131, CH-1211 Geneva 20, Switzerland Phone: 41 22 919 02 11, Fax: 41 22 919 03 00, http://www.iec.ch/index.html

2 Instruments, Systems, and Automation Society, 67 Alexander Drive, PO Box 12277, Research Triangle Park, NC 27709, Phone: 919-549-8411, Fax: 919-549-8288, http://www.isa.org

meters this is full scale or the highest actual flow value at which the instrument is specified.

6 Significance and Use

6.1 The linearity of a mass flow controller (MFC) is expressed in terms of its actual flow output as a function of the setpoint input (control voltage) (see Figure 2).

6.2 The linearity of a mass flow meter (MFM) is expressed in terms of its electrical output as a function of the actual flow (input) through the device (see Figure 1).

6.3 Terminal-based linearity shall be used to describe the linearity of MFCs and MFMs. The maximum deviation is expressed as a percentage of the algebraic difference between the output at the upper range value and the output at the lower range value.

$$\text{Linearity} = \pm\frac{d_{MAX}}{O_U - O_L} \times 100$$

where O_U = output at the upper range value

O_L = output at the lower range value

d_{MAX} = maximum deviation

6.3.1 Terminal-based linearity may be expressed as a percentage of some other value (such as a percentage of reading) if it is so identified.

6.3.2 If results are reported using range values other than zero and full scale, the actual range values used in the calculation shall be reported.

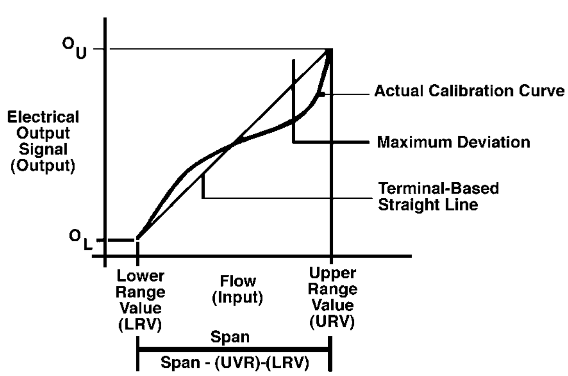


Figure 1
Terminal-Based Linearity for Mass Flow Meter

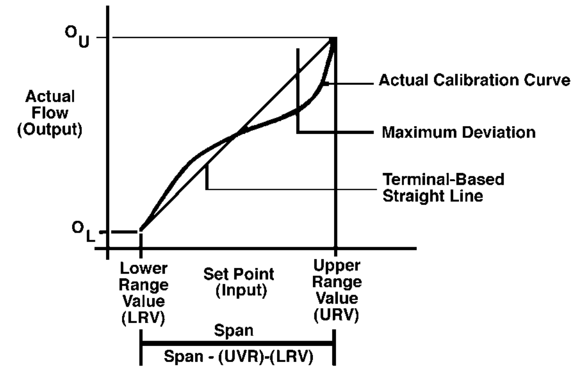


Figure 2
Terminal-Based Linearity for Mass Flow Controller

SEMI E28-92 (Reapproved 1104)
GUIDELINE FOR PRESSURE SPECIFICATIONS OF THE MASS FLOW CONTROLLER

This guideline was technically reapproved by the Global Gases Committee and is the direct responsibility of the North American Gases Committee. Current edition approved by the North American Regional Standards Committee in July 11, 2004. Initially available at www.semi.org September 2004; to be published November 2004. Originally published in 1992; last published February 1999.

1 Purpose

1.1 The purpose of this guideline is to establish a uniform, worldwide means to describe pressure parameters as they relate to mass flow controllers. It is intended to prevent confusion and misunderstanding between manufacturers and users.

2 Scope

2.1 This guideline contains definitions of terms which describe gas pressure in mass flow controllers as used in the semiconductor industry. SI units are the reference units for this document.

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 Referenced Standards

3.1 *SEMI Standard*

SEMI E12 — Standard for Standard Pressure and Standard Temperature for Flow Units Used in Mass Flow Meters and Mass Flow Controllers

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

4 Terminology

4.1 *Definitions*

4.1.1 *units of pressure* — several units of pressure are commonly used in conjunction with MFCs. The Pascal is the preferred unit of pressure for use within the semiconductor industry. Units of pressure include the following:

- Pascal (Pa)
- Pounds per square inch (psi)
- Torr (T)
- Kilograms per square centimeter (kg/cm^2)
- Bar (B)

NOTE 1: Units of pressure are sometimes expressed as an equivalent height of a column of some liquid, such as millimeters of mercury or inches of water. These units require correction to some standard for liquid density and gravity. As these corrections are neither broadly standardized nor often even addressed, their use should be avoided.

4.1.2 *absolute pressure* — the pressure measured relative to zero pressure (perfect vacuum) (see Figure 1).

NOTE 2: Absolute pressure is the pressure illustrated by the ideal gas law, PV = nRT. For example, when the number of moles, n, equals zero (no molecules), absolute pressure, P, equals zero. To indicate unambiguously that a pressure measurement is absolute, the following abbreviations should be used:

- Pa — Pascal (absolute assumed)
- psi (a) — Pounds per square inch, absolute
- Torr — Torr (absolute assumed)
- kg/cm^2(a) — Kilograms per square centimeter, absolute
- B (a) — Bar, absolute

4.1.2.1 Units such as Pascal and Torr are customarily absolute units.

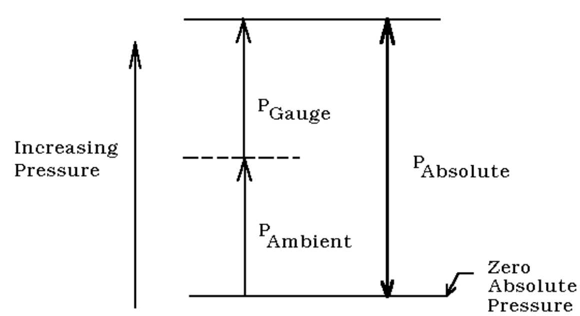


Figure 1
Relationship Between Absolute, Gauge, and Ambient Pressure

4.1.3 *ambient pressure* — the absolute pressure of the medium surrounding the MFC (see Figure 2).

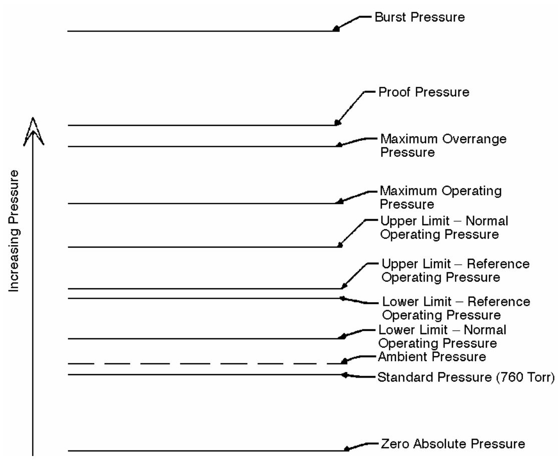


Figure 2
Pressure Definitions for MFCs

4.1.4 *burst pressure* — the gas pressure at which the MFC may rupture.

4.1.5 *differential pressure* — the difference in absolute pressure between two points of measurement in a system (see Figure 3).

NOTE 3: To indicate unambiguously that a pressure measurement is differential, the following abbreviations should be used:

- Pa (d) — Pascal, differential
- psi (d) — Pounds per square inch, differential
- Torr (d) — Torr, differential
- kg/cm^2(d) — Kilograms per square centimeter, differential
- B (d) — Bar, differential

4.1.5.1 Gauge pressures may also be used in the differential pressure calculation if consistency is maintained. A common error would be to take the difference between an inlet gauge pressure and an outlet absolute pressure without first converting to common units.

4.1.5.2 As it applies to an MFC, differential pressure is usually the measured difference in pressures between the gas inlet and outlet fittings of the MFC.

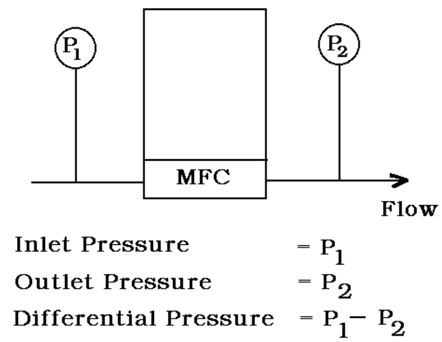


Figure 3
Definition of Differential Pressure for MFCs

4.1.6 *gauge pressure* — the differential pressure measured relative to ambient pressure. For example, when the pressure within a system equals the prevailing ambient pressure, the gauge pressure equals zero (see Figure 1).

NOTE 4: To indicate unambiguously that a pressure measurement is gauge, the following abbreviations should be used:

- Pa (g) — Pascal, gauge
- psi (g) — Pounds per square inch, gauge
- Torr (g) — Torr, gauge
- kg/cm^2 — Kilograms per square centimeter, gauge
- B (g) — Bar, gauge

NOTE 5: The performance of MFCs can vary significantly with gas density. Atmospheric pressure varies with the weather and altitude at various geographical locations. Gauge pressure units commonly reference atmospheric pressure. Therefore, the same gauge pressures measured at different geographical locations may correspond to different gas densities. For this reason, the use of gauge pressure units with MFCs can be imprecise and should be avoided.

4.1.7 *inlet pressure* — the pressure at the inlet fitting of the MFC (see Figure 3).

4.1.8 *maximum operating pressure* — operation is permitted up to this inlet pressure, but performance is not specified above normal operating pressure (see Figure 2).

4.1.9 *maximum overrange pressure* — the maximum gas pressure to which the MFC may be subjected without degrading specified performance. When returned to normal operating pressure, the MFC must require no adjustment to return to specified performance (see Figure 2).

4.1.10 *MFC calibration pressure, inlet and outlet* — the inlet and outlet pressure at which the MFC was calibrated (see Figure 2).

4.1.11 *normal operating pressure, inlet and outlet* — the pressure range within which the MFC meets its stated performance specifications (see Figure 2).

4.1.12 *normal operating differential pressure* — the range of differential pressure (see Section 4.1.5) required by the MFC to meet its stated performance specifications.

NOTE 6: The upper and lower limits are dependent upon the absolute inlet or outlet pressure. These limits are manufacturer-specific.

4.1.13 *outlet pressure* — the pressure at the outlet fitting of the MFC (see Figure 3).

NOTE 7: To completely specify the pressure operating environment for MFCs, at least two of the following three pressures must be listed: inlet, outlet, and differential.

4.1.14 *proof pressure* — the maximum gas pressure the MFC may be subjected to without permanent damage. Some adjustment may be necessary to make it meet its specified performance when returning to normal operating pressure. (see Figure 2.)

4.1.15 *reference ambient* — the composition and pressure range of the ambient medium surrounding the MFC within which performance specifications apply without requiring correction for changes in the ambient medium.

4.1.16 *reference operating pressure, inlet and outlet* — the range of gas pressures on the inlet of the MFC and across the MFC within which performance specifications apply without requiring correction for gas pressure effects (see Figure 2).

4.1.17 *standard pressure* — SEMI E12 defines standard pressure as 760 Torr (101.32 kPa) (see Figure 2).

5 Gas Pressure Effects

5.1 *Specified Gas* — Gas pressure effects may be gas species sensitive. The gas must be specified when stating gas pressure effects. Nitrogen is recommended as the standard gas.

5.2 *Pressure Measurement Point* — In this section, pressure is assumed to be measured at the fitting of the MFC, inlet or outlet, that is adjacent to the flow transducer.

5.3 *Total Calibration Effect* — The change in output, including zero and span, due to a change in gas pressure from one normal operating pressure to a second normal operating pressure. All other conditions must be held within the limits of reference operating conditions.

5.4 *Zero Calibration Effect* — the change in zero due to a change in gas pressure from one normal operating pressure to a second normal operating pressure. All other conditions must be held within the limits of reference operating conditions.

5.4.1 The effect of gas pressure change on zero may be expressed as a coefficient calculated as the ratio of full-scale percent change in output to the corresponding change in gas pressure. The change in gas pressure should be specified. This coefficient is defined as the "pressure coefficient of zero."

5.4.1.1 *Example* — Pressure coefficient of zero may be expressed as:

$$\frac{0.2\%\text{ of full scale}}{240\text{ kPa} - 220\text{ kPa}} = 0.01\%\text{ of full scale/kPa with }N_2$$

NOTE 8: If the relation between gas pressure and change in output is linear, one coefficient will suffice.

5.4.2 If the gas pressure influence is non-linear, a different method of expression may be used. Two examples:

5.4.2.1 The percent of full-scale change in output will not exceed a specified value for any value of gas pressure within a specified gas pressure range.

5.4.2.1.1 *Example* — "± 0.15% of full-scale maximum error over 200 kPa to 250 kPa with N_2"

5.4.2.2 It may be desirable to state a series of coefficients for successive increments of gas pressure within a specified gas pressure range.

5.5 *Span Calibration Effect* — The change in span due to a change in gas pressure from one normal operating pressure to a second normal operating pressure. All other conditions must be held within the limits of reference operating conditions.

5.5.1 The effect of gas pressure change on span may be expressed as a coefficient calculated as the ratio of percent of reading change in output to the corresponding change in gas pressure. The change in gas pressure should be specified. This coefficient is defined as the "pressure coefficient of span."

5.5.1.1 *Example* — Pressure coefficient of span may be expressed as:

$$\frac{0.1\% \text{ of reading}}{240 \text{ kPa} - 220 \text{ kPa}} = 0.005\% \text{ of reading/kPa with } N_2$$

NOTE 9: If the relation between gas pressure and change in output is linear, one coefficient will suffice.

5.5.2 If the gas pressure influence is non-linear, a different method of expression may be used. Two examples:

5.5.2.1 The percent of span change in output will not exceed a specified value for any value of gas pressure within a specified pressure range of a particular gas.

5.5.2.1.1 *Example* — "± 0.1% of reading maximum error over 200 kPa to 250 kPa with Nitrogen"

5.5.2.2 It may be desirable to state a series of coefficients for successive increments of gas pressure within a specified pressure range.

SEMI E29-93 (Reapproved 1104)
STANDARD TERMINOLOGY FOR THE CALIBRATION OF MASS FLOW CONTROLLERS AND MASS FLOW METERS

This standard was technically approved by the Global Gases Committee and is the direct responsibility of the North American Gases Committee. Current edition approved by the North American Regional Standards Committee on July 11, 2004. Initially available at www.semi.org September 2004; to be published November 2004. Originally published in 1993; last published February 1999.

1 Purpose

1.1 This standard defines terms commonly used in the calibration of mass flow controllers (MFC) and mass flow meters (MFM). It is intended to provide for worldwide terminology to be used by manufacturers and users.

2 Scope

2.1 This standard defines terminology related to MFC/MFM calibration. At present, there are often several words used by the semiconductor industry to describe the same concept or device. This standard is intended to eliminate confusion and provide for a common language which users and manufacturers can employ to discuss MFC/MFM calibration.

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 This standard attempts to provide basic definitions. In some instances, it may be impossible to provide definitions which thoroughly explain a concept. It is suggested, in such instances, that the user consult other sources or SEMI standards related to this topic.

4 Referenced Standards

4.1 *SEMI Standards*

SEMI E12 — Standard for Standard Pressure and Standard Temperature for Flow Units Used in Mass Flow Meters and Mass Flow Controllers

SEMI E18 — Guideline for Temperature Specifications of the Mass Flow Controller

SEMI E28 — Guideline for Pressure Specifications of the Mass Flow Controller

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

5 Terminology

5.1 *Definitions*

5.1.1 *attitude* — for mass flow controllers and mass flow meters, the relationship between the base mounting plane of the MFC, the gas flow direction and the gravity vector. It may be stated as horizontal (base down), vertical (inlet up), vertical (inlet down), horizontal (upside down), or horizontal (either side down).

5.1.2 *calibration gas* — for mass flow controllers and mass flow meters, the gas which is flowed while the device is being calibrated.

5.1.3 *calibration temperature* — for mass flow controllers and mass flow meters, the ambient temperature at which the device is calibrated. (SEMI E18)

5.1.4 *mass flow controller (MFC)* — a self-contained device, consisting of a mass flow transducer, control valve, and control and signal-processing electronics, commonly used in the semiconductor industry to measure and regulate the mass flow of gas.

5.1.5 *mass flow meter (MFM)* — a self-contained device, consisting of a mass flow transducer and signal-processing electronics, commonly used in the semiconductor industry to measure the mass flow of gas.

5.1.6 *molar flow* — the number of moles per unit of time flowing in a closed channel.

5.1.7 *nameplate gas* — for mass flow controllers and mass flow meters, the gas, as labeled on the product, intended to be controlled or measured.

5.1.8 *primary flow standard* — a device or system which measures flow using a method based on some or all of the primary measurements of length, time, temperature, volume, pressure, or mass.

5.1.9 *process gas* — for mass flow controllers and mass flow meters, the principal gas which the user requires the device to control or measure.

5.1.10 *standard pressure* — the pressure in pascals specified as a reference for measurement and comparison. It is defined for use in the semiconductor industry as 101.32 kilo pascals (760 torr).

5.1.11 *standard temperature* — the temperature, in degrees Celsius, specified as a reference for measurement and comparison. It is defined for use in semiconductor industry as 0.0°C.

5.1.12 *standard volumetric flow* — for mass flow controllers and mass flow meters, the calculated volumetric flow, at standard temperature and pressure, of gas in a closed fluid channel. Volume at standard temperature and pressure assumes the ideal gas law, PV = nRT. Units of standard volumetric flow are commonly used to express mass flow in mass flow controllers and mass flow meters.

5.1.13 *surrogate gas* — for mass flow controllers and mass flow meters, a gas intended to simulate the calibration characteristics of another gas.

5.1.14 *transfer standard* — for mass flow controllers and mass flow meters, a device typically calibrated against a primary standard which can guarantee sufficient accuracy to, in turn, calibrate another device.

5.1.15 *warm-up time* — for mass flow controllers and mass flow meters, the time required, after going from an unpowered to a powered state, for the device to achieve sufficient electrical and thermal stability such that rated performance specifications can be met.

SEMI E31-93
SPECIFICATION FOR ELECTRICAL INTERFACE, JAPAN ONLY

NOTE: For U.S. electrical interface requirements, see SEMI E7.

1 Introduction

1.1 *Purpose* — The purpose of this standard is to ensure common electrical interfaces that fulfill the requirements of equipment suppliers and users in the Japan region and to ease the design and functionality of semiconductor equipment manufacturing facilities in the future.

1.2 *Scope* — This standard recommends electrical interfaces for selected power supplies as follows:

— Facilities-Systems Motors and electrical loads having various voltages, currents, and phases

— Electrical connectors

— Cords/cables

2 Referenced Documents

2.1 *JIS-C-8303* — Japanese Industrial Standard[1]

2.2 *JCS 168C-73* — Japanese Cable Standard[2]

JEAC-78 — Japanese Electrical Association Committee[3]

3 Facilities

3.1 *Motor*

Power (W)	*Phase/Voltage*	*JEAC-78 Specified Current (A)*
35 to 400	1P 100 V 1P 200 V	2.2 to 9.5 1.1 to 4.4
200 to 3700	3P 200 V	1.8 to 17.4
200 to 7500	3P 400 V	0.9 to 17

Note: Specified currents are 0.9 times each current, respectively, in the case of 110 V/220 V/440 V. Direct current motors are excluded.

3.2 *Voltage, Current, and Phase of Electrical Loads (for calculation)*

Power (W)	*1P 100V*	*1P 200V*	*3P 200V*	*JEAC-78 3P 400V*
0 to 3000	0 to 30A	0 to 15A	0 to 8.7A	
3000 to 5000		15 to 25A	8.7 to 14.5A	
5000 to 30000			14.5 to 87A	
30000 or more			88A or more	44A or more

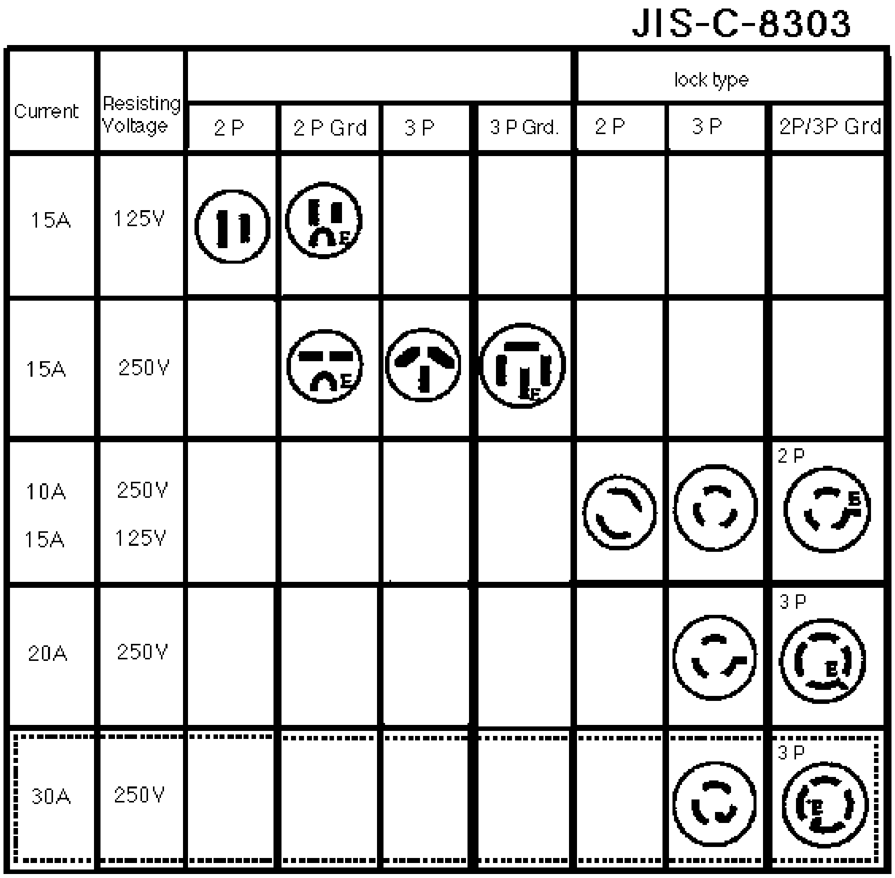
Note: Specified currents are 0.9 times each current respectively, in the case of 110V/220V/440V.

1 Japan Standard Association, 4-1-24 Akasaka, Minato-ku, Tokyo

2 Japan Cable Industry Association, 1-12-22 Tsukiji, Chuo-ku, Tokyo

3 Japan Electrical Association, 1-7-1 Yurakucho, Chiyoda-ku, Tokyo

4 Electrical Connectors (shown as receptacle)



Note: Direct terminal connections are used for most fixed facilities and loads, which require higher current than the value specified above. 30A/250V shows at reference which is specified by the NEMA standards L6-30R and L15-30R.

5 Cable Current Tolerances

Key:

VV	Vinyl insulation, vinyl sheathed cable
CV	Construction polyethylene insulation, vinyl sheathed cable

JCS 168C-73 Unit (A)

		1.0Ø	2.0Ø	2sq	3.5sq	5.5sq	8sq	14sq	22sq
VV	*	11	14	19	28	38	47	67	91
	**	10	12	18	25	33	42	60	79
	***	9	10	15	22	29	37	53	70
CV	*	16	23	33	46	59	74	105	135
	**	17	20	28	40	52	66	94	125
	***	14	17	24	34	45	56	79	105

* Single Conductor Three Cables
** Twin Conductors One Cable
*** Three Conductors One Cable

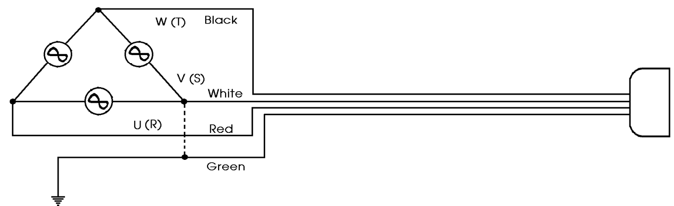
Note: The above specification is for cable in conduit in air. Current tolerance of CV is different than that of VV due to the difference in temperature tolerances (VV/60°C and CV/90°C).

Ø: Diameter of Conductor (mm)

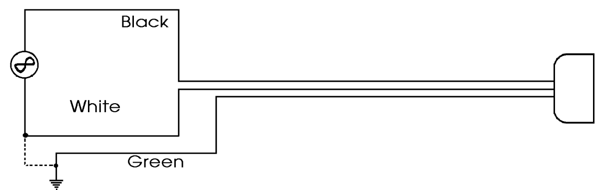
Sq: Cross-Sectional Area of Conductor (mm2)

APPENDIX

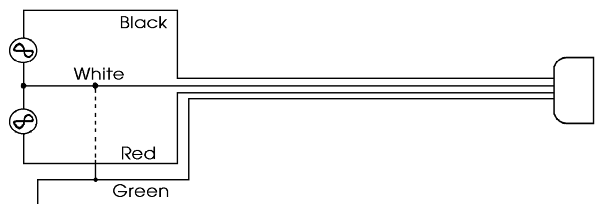
Examples of Wire Connection of Power Supply in Japan



2) 1 P 2w 2w (AC100)

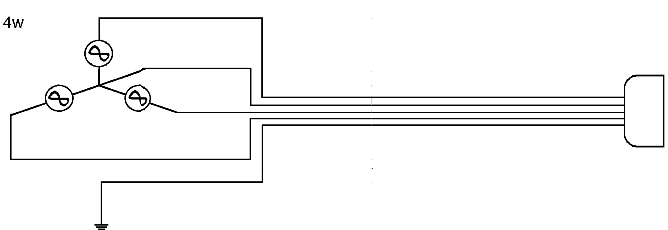


3) 1 P 3w (AC100, 200V)

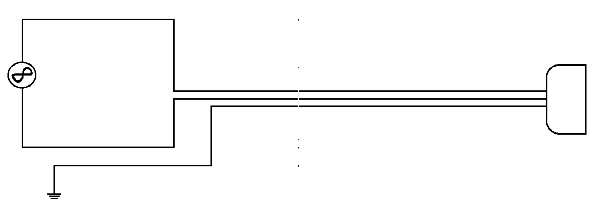


Examples of Wire Connection of Power Supply in United States (Reference)

1) 3 P 4w



2) 1 P 2w



Notes: White wire connected at the grounded side. [White is also used for a neutral line (grounded side) in the U.S.] A single green wire other than a cable is typically used for ground. In the case of a single wire, sometimes a black wire is substituted for blue. - - - - indicates that the wires are normally grounded, with some exceptions. There are no special rules regarding colors of wires except a wire used for ground (green). However, the figure shows common examples in Japan.

NOTICE: These standards do not purport to address safety issues, if any, associated with their use. It is the responsibility of the user of these standards to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. SEMI makes no warranties or representations as to the suitability of the standards set forth herein for any particular application. The determination of the suitability of the standard is solely the responsibility of the user. Users are cautioned to refer to manufacturer's instructions, product labels, product data sheets, and other relevant literature respecting any materials mentioned herein. These standards are subject to change without notice.

The user's attention is called to the possibility that compliance with this standard may require use of copyrighted material or of an invention covered by patent rights. By publication of this standard, SEMI takes no position respecting the validity of any patent rights or copyrights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of any such patent rights or copyrights, and the risk of infringement of such rights, are entirely their own responsibility.

SEMI E33-94
SPECIFICATION FOR SEMICONDUCTOR MANUFACTURING FACILITY ELECTROMAGNETIC COMPATIBILITY

NOTICE: This standard does not purport to address safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to the use.

1 Introduction

1.1 *Purpose* — The purpose of this specification is to assure that semiconductor manufacturing facilities and the equipment used for manufacturing semiconductor devices will operate together reliably without failures caused by electromagnetic interference or electrostatic discharge. This goal is generally known as “electromagnetic compatibility” or EMC.

1.2 *Scope* — This specification applies to facilities and equipment constructed for the purpose of manufacturing semiconductor devices including all facilities alarm, safety, communications and control systems, processing equipment, metrology equipment, automation equipment, and information technology equipment.

1.3 *Limitations* — This specification does not apply to the equipment and facilities used for the assembly and functional testing of integrated circuits. This specification does not apply to process-specific charging that may occur to semiconductors under manufacture.

2 Referenced Documents

2.1 *ANSI, C63.4-1991*[1] — American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz

2.2 *CISPR, Publication 22, 19852*[2] — Limits and Methods of Measurement of Radio Interference Characteristics of Information Technology Equipment

2.3 *CENELEC, EN 55 022, 1987*[2] — Modifications to CISPR 22

Draft British Standard EN 50 082-2[3] — Electromagnetic Compatibility — Generic Immunity Standard: Industrial (CLC/TC 110 (Sec) 44)

2.4 *Emerald Book*[1] — IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment, IEEE, 1992

2.5 *EOS/ESD Association Advisory for Electrostatic Discharge Terminology*[4] — Glossary, 1992

2.6 *FIPS (Federal Information Processing Standards) Publication 94, 21 September 1983*[5] — Guideline on Electrical Power for ADP Installations

2.7 *IEC 801-2, Second Edition, 1991-04*[2] — Electrostatic Discharge Requirements

2.8 *IEC 801-3, First Edition, 1984*[2] — Radiated Electromagnetic Field Requirements

2.9 *IEC 801-4, First Edition, 1988*[2] — Electrical Fast Transient/Burst Requirements

2.10 *IEC TC 65 (Sec.) 137 (801-5) Committee Draft, July 1992*[2] — Surge Immunity Requirements

2.11 *IEC TC 65 (Sec.) 144 (801-6) Committee Draft, February 1992*[2] — Immunity to Conducted Disturbances Induced by Radio Frequency Fields above 9 kHz.

3 Terminology

3.1 *earth port* — European term for an equipment ground. This term is used extensively in the basic standards.

3.2 *electromagnetic compatibility (EMC)* — The ability of electronic equipment to function properly with respect to environmental EMI and ESD.

3.3 *electromagnetic interference (EMI)* — Any electrical signal in the non-ionizing (sub-optical) portion of the electromagnetic spectrum with the potential to cause an undesired response in electronic equipment.

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1 *IEEE Service Center, 445 Hoes* Lane, P.O. Box 1331, Piscataway, NJ 08855.

2 Sales Department of the Central Office of the IEC, P.O. Box 131, 3, Rue de Varembe, 1121 Geneva 20, Switzerland. Some of the IEC publications are available from the Sales Department, American National Standards Institute, 11 W. 42nd Street, New York, NY 10036.

3 Sales Administration (Drafts), BSI, Linford Wood, Milton Keynes MK 14 6LE, United Kingdom.

4 EOS/ESD Association, Inc., 200 Liberty Plaza, Rome, NY 13440.

5 National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161.

3.4 *electrostatic discharge (ESD)* — The transfer of electrostatic charge between bodies at different electrostatic potentials.

3.5 *ELF* — Extremely low frequency (about 1 Hz to 1 kHz) magnetic fields generated by current flow (most commonly 60 Hz in the U.S. and 50 Hz in Europe) within equipment and facilities.

3.6 *ELF sensitive equipment* — Any equipment whose performance is adversely affected by ELF, such as a scanning electron microscope (SEM).

3.7 *EUT* — Equipment under test.

3.8 *port* — (For purposes of this specification), a particular interface of the specified equipment with the external electromagnetic environment, (see Figure 1).

3.9 *enclosure port* — (For purposes of this specification), the physical boundary of the apparatus through which electromagnetic fields may radiate or impinge.

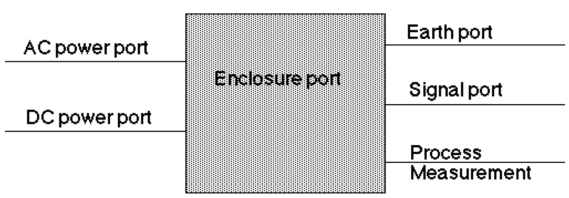

Figure 1

4 Requirements

4.1 *Performance Criteria* — The following are generic failure criteria for the various classes of equipment and electronic systems used in semiconductor manufacturing. However, any kind of failure or aberration during EMC testing shall be noted in the test report.

4.1.1 *Performance Criteria A* — The equipment operates as intended during and after the test. In the case of process equipment, all process results are within specifications. No safety hazards nor false alarms are present. In some cases, the performance level may be replaced by a documented permissible loss of performance if such loss is minor and agreeable to the concerned parties.

4.1.2 *Performance Criteria B* — The equipment operates as intended after the test, but experiences a loss of function or degradation of performance during the test to a level specified by the manufacturer. No change of operating state or loss of stored data is allowed. Restoration of performance or function does not require human intervention.

4.1.3 *Performance Criteria C* — Temporary loss of function is allowed, provided the loss of function is recoverable, either automatically or through operation of the controls. Any failure of control or alarm systems is in a fail-safe mode, such as a false alarm or equipment shutdown.

4.1.4 *Safety Criteria* — Equipment will automatically fail if testing results in an unsafe or potentially unsafe condition, such as threat to life or property. Examples would be failure of an emergency machine off (EMO) button to operate or faulty opening of a toxic gas valve.

4.1.5 *Conditions during Testing* — All EMC testing is to be done with the equipment installed and operational. As much as possible, the test installation should be identical to the final production installation. Substitutes may be used for hazardous gases and chemicals, and other modifications may be made as deemed reasonable to ensure testing can be performed in a completely safe and environmentally acceptable manner. Special EMC facilities are not required by this standard.

5 Test Methods

The tables below are organized by ports to which the tests apply, as defined above. The basic standards provide the test setup and procedures to be followed, except as noted. In all events, EMC testing is intended to prevent EMC problems when the equipment is installed and operating in a semiconductor manufacturing facility. Any modification or interpretation of the test setup and procedure should be judged by this overriding goal.

5.1 *Immunity Tests*

Table 1 Enclosure Ports

	Test Type	*Specification*	*Basic Standard*	*Remarks*	*Performance Criteria*
1.1	ESD immunity	4 kV Contact 8 kV Air discharge	IEC 801-2 (1991)	See Appendices A and B	A
1.2	Radiated immunity Amplitude modulated	10 V/m 450-520 MHz 800-950 mHz 80% AM (1 kHz)	IEC 801-3	See facilities requirements (See Section 5.1.1)	A
1.3	ELF immunity	Level A - E as required	ELF testing (See Section 5.1.2)	Required only of ELF-sensitive equipment	A
1.4	Radiated immunity Pulse modulated	3 V/m 1.89 GHz 50% Duty cycle 100 Hz rep freq.	TC 65 (Sec.) 136 Draft	Europe only Cellular phone band	A

5.1.1 *Facilities Requirements* — Due to the size and complexity of much semiconductor factory equipment, testing in a shielded enclosure, anechoic chamber, or other special facility is not required. If such facilities can be used, the results will be more reproducible and accurate.

Note that radiated immunity testing is required only at frequencies used for mobile communications. As shown in Table 1, Row 1.2. Testing should be conducted in conformance with national and local emission requirements at the frequencies specified (see Appendix D).

5.1.2 *ELF Testing* — The following sensitivity levels are defined:

Level A — ELF of less than 0.25 milliGauss rms
Level B — ELF of less than 0.50 milliGauss rms
Level C — ELF of less than 1.00 milliGauss rms
Level D — ELF of less than 2.00 milliGauss rms
Level E — ELF of 2.00 milliGauss rms and greater

ELF sensitivity is to be determined by applying ELF through a coil or set of coils designed to produce a uniform magnetic field at or near the power-line frequency at the position of maximum ELF sensitivity of the EUT. The direction of the applied field shall be set to produce the maximum disturbance to the EUT. The field level shall be determined using a calibrated ELF meter.

If allowable performance degradation is permitted at the higher ELF levels, the performance shall be specified at each level.

Table 2 Ports for Signal Lines and Short Distance (< 30 m) Data Buses Not Involved in Process Control

	Test Type	*Specification*	*Basic Standard*	*Remarks*	*Performance Criteria*
2.1	Fast transients common mode	1 kV (peak) 5/50 Tr/Th ns 5 kHz rep. frequency	IEC 801-4 Capacitive clamp	Applicable to cables whose length can exceed 3 m	B
2.2	Radio Frequency common mode 1 kHz 80% AM	0.15-100 MHz 3 V (rms) (unmod) 150 Ω source impedance	IEC TC 65 (Sec.) 144	Applicable to cables whose length can exceed 1 m	A

Table 3 Ports for Process, Measurement and Control Lines, and Long Bus and Control Lines

	Test Type	*Specification*	*Basic Standard*	*Remarks*	*Performance Criteria*
3.1	Fast transients common mode	2 kV (peak) 5/50 Tr/Th ns 5 kHz rep. frequency	IEC 801-4 Capacitive clamp		B
3.2	Radio Frequency common mode 1 kHz 80% AM	0.15-100 MHz 3 V (rms) (unmod) 150 Ω source impedance	IEC TC 65 (Sec.) 144	Applicable to cables whose length can exceed 1m	A

Table 4 Input and Output DC Power Ports

	Test Type	*Specification*	*Basic Standard*	*Remarks*	*Performance Criteria*
4.1	Fast transients common mode	2 KV (peak) 5/50 Tr/Th ns 2.5 kHz rep. frequency	IEC 801-4	4 kV (peak) when coupling with capacitive clamp	B
4.2	Radio Frequency common mode 1 kHz 80% AM	0.15-100 MHz 3 V (rms) (unmod) 150 Ω source impedance	IEC TC 65 (Sec.) 144	Applicable to cables whose length can exceed 1 m	A

Note: Direct injection method shall be used if current consumption is less than 100 A. This test is not applicable to input ports intended for connection to dedicated non-rechargeable power supplies.

Table 5 Input and Output AC Power Ports

	Test Type	*Specification*	*Basic Standard*	*Remarks*	*Performance Criteria*
5.1	Fast transients common mode	4 kV (Peak) 5/50 Tr/Th ns 5 kHz rep. frequency	IEC 801-4	4 kV (peak) when coupling with capacitive clamp	B
5.2	Radio Frequency common mode 1 kHz 80% AM	0.15-100 MHz 150 Ω source impedance	IEC TC 65 (Sec.) 144	Applicable to cables whose length can exceed1 m	A
5.3	Surge	4.0 kV	IEC TC 65 (Sec.) 137	Use combination wave test generator:1.2/50 µs open circuit, 8/20 µs short circuit wave form	C

5.2 *Emissions Test*

5.2.1 *EMI Testing Required* — Equipment shall be tested in accordance with CISPR 22 and EN 55 022. Test limits are Class A, which is generally limited to non-residential use.

As noted above for radiated immunity testing, the size and complexity of semiconductor factory equipment may rule out the use of special facilities. Thus, the tests in CISPR 22 may be adapted as required due to test site limitations. Again, use of such facilities will yield more reproducible and accurate data, and is recommended whenever possible.

In any event, emissions greater than 6 dB above the Class A limits are not allowed.

5.2.2 ELF Testing Required — ELF emission testing is required for all ELF-sensitive equipment, since such equipment is commonly grouped together. ELF emission testing for other types of equipment is required on request of a purchaser intending installation of ELF-sensitive equipment in the immediate vicinity.

ELF emissions shall be measured using a calibrated ELF meter. Equipment emissions shall be measured at a distance of 1.5 meters from the entire perimeter of the EUT at a height of 1 meter. Facility ELF shall be measured at a height of 1 meter in the region where ELF-sensitive equipment installation is intended. Measurement points shall be no greater than 0.5 meter apart in the regions specified above. Facilities electrical systems and adjacent equipment should be in normal operation to assure accurate measurement of the actual operating environment.

At each measurement point, the ELF sensor should be oriented to produce the maximum reading. The maximum from all the measurement points is then used to determine the level from the table below:

Level A — ELF of less than 0.25 milliGauss rms

Level B — ELF of less than 0.50 milliGauss rms

Level C — ELF of less than 1.00 milliGauss rms

Level D — ELF of less than 2.00 milliGauss rms

Level E — ELF of 2.00 milliGauss rms and greater

6 Equipment Installation and Grounding

Special installation, power, and grounding requirements necessary to meet this standard shall be thoroughly documented by the equipment supplier. FIPS Publication 94 and the IEEE Emerald Book are suggested sources of information for recommended practices in this area.

Removable shielded panels or doors that must be properly secured to meet this standard should be labeled “SECURE THIS PANEL TO REDUCE ELECTROMAGNETIC EMISSIONS.” This labeling requirement is not applicable to interlocked panels that must be in place for the equipment to operate.

7 Documentation

Upon request of the purchaser a report of the test results against this standard shall be furnished. Similarly, the supplier may use this standard as a reference in specifying the environmental requirements of equipment.

8 Alternate Testing

Testing completed under a different, but substantially similar standard may be substituted for the basic standards specified herein if the performance criteria and test levels are similar to those above. Such substitution shall be noted in the test report, and must be agreed to by the concerned parties. Examples include substitution of ANSI C63.4-1991 testing for CISPR 22.

Similarly, equipment which satisfies the European EMC Directive and bears the CE mark meets this specification.

NOTICE: These standards do not purport to address safety issues, if any, associated with their use. It is the responsibility of the user of these standards to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. SEMI makes no warranties or representations as to the suitability of the standards set forth herein for any particular application. The determination of the suitability of the standard is solely the responsibility of the user. Users are cautioned to refer to manufacturer’s instructions, product labels, product data sheets, and other relevant literature respecting any materials mentioned herein. These standards are subject to change without notice.

The user’s attention is called to the possibility that compliance with this standard may require use of copyrighted material or of an invention covered by patent rights. By publication of this standard, SEMI takes no position respecting the validity of any patent rights or copyrights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of any such patent rights or copyrights, and the risk of infringement of such rights, are entirely their own responsibility.

APPENDICES

The appendices are not an official part of this standard. However, they contain relevant information for customizing the basic standards for testing of semiconductor equipment and facilities, and point out areas of concern for which no standard currently exists.

A.1 Appendix A: Charged Wafer Testing

Due to overriding microcontamination concerns, non-static-dissipative wafer carriers must be used during semiconductor fabrication. It is suggested that any equipment which handles wafers be tested with wafers charged to 18 kV/in. The charge generator used for 801-2 testing can be used to charge the wafer. Some experimentation will be required to determine the best means to carry out this test. Alternately, the handling mechanism may be challenged by air or contact discharge directed to the mechanism.

It is suggested that wafer handlers be designed to dissipate charge on incoming wafers in a controlled, non-sparking manner. A simple AM radio tuned between stations and placed near the handler has been found to be a good qualitative means to detect sparking. Sparking will result in pops and static being heard on the radio.

A.2 Appendix B: ESD Test Methods

Although the contact method of ESD testing has been found to be much more reproducible than the air discharge, the air discharge is a more realistic simulation of possible events that can occur in the semiconductor factory. Also, the air discharge method is the only realistic way to test objects that are primarily fabricated from insulators, such as wet stations and keyboards.

In addition to testing surfaces that come in contact with humans and wafers, it is important to test any area of the equipment that can be exposed to ESD. For instance, wet stations are composed of assemblies involving large masses of insulators in proximity to metallic sensors and controllers. It is possible for the insulating surfaces to build up charge, which then sparks to a sensor or controller — all internal to the equipment itself.

A.3 Appendix C: Future Directions

Items in this section are not requirements of this standard, but are included to indicate currently ill-defined goals for further improvements to semiconductor factory EMC.

A.3.1 *Static Charge* — Minimization of static charge promotes cleanliness, and avoids damage to material in process and reticles.

It is suggested that electrostatic fields be held to under 200 V/cm (500 V/in). This would be applicable to personnel, wafers, cassettes, cassette boxes, reticles, reticle boxes, and all equipment and facility surfaces in proximity to these items as well as all surfaces exposed to filtered airflow. Measurements shall be made using a properly-grounded electrostatic field meter in accordance with its manufacturer's instructions.

A.4 Appendix D: National Requirements

A.4.1 *U.S.* — Section 5.1.1 Table 1, row 1.2: Radiated immunity testing outside a shielded enclosure is legally accomplished by obtaining an experimental license from the FCC using FCC form 442. The FCC recommends using techniques such as scanning or hopping to avoid interference.

A.4.2 *Europe* — The earth port: Refer to Table 1.6 of the informative annex to EN 50 082-2 for test requirements applicable to the earth.

SEMI E34-95
GUIDELINE FOR MASS FLOW DEVICE RETURN

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

1 Purpose

Mass flow devices (mass flow controllers, mass flow meters and flow control valves) are used as an integral part of the chemical delivery system in semiconductor processing equipment. Many of the chemicals used in semiconductor processes can be hazardous to equipment and personnel. Once exposed to these chemicals, the contaminated mass flow devices can present a hazard to repair personnel and equipment if not handled properly.

Implementing the procedures outlined in this guideline provide a mechanism to reduce the risk associated with shipping and/or receiving any potentially hazardous mass flow device used to monitor or control gases or liquids.

2 Scope

This guideline is intended to:

Recommend and encourage the purging of devices used with hazardous materials prior to removal to reduce the risk of handling them.

Alert the recipient of possibly hazardous mass flow devices to the nature of the hazard.

Establish mechanism for properly identifying and documenting possibly hazardous mass flow devices by using an orange tag and a health and safety disclosure form.

3 Referenced Documents

49 CFR[1] — Title 49 of the Code of Federal Regulations (CFR)

NFPA 704[2] — Standard System for the Identification of Fire Hazards of Materials

1 United States Government Printing Office, Washington, D.C. 20402

2 National Fire Protection Association, Batterymarch Park, Quincy, MA 02269

4 Terminology

4.1 *hazardous materials* — Those chemicals or substances that are physical hazards or health hazards as defined and classified in NFPA 704 whether the materials are in use or in waste conditions.

4.2 *mass flow controller (mfc)* — A self-contained device, consisting of a mass flow transducer, control valve, and control- and signal-processing electronics, commonly used in the semiconductor industry to measure and regulate the mass flow of gas.

4.3 *mass flow meter (mfm)* — A self-contained device, consisting of a mass flow transducer and signal-processing electronics, commonly used in the semiconductor industry to measure the mass flow of gas.

4.4 *material safety data sheet (msds)* — Written or printed material concerning a hazardous material which is prepared in accordance with the provisions of 29 CFR 1910.1200.

4.5 *protective container* — A sealable plastic bag or other container which will keep hazardous material from the mass flow device from contaminating the outer package. The container should be transparent, if possible.

4.6 *purge* — To dilute potentially harmful material in the mass flow device by flowing an inert gas through the device. Purging a chemical delivery line containing a mass flow device with an inert substance is intended to dilute hazardous materials and reduce the level of the hazard. To be effective, the inert substance must be able to reach all points within the chemical delivery system in sufficient quantity to dilute the hazardous material to safe levels. The nature of the hazard and the physical configuration of the chemical delivery system must be considered when developing a purge procedure.

4.7 *safe* — Free of conditions that can cause occupational illness, injury, or death to personnel or damage to or loss of equipment or property or the environment.

5 Procedure

5.1 *Disclosure Form*

- Complete the disclosure form for mass flow device return.
- Send the completed form via Fax or other suitable method to the recipient of the mass flow device.

- Attach a copy of the form to the exterior of the shipping container.
- Enclose another copy inside the package attached to the protective plastic bag containing the mass flow device during shipment.
- Retain the original form for your records.

5.2 *Purging Prior to Removal* — Thoroughly purge the mass flow device following the applicable purge procedure. Purge procedures are usually unique to the equipment and installation. Obtain purging procedures from your facilities manager, corporate safety department, and/or the equipment manufacturer. If a formal purge procedure is available, note on the disclosure form the purge procedure document number and source.

5.3 *Equipment Removal* — WARNING: Do not remove the mass flow device until it has been properly purged.

5.3.1 The person removing the mass flow device should fill out an orange-colored device tag indicating the process gas(es) or chemicals used, possible exterior contamination and the purge procedure document number prior to removal of the device. A sample orange device tag is shown in Figure 1.

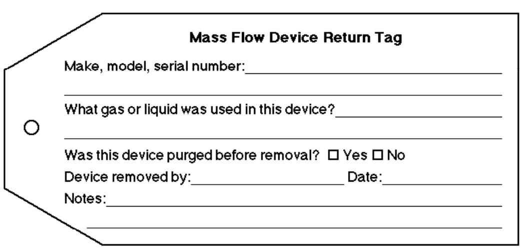

Figure 1

Sample Orange Device Tag

5.3.2 Carefully remove the mass flow device from the installation or system.

5.3.3 The inlet and outlet ports should be sealed to prevent any leakage into or out of the mass flow device.

5.3.4 The person removing the mass flow device should attach the orange tag to the device.

5.4 *Equipment Packaging* — Package all mass flow devices for shipment per government regulations including the following:

5.4.1 Seal the device in a protective container to prevent the contamination of the shipping package. If the orange tag is not visible through the container, an additional tag should be attached to the outside of the container.

5.4.2 Place the device in a shipping container with adequate packing to avoid damage to the device and the protective container during shipment.

5.5 *Shipping* — Ship the device so that it conforms to all applicable regulations of the countries of origin, trans-shipment, and destination governing the shipment of materials.

HEALTH AND SAFETY DISCLOSURE FORM FOR MASS FLOW DEVICE RETURN

1. Mass Flow Device Information

1.1 Manufacturer ____________________________________

1.2 Model Number ____________________________________

1.3 Serial Number ____________________________________

1.4 Nameplate Gas __________ Nameplate Range ___________

1.5 Details of all substances to which the equipment has been exposed, Interior and Exterior:

Chemical name(s) and attach applicable MSDS(s)

	Interior	Exterior
a) ____	o	o
b) ____	o	o
c) ____	o	o
d) ____	o	o
1.6 Was this device purged with an inert gas?	o Yes	o No

1.7 Any further safety information that you consider to be relevant:

____

____

____

1.8 Document number and source of purge procedure used.

____

____

____

1.9 Person to contact regarding the above information:

Name:____

Company:____

Title:____

Phone Number: (_______)__(______)__(__________)_(_____)

Country Code Area Code Number Extension

Address:____

____

____

Signature of Sender:___________________________________

1.10 Carrier to be used

____

Expected Delivery date

____

NOTICE: These standards do not purport to address safety issues, if any, associated with their use. It is the responsibility of the user of these standards to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. SEMI makes no warranties or representations as to the suitability of the standards set forth herein for any particular application. The determination of the suitability of the standard is solely the responsibility of the user. Users are cautioned to refer to manufacturer's instructions, product labels, product data sheets, and other relevant literature respecting any materials mentioned herein. These standards are subject to change without notice.

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SEMI E35-0305
GUIDE TO CALCULATE COST OF OWNERSHIP (COO) METRICS FOR SEMICONDUCTOR MANUFACTURING EQUIPMENT

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 December 10, 2004. Initially available at www.semi.org February 2005; to be published March 2005. Originally published in 1995; previously published March 2004.

NOTICE: This document was completely rewritten in 2005.

1 Purpose

1.1 The purpose of this guide is to provide standard metrics for evaluating unit production cost effectiveness of manufacturing equipment in the semiconductor industry.

1.2 This guide establishes a well-defined procedure to facilitate an understanding of equipment-related costs by providing definitions, classifications, algorithms, methods, and default values necessary to build a full or constrained cost of ownership (COO) calculator.

NOTE 1: Related Information 1 provides a graphical representation of calculating COO to expand upon the guide text.

2 Scope

2.1 This guide is applicable to any type of equipment for processing semiconductor units, which may be wafers, devices, flat panels or other material. Some terms are specialized to integrated circuit wafer and device production.

2.2 Effective use of the metric to build a COO model requires identification of constraints and data values. Where possible, use direct values for inputs rather than deriving them from secondary models or using example values.

NOTE 2: Related Information 2 provides some example data.

2.3 Full calculation of COO often requires data held proprietary and is coupled to the overall factory yield and the related cost of yield loss. It is envisioned that this guide will be used for internal factory and equipment optimization, investment evaluation, and equipment design improvements.

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 Certain cost factors are more difficult than others to accurately determine. Figure 1 depicts the relationship of some of the COO model input factors to ability to collect and validate them. The accuracy of a COO calculation may be prone to a variety of errors or omissions.

3.2 Line balance considerations are not included in the COO calculation. Line balance considerations are not included because it is difficult, in an individual COO model, to show the impact of equipment being modeled on the complete manufacturing facility. A factory-level cost model should be used for this purpose.

3.3 A COO calculation may have more detail than presented explicitly in this guide. The structure of the guide, however, allows for these situations.

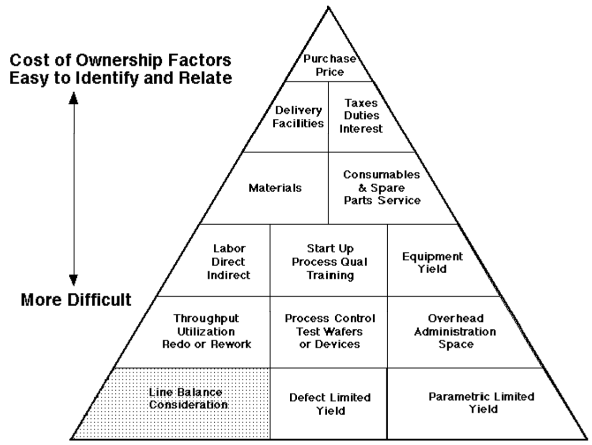

Figure 1
Relationship of Factors to Difficulty of Collection and Validation

4 Referenced Standards

4.1 *SEMI Standards*

SEMI E10 — Specification for Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM)

SEMI E81 — Provisional Specification for CIM Framework Domain Architecture

SEMI E89 — Guide for Measurement System Capability Analysis

4.2 *ISO Document*[1]

International Vocabulary of Basic and General Terms in Metrology, Second Edition [VIM]

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

5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 *CEO* — Cost of equipment ownership

5.1.2 *COO* — Cost of ownership

5.1.3 *CYL* — Cost of yield loss

5.1.4 *DLY* — Defect limited yield

5.1.5 *ER* — Equipment required (integer number)

5.1.6 *EY* — Equipment yield

5.1.7 *GUE* — Good unit equivalents

5.1.8 *P/T* — Precision-to-tolerance (ratio)

5.1.9 *PLY* — Parametric limited yield

5.1.10 *PRY* — Product yield

5.1.11 *PU* — Production utilization (total)

1 International Organization for Standardization, ISO Central Secretariat, 1, rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland. Telephone: 41.22.749.01.11; Fax: 41.22.733.34.30, Website: /www.iso.ch

5.1.12 *TP* — Throughput

5.2 *Definitions*

5.2.1 *alpha error* — the error that occurs when a conforming item is incorrectly reported as nonconforming. This is also called Type I error.

5.2.2 *alpha probability,* α — the probability of an alpha error, also called the alpha error rate.

5.2.3 *baseline cost of ownership* — a constrained version of cost of ownership (COO) that only includes equipment yield [i.e., defect limited yield and parametric limited yield are not included].

5.2.4 *beta error* — the error that occurs when a nonconforming item is incorrectly reported as conforming. This is also called Type II error.

5.2.5 *beta probability,* β — the probability of a beta error, also called the beta error rate.

5.2.6 *bias,* δ — the difference between the mean value of measurements made on the same object and a true value.

NOTE 3: In many cases the true value of bias is unknown. A value established by reference gauges or a consensus value may be used as a substitute.

5.2.7 *comprehensive cost of ownership* — cost of ownership (COO) calculated with no constraints.

5.2.8 *constrained cost of ownership* — cost of ownership (COO) version with a set of defined restrictions to facilitate comparisons or to remove ambiguity.

5.2.9 *consumable* — part of the piece of equipment that is worn out by the process operation of the piece of equipment and requires replacement after less than one year of operation.

5.2.10 *cost footprint* — the area (A) of the smallest horizontal rectangle that contains all of the shadow footprint and half of the easement space around the piece of equipment. This is calculated as:

$$\begin{aligned} A &= \left[Wt + 1/2\left(Ws - We\right)\right] \times \left[De + 1/2\left(Ds - De\right)\right] \\ &= 1/4\left(We + Ws\right) \times \left(De + Ds\right) \end{aligned} \qquad (1)$$

where:

De = Depth of the piece of equipment

Ds = Combined depth of the piece of equipment and easement space

We = Width of the piece of equipment

Ws = Combined width of the piece of equipment and easement space

5.2.11 *cost of equipment ownership (CEO)* — a factor in cost of ownership that includes all costs not associated with yield loss.

5.2.11.1 Discussion — See ¶ 6.4 and ¶8.3 for more details.

5.2.12 *cost of ownership (COO)* — full cost of embedding, operating, and decommissioning in a factory environment equipment needed to accommodate the required volume of production units.

5.2.13 *cost of yield loss (CYL)* — a unit lost at the end of a given step represents the loss of the cost of the starting unit and the manufacturing to that point. In addition, units leaving a step may be lost at some later step. Calculating CYL therefore requires knowing the starting unit cost and the accumulated cost of manufacturing before the unit is lost. Therefore, CYL should be tracked as a separate cost for factory optimization.

5.2.14 *cumulative distribution function (CDF)* — a mathematical formula that describes the probability a measurable event occurs at or below a specific value.

5.2.15 *default* or *default value* — a value to be used if actual data are not available. Also called example value. Where possible, actual data should be used in COO calculations.

5.2.16 *defect limited yield (DLY)* — the fraction of units that are not lost from defects added by the equipment. For wafer processing, defect yield is usually derived from a model.

5.2.17 *distribution* — a characterization of the probability of realization for a measurable event over the range of values that the measurements may assume.

5.2.18 *easement space* — the floor space that must remain clear to the rear and sides of the piece of equipment (but not in front of the load face plane). This includes safety aisles, ergonomic maintenance access space, component removal space, and room for doors to swing out.

5.2.19 *equipment required (ER)* — the integer number of pieces of equipment required to obtain the throughput for the step.

5.2.20 *equipment throughput* — see throughput.

5.2.21 *equipment yield (EY)* — the fraction of units received by the equipment that can be passed to the next step based on any criteria such as damaged units, or units determined to be defective by inspection or test. Inclusion of equipment yield results in a decreasing population of units flowing through the factory. At later steps, equipment will process fewer units than the full factory unit starts. For test equipment, validly rejected units are scrap, but not a component of equipment yield.

5.2.22 *fixed costs* — costs incurred once and usually associated with the acquisition and incorporation of a piece of equipment into the factory.

5.2.23 *good unit equivalents (GUE)* — the calculated number of equivalent units required to produce the same number of units output if product yield was 100%.

5.2.24 *joint probability* — a probability density or cumulative distribution function comprised of two or more random variables.

5.2.25 *lifetime* — the time over which the fixed and recurring costs are spread on an annualized basis.

5.2.25.1 *production lifetime* — the number of years a piece of equipment is used for manufacturing.

5.2.25.2 *tax lifetime* — the number of years as defined in compliance with local tax or accounting depreciation practices.

5.2.26 *lower specification limit (LSL)* — value of a characteristic, below which a product is said to be nonconforming.

5.2.27 *material* — bulk gas, specialty gas, or general or specialty chemical used in the process. Includes monitor units consumed in the support of the piece of equipment.

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

5.2.29 *measurement variability* — differences associated with making multiple measurements on a given measurand under specific conditions.

NOTE 4: Common (general) estimators of measurement variability are the variance, standard deviation, and variance components. Specific estimators include repeatability and reproducibility.

5.2.30 *monitor unit* — test or filler unit (e.g., wafer or device) consumed in the support of the piece of equipment. Also called test unit.

5.2.31 *operational uptime (OU)* — the percentage of time the piece of equipment is in a condition to perform its intended function during the period of operations time. This calculation is intended to reflect overall operational performance for a piece of equipment (SEMI E10).

5.2.31.1 *Discussion* — As defined, OU has components attributable to both the unit manufacturer and the equipment supplier.

5.2.32 *parametric limited yield (PLY)* — the fraction of units that are not lost from device parameters being outside the required range.

5.2.33 *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) (SEMI E89).

5.2.34 *probability density function (PDF)* — a mathematical formula that specifies the relationship between values that a random variable may assume and their likelihood of occurrence. It is the first derivative of the CDF.

5.2.35 *process step* — the smallest unit of processing activity that can be defined in a process flow (SEMI E81).

5.2.36 *product yield (PRY)* — the fraction of units that pass through the factory and result in good product. Product yield for units is the composite of all sources of yield loss.

5.2.37 *random variable* — a measurable event occurring such that any value from its distribution is equally likely to take place.

5.2.38 *recurring cost* — cost that is incurred on an ongoing basis, based on time and/or usage.

5.2.39 *repair part* — component to service the piece of equipment purchased at the time of repair.

5.2.40 *rework* — the percentage of units being reprocessed by the piece of equipment because of a fault or defect. Also called redo.

5.2.41 *service contract* — an agreement for the supplier to provide equipment service or maintenance under specified terms and conditions beyond that which is supplied with the piece of equipment.

5.2.42 *shadow footprint* — the area of the floor space directly under every part of the piece of equipment during its operation. This area includes any temporary projections from the piece of equipment during loading or processing (e.g., carriers that stick out from the piece of equipment or equipment load ports that protrude only when the piece of equipment is being loaded).

5.2.43 *spare part* — prepurchased inventory of a part maintained to service the piece of equipment.

5.2.44 *standard deviation, σ* — the positive square root of the variance.

NOTE 5: The standard deviation of a population may be estimated from experimentally obtained data by the sample standard deviation (s):

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{2}$$

where:

n = number of data values,

x_i = value of the i^{th} data point, and

$\bar{x}$ = mean of the data distribution.

5.2.45 *step* — see process step.

5.2.46 *supplier* — provider of equipment or services to the unit manufacturer. Also called equipment vendor or equipment manufacturer.

5.2.47 *test unit* — see monitor unit.

5.2.48 *throughput (TP)* — the number of units (e.g., wafers, devices) per hour the piece of equipment delivers to the factory, including all input, output, and internal overhead operation. TP includes all test or monitor units processed, since the cost of these non-product units is accounted for directly.

5.2.49 *tool* — often used synonymously with equipment or system in the silicon wafer processing industry

5.2.50 *tooling* — fixtures and adaptors required to modify a piece of equipment to the requirements of a specific unit, test, or operation.

5.2.51 *unit* — any wafer, die, packaged device, or piece part thereof (includes product and non-product units).

5.2.52 *upper specification limit (USL)* — value of a characteristic, above which a product is said to be nonconforming.

5.2.53 *variance* — a statistical estimator that quantifies spread around the mean of a probability density function.

5.2.54 *volume requirement* — the number of units required to be processed by the equipment in a specific time period, normally units per week.

5.2.55 *yield* — see product yield.

5.3 *Symbols*

5.3.1 α — alpha probability

5.3.2 β — beta probability

6 Cost of Ownership

$$\text{Cost of Ownership} = \text{Cost of Equipment Ownership} + \text{Cost of Yield Loss}$$
$$COO = CEO + CYL \qquad (3)$$

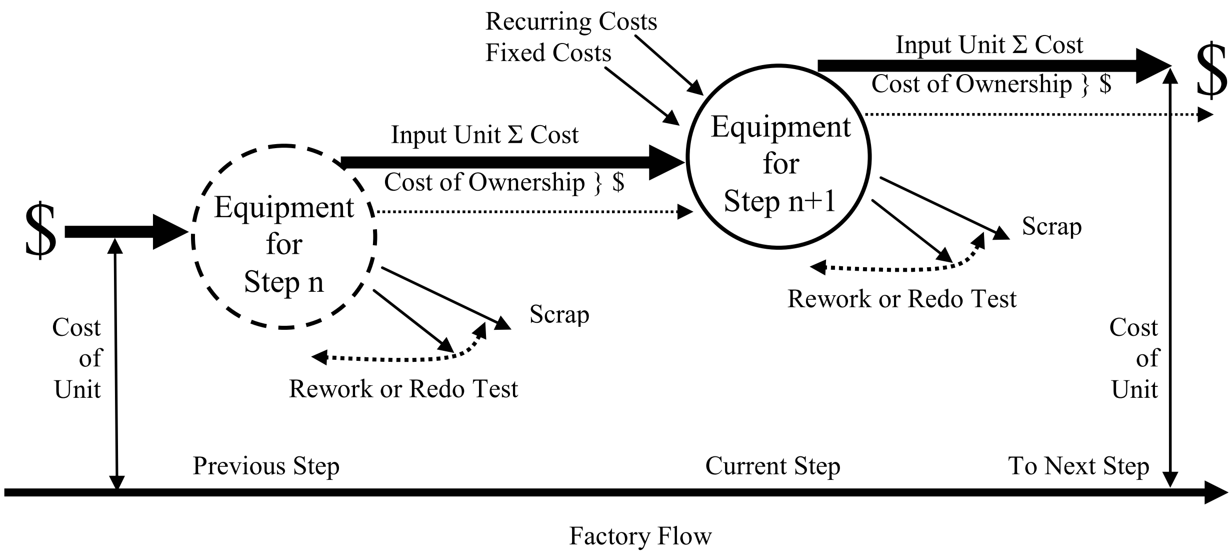

Figure 2
Accumulation of Cost during Factory Flow

6.1 *Description of COO*

6.1.1 COO is a metric for evaluating the incremental cost added to a unit of good product material flowing through equipment embedded in a factory environment for a specified lifetime, including the CYL. COO is calculated on an annualized basis. The metric is expressed as cost per good unit for one pass through the equipment. Figure 2 depicts this accumulation of cost which can be factored into two components, CEO and CYL, as shown in Equation 3.

6.1.2 COO is the full cost of embedding, operating, and decommissioning in a factory environment equipment needed to accommodate the required volume of product material.

6.1.2.1 COO calculated with no constraints is referred to as comprehensive COO.

6.2 *Constrained Versions of COO*

6.2.1 A constrained version of COO imposes a set of defined restrictions to facilitate comparisons or to remove ambiguity. An example is a baseline COO that only includes EY (i.e., DLY and PLY are not included.

6.2.2 Constraints should be predefined by all stakeholders in a specific equipment COO model, prior to estimating COO, to minimize biasing of the COO estimate.

6.3 *Lifetimes*

6.3.1 The lifetime of a piece of equipment is the time over which the fixed and recurring costs are considered for evaluating the annualized COO. The number of years that a piece of equipment is planned to be used in manufacturing is the piece of equipment's production lifetime.

6.3.2 Tax lifetime for depreciation allocation purposes is another measure of the piece of equipment's lifetime that is customarily used in evaluating COO. Tax lifetime is based upon local tax or standard accounting practices.

6.3.3 The piece of equipment usually remains in production much longer than the tax lifetime, so it is useful to consider both lifetimes in evaluating COO.

6.4 *CEO: Fixed and Recurring Costs*

6.4.1 Determining CEO requires enumerating all of the fixed and recurring costs that are incurred in the life cycle of the piece of equipment. The calculation is shown in §8.

6.4.2 Fixed costs are those incurred once and are usually associated with the acquisition and incorporation of a piece of equipment into the factory. End-of-life costs, such as decontamination and removal costs, are also part of fixed costs.

6.4.3 Recurring costs are those that arise on a regular basis from the operation and maintenance of the piece of equipment. Some infrequent recurring costs, including the costs of upgrading a piece of equipment to new technologies may be included in fixed costs if the CEO is being calculated to compare an upgraded existing piece of equipment with a new acquisition.

6.4.3.1 Costs that are depreciated should be included as fixed costs.

6.5 *Yield*

6.5.1 Yield is a metric of the percentage of the unit volume that results in good product. Yield affects the COO in a number of ways.

- Volume of units that must be processed for the required product requirements.
- Cost of units that do not produce good product.

6.5.2 Product yield (PRY) is the percentage of units that pass through the factory and result in good product. Product yield for units is the composite yield from all sources of yield loss, as shown in Equation 4. The components are defined in §5.

$$PRY = EY \times (1-\alpha) \times (1-\beta) \times DLY \times PLY \times (1 - Rework) \tag{4}$$

6.5.2.1 Since DLY is generally a wafer-level phenomena, Equation 4 may be simplified for other types of units by setting DLY = 1. Particle additions are a predictor of defect yield loss at a future step, but not a complete predictor of all the possible loss since there may be other defects or parametric problems.

6.5.2.2 The P/T ratio of test and measurement equipment also affects PRY. P/T ratio is reflected in Equation 4 by the inclusion of α and β. The formulas for calculating α and β are provided in Appendix 1.

6.6 *Cost of Yields*

6.6.1 A unit lost at the end of a given step represents the loss of the starting unit cost and all costs of manufacturing a unit prior to that step. In addition, units leaving a step with undetected defects may be lost at a later step. Calculating CYL therefore requires knowing the accumulated costs of manufacturing before the unit is lost. Therefore, although CYL is a recurring cost, it should be tracked separately. CYL is given in Equation 7 in ¶8.2.

6.7 *Volume Requirement*

6.7.1 The volume requirement is the number of units to be processed and can be derived from specification of the product units needed corrected for yield and the number of other units required to be processed by the equipment in a specific time period such as rework or monitor units. One complication in accurately estimating the volume requirement is that the volume of units actually reaching the equipment will depend on the equipment yields from all prior steps.

6.8 *Equipment Required*

6.8.1 Once the volume of units is specified, the number of pieces of equipment required (ER) is obtained from the TP and the OU.

$$ER = \text{Volume Requirement} / (TP \times OU) \tag{5}$$

For CEO calculations, ER is a whole number. Thus, a fractional result from Equation 5 is increased to the next larger whole number to represent whole pieces of equipment.

7 Reporting Results

7.1 Reports on COO should always show the following items. Other data items should be reported as required by clarity.

7.1.1 *Input Items*

7.1.1.1 Identification of standard conformance

7.1.1.2 Identification of constraint conditions

7.1.1.3 Declarations

7.1.1.3.1 Summed categories: all or enumerate

7.1.1.3.2 Volume requirement

7.1.1.3.3 Operational uptime

7.1.1.3.4 Equipment throughput

7.1.1.3.5 Number of pieces of equipment and chambers

7.1.2 *Output Items*

7.1.2.1 Cost per unit

7.1.2.2 Cost distribution

7.1.2.3 Related statistics

8 Procedures

8.1 *COO Calculation*

8.1.1 The COO algorithm requires the specification or calculation of the volume level, the determination of the number of pieces of equipment required to process the volume, the enumeration of all fixed and recurring costs associated with processing the volume by the equipment, and the yield-related costs. The COO metric is a function defined by Equation 6 to be:

$$\mathrm{COO} = \mathrm{CEO} + \mathrm{CYL} \tag{6}$$

The CYL is given by Equation 7. The CEO component is described in Equation 8 and is expressed in Equation 9 as the sum of a number of cost categories. Constrained versions of COO exclude certain cost categories from the calculation.

8.2 *Cost of Yield Loss*

$$CYL = \left[\begin{pmatrix}\textit{annualized}\\ \textit{cost of units}\\ \textit{lost to EY}\end{pmatrix} + \begin{pmatrix}\textit{annualized}\\ \textit{attributed cost of}\\ \textit{units lost to DYL}\end{pmatrix} + \begin{pmatrix}\textit{annualized}\\ \textit{attributed cost of}\\ \textit{units lost to PYL}\end{pmatrix}\right] \times \frac{1}{\textit{GUE per year}} \tag{7}$$

where the recurring scrap cost elements are given in Table 3.

8.3 *Cost of Equipment Ownership*

$$CEO = \left[\begin{pmatrix}\textit{annualized}\\ \textit{fixed cost per}\\ \textit{equipment}\end{pmatrix} + \begin{pmatrix}\textit{annualized}\\ \textit{recurring cost per}\\ \textit{units lost to DYL}\end{pmatrix}\right] \times \frac{ER}{\textit{GUE per year}} \tag{8}$$

$$= \sum_{ij} F_{ij} + \sum_{km} R_{km} \times \frac{ER}{GUE\ per\ year} \tag{9}$$

where i and k are the number of primary categories and cost elements, respectively, in Tables 1 and 2. F_{ij} and R_{km} are the detailed elements, each of which is defined in Tables 1 and 2.

9 Cost Elements

9.1 Cost elements are expanded into further items and then summed.

9.2 Constrained versions of the COO calculation are created by defining a modification of the calculation such as the way yield is included or in restricting the items in a cost element that are used. This set is similar to the original Sematech COO model.

NOTE 6: Default values for some cost elements are given in Related Information 2.

Table 1 Elements of Fixed Cost by Category

Category (i)	*Cost Element (j)*	*Description*	*Method*
Equipment	Acquisition	Costs of acquiring the piece of equipment.	Expressed in terms of equipment cost (i.e., purchase price), transportation, taxes, duties, actual burdened costs for labor-hours of effort multiplied by the number of hours for each equipment user's personnel type, etc. May be allocated to annual costs using any accepted depreciation schedule (e.g., straight-line, double declining balance).
Equipment	Installation	Costs of installing the piece of equipment for production.	Expressed in terms of actual burdened costs for labor-hours of effort multiplied by the number of hours for each equipment user's personnel type and cost of materials.
Equipment	Training	Costs of the initial training requirements for the new piece of equipment for operators, supervision, engineers, and maintenance personnel.	Expressed in terms of actual burdened costs for labor-hours of training multiplied by the number of training hours and training course costs, if applicable, for each equipment user's personnel type. Note that depending on accounting rules, some training may be included as part of the equipment acquisition cost.
Equipment	Qualification	Costs of qualifying the piece of equipment for production including acceptance testing	Expressed in terms of actual burdened costs for labor-hours of effort multiplied by the number of hours for each equipment user's personnel type and cost of materials.
Equipment	Decommissioning	Costs of removing the piece of equipment from production.	Expressed in terms of actual burdened costs for labor-hours of effort multiplied by the number of hours for each equipment user's personnel type and costs of transportation and materials. May deduct the salvage value from the fixed costs.
Facilities	Moves and Rearrangements	Costs of displacing an existing piece of equipment in order to install the new piece of equipment.	Expressed in terms of actual burdened costs for labor-hours of effort multiplied by the number of hours for each equipment user's personnel type and costs of transportation and materials.
Facilities	Floor Space	Costs of the cleanroom overhead allocated to the piece of equipment.	Multiply the cost footprint of the piece of equipment by the cost of cleanroom space for each class of cleanroom space used. [#1]

[#1] The cost of cleanroom space per unit area of effective usable production space includes both the fixed and recurring operations costs as determined by a separate COO analysis outside the scope of this document.

Table 2 Elements of Recurring Costs by Category

Category (k)	*Cost Element (m)*	*Description*	*Method*
Consumable	Consumable Parts	Cost of all parts of the piece of equipment that are worn out by the process operation of the piece of equipment and require replacement after less than 1 year of operation.	Expressed in terms of cost per piece of equipment per year.
Consumable	Monitor Units	Costs of all test and filler units consumed in the support of the piece of equipment.	Multiply the number of monitor units consumed per piece of equipment by the cost of each type of monitor unit. [#1]
Consumable	Utilities	Costs of all utilities (e.g., electricity, city water, ultrapure water, process cooling water, natural gas) used by the piece of equipment.	Multiply the annual amount of each utility used per piece of equipment by the unit cost of each type of utility.
Consumable	Supplies	Cost of all supplies used by, or in support of, the piece of equipment (e.g., bulk gases, specialty gases, specialty chemicals).	Multiply the annual amount of each supply used per piece of equipment by the unit cost of each type of supply.
Consumable	Waste Disposal	Costs of removing and treating spent chemical or effluent.	Multiply the annual amount of each spent chemical or effluent produced per piece of equipment by the unit cost of disposal of each type of spent chemical or effluent. Equipment user may need to deduct the salvage value, if any, from the costs.
Maintenance	Labor	Costs of equipment user's internal repair and maintenance labor to maintain the piece of equipment.	Calculate the number of maintenance labor hours required for scheduled and unscheduled downtime based on using SEMI E10 metric inputs. Multiply the actual burdened costs for labor-hours of effort multiplied by the number of hours for each equipment purchaser's personnel type. Equipment user may need to adjust actual hours required due to warranty and service contract coverage. Note that operation labor hours are not included in this category.
Maintenance	Spare Parts	Costs of spare parts inventory for equipment user.	Expressed in terms of cost per piece of equipment per year. Note that depending on accounting rules, an initial set of spare parts may be included as part of the equipment acquisition cost, a fixed cost.
Maintenance	Repair Parts	Costs of repair parts charged to the equipment user.	Expressed in terms of cost per piece of equipment per year. Equipment user should not double count the cost of a part as both a spare part and a repair part.
Maintenance	Service Contract	Costs of service contract charged to the equipment user.	Expressed in terms of cost per piece of equipment per year.
Labor	Operation	Costs of the operator labor required to support the equipment set needed to meet the wafer start requirements of the equipment user.	Calculate the number of operator labor hours required based on equipment and manufacturing specifications. Multiply the actual burdened costs for labor-hours of effort by the total number of hours for equipment purchaser's operators.
Labor	Supervision	Costs of the supervision labor required to support the equipment set needed to meet the wafer start requirements of the equipment user.	Calculate the number of supervision labor hours required based on equipment and manufacturing specifications. Multiply the actual burdened costs for labor-hours of effort by the total number of hours for equipment purchaser's supervisors.

Category (k)	Cost Element (m)	Description	Method
Labor	Engineering	Costs of the engineering labor required to support the equipment set needed to meet the wafer start requirements of the equipment user.	Calculate the number of engineering labor hours required based on equipment and manufacturing specifications. Multiply the actual burdened costs for labor-hours of effort by the total number of hours for equipment purchaser's engineers.
Labor	Support Services	Costs of the support service labor required to support operations and engineering.	Calculate the number of support service labor hours required. Multiply the actual burdened costs for labor-hours of effort by the total number of hours for equipment purchaser's support service personnel.

[#1] The cost of monitor units includes both their initial acquisition cost and any initial preparation or reprocessing costs, if applicable. Preparation and reprocessing costs may be calculated by summing the COOs from separate COO analyses of each of the preparation and reprocessing steps performed.

Table 3 Elements of Recurring Scrap Cost

Category	Cost Element	Description	Method
Scrap	Equipment Yield (EY) Loss	Costs of units lost, broken, or irreversibly misprocessed by the piece of equipment.	Calculate the EY Loss as the fraction of units lost, broken, or irreversibly misprocessed by the piece of equipment to the total number of units through the piece of equipment (i.e., 1-EY). Multiply EY Loss by the total number of units started through the piece of equipment and by the actual total costs invested in a unit at that step in the process (e.g., sum of initial unit starting material cost and COOs for all prior process steps).
Scrap	Defect Limited Yield (DLY) Loss	Costs of units lost due to electrical or inspection rejects due to defects caused by the piece of equipment.	Calculate the DLY Loss as the fraction of units lost due to electrical or inspection rejects due to defects caused by the piece of equipment (i.e., 1-DY). For wafers, DY may be calculated using a modified Seed's formula: $$DY = \frac{1}{1 + (AA \times D \times P)} \qquad (10)$$ where AA is the active area of the device, D is the defect density, and P is the probability that a defect caused by the piece of equipment will be fatal. Multiply DLY Loss by the total number of units started through the piece of equipment and by the actual total costs invested in a unit at that step in the process where it is lost (e.g., sum of initial unit starting material cost and COOs for all prior process steps to the end of the process where it is tested).
Scrap	Parametric Limited Yield (PLY) Loss	Costs of units lost due to electrical or inspection rejects due to unit operating parameters being outside the required range caused by the piece of equipment.	Calculate the PLY Loss as the fraction of units lost (i.e., 1-PY). Multiply PLY Loss by total number of units started through the piece of equipment and by actual total costs invested in a unit at that step in the process where it is lost (e.g., sum of initial unit starting material cost and COOs for all prior process steps to the end of the process where it is tested).

[#1] The cost of cleanroom space per unit area of effective usable production space includes both the fixed and recurring operations costs as determined by a separate COO analysis outside the scope of this document.

APPENDIX 1
METHODOLOGY FOR DETERMINING ALPHA AND BETA ERRORS

NOTICE: The material in this appendix is an official part of SEMI E35 and was approved by full letter ballot procedures on December 10, 2004.

A1-1 Purpose

A1-1.1 In silicon manufacturing product disposition is typically contingent on metrology equipment output. For example, a unit may be shipped, scrapped, or reworked based on information from one or more measured output characteristics.

A1-1.2 This appendix provides a standard methodology to include the cost due to misclassification of product because of measurement variability and bias during testing of the product for conformance to a specification.

A1-1.3 This appendix is also intended to be useful for pre-purchase evaluation of pieces of measurement equipment with different P/T ratios. It is also intended to be useful when comparing the operation of a single measurement instrument in different throughput modes where P/T ratio changes with the throughput mode utilized or other equipment setup factors. This appendix can help users select the optimum cost solution based on their specific process capability and requirements.

A1-2 Scope

A1-2.1 This appendix covers a methodology to determine the alpha and beta probabilities associated with misclassification of product due to variability and bias of measurement equipment. Alpha probability (α) is associated with failing units that conform to specifications. Beta probability (β) is associated with passing units that do not conform to specifications.

A1-2.2 This appendix can be applied to make relative misclassification cost comparisons as part of a COO analysis between two or more measurement gauges operating under conditions specified by the user. These conditions may include any aspects of the measurement system affecting the measurement results directly or indirectly (e.g., ambient conditions, throughput, recipe). This appendix can also be used to compare the relative costs of a single instrument under different operating conditions.

A1-2.2.1 A measurement gauge is defined by a specific realization of systems and subsystems required to make measurements. Gauges that differ in at least one system or subsystem may be considered different for the purpose of comparison.

A1-2.3 This appendix can be applied to any piece of metrology equipment or to the metrology portion of any piece of equipment that includes metrology.

A1-2.4 This appendix covers the case in which the piece of metrology equipment is used to make binary decisions about the item being measured, that is, only two outcomes are possible (e.g., pass/fail, go/no-go, ship/scrap). Models for decisions with more than two outcomes, such as the binning of data, are beyond the scope of this Appendix.

A1-2.5 To apply the formulae in this appendix, the user must estimate either the probability density function (PDF) or cumulative distribution function (CDF) of the process characteristic or characteristics of interest. The distributions can be based on a theoretical model or on empirical information obtained from manufacturing data.

A1-2.6 To apply the formulae in this appendix, the user must be able to estimate all biases and variances associated with the piece of equipment being compared under the specified operating conditions and with respect to the process characteristic(s) of interest. These values can be obtained from a measurement system capability analysis (see SEMI E89).

A1-2.7 This appendix does not consider costs associated with other components of uncertainty outside of measurement variability and bias.

A1-3 Limitations

A1-3.1 Application of this appendix requires that all measurement variances, biases, and process characteristic distributions be accurately characterized. If this is not done, the resulting calculation may be in error.

A1-3.2 Application of this appendix also requires that measurement variances and biases be constant over the measurement range interval of interest. If this is not the case, the resulting calculation may be in error.

A1-3.3 This appendix considers only the case of two convolved distributions, process characteristic variability and measurement variability; consideration of additional distributions (such as would be required if the measurement bias or variance were assumed to be a function of the measured value) is beyond the scope of this appendix.

A1-3.4 Extension of the model to the cases of decisions based on (1) measurements on multiple gauges, (2) multiple inspections with the same gauge, or (3) on multiple characteristics is provided in §A1-5.

A1-4 Procedure

A1-4.1 Estimate the PDF for the process characteristic to be studied. This can be done using empirical data that represents the process. Although actual data may be used to create a discrete PDF, it is sometimes convenient to use the data to parametrically fit a PDF model (e.g., log normal).

A1-4.2 Unless already known, establish the bias and standard deviation for each measurement gauge to be compared in accordance with SEMI E89.

A1-4.3 In all cases take the measurement influence into account so that it does not broaden the PDF. This may be done by taking repeated measurements at each point in the measurement range and calculating the mean, or by deconvolving the process characteristic PDF, $f(x)$, and the measurement variability CDF, $G(u)$, generally assumed to be a Gaussian (or normal) distribution with arithmetic mean equal to the bias, so that:

$$G(u) = \Phi(u) = \int_{-\infty}^{u} \frac{1}{\sqrt{2\pi}\sigma_M} \exp\left[-\frac{(x-\delta)^2}{2{\sigma_M}^2}\right] \mathrm{d}\,x \tag{1}$$

where:

δ = bias,

σ_M = standard deviation of the measurement distribution.

NOTE 1: The quantity σ_M includes the effects of the change in bias over the time interval in which σ_M has been established.

A1-4.4 Calculate α and β as follows. Note that the symbols in the equations for α and β have the following meanings:

$f(x)$ = PDF of process characteristic x,

USL = upper specification limit,

LSL = lower specification limit, and

$\Phi(u)$ = Gaussian CDF (see Equation (1) in ¶A1-4.3).

A1-4.4.1 For a characteristic with only a USL, use the following equations to calculate α and β:

$$\alpha = \int_{-\infty}^{USL} \left[1 - \Phi\left(\frac{USL - x + \delta}{\sigma_M}\right)\right] f(x)\,\mathrm{d}\,x \tag{2}$$

$$\beta = \int_{USL}^{\infty} \left[\Phi\left(\frac{USL - x + \delta}{\sigma_M}\right)\right] f(x)\,\mathrm{d}\,x \tag{3}$$

A1-4.4.2 For a characteristic with only an LSL, use the following equations to calculate α and β:

$$\alpha = \int_{LSL}^{\infty} \left[\Phi\left(\frac{LSL - x + \delta}{\sigma_M}\right)\right] f(x)\,\mathrm{d}\,x \tag{4}$$

$$\beta = \int_{-\infty}^{LSL} \left[1 - \Phi\left(\frac{LSL - x + \delta}{\sigma_M} \right) \right] f(x) \mathrm{d}\, x \tag{5}$$

A1-4.4.3 For a characteristic with both upper and lower specifications limits, use the following equations to calculate α and β:

$$\begin{aligned} \alpha = & \int_{LSL}^{USL} \left[1 - \Phi\left(\frac{USL - x + \delta}{\sigma_M} \right) \right] f(x) \mathrm{d}\, x \\ & + \int_{LSL}^{USL} \Phi\left(\frac{LSL - x + \delta}{\sigma_M} \right) f(x) \mathrm{d}\, x \end{aligned} \tag{6}$$

$$\begin{aligned} \beta = & \int_{-\infty}^{LSL} \left[\Phi\left(\frac{USL - x + \delta}{\sigma_M} \right) - \Phi\left(\frac{LSL - x + \delta}{\sigma_M} \right) \right] f(x) \mathrm{d}\, x \\ & + \int_{USL}^{\infty} \left[\Phi\left(\frac{USL - x + \delta}{\sigma_M} \right) - \Phi\left(\frac{LSL - x + \delta}{\sigma_M} \right) \right] f(x) \mathrm{d}\, x \end{aligned} \tag{7}$$

A1-5 Extensions of the Methodology to More Complex Situations

A1-5.1 In general, when a single characteristic on a unit is measured once on a single gauge and 100% sampling is employed, the model will take the form described earlier. If the situation is more complex, the nature of the model will be different. Factors that can affect the nature of the model include the following:

- number of units examined (lot acceptance sampling vs. 100% sampling),
- number of times a unit is inspected (single vs. multiple),
- effect of the inspection process on the unit (destructive vs. non-destructive),
- number of item characteristics examined for a single decision (one vs. many), and
- cost functions associated with the business decisions (fixed vs. variable).

A1-5.2 *Extension to Multiple Gauges*

A1-5.2.1 To extend the model to multiple gauges, one must make the additional assumption that all measuring gauges are measuring the same characteristic.

A1-5.2.1.1 In addition, define a conforming item as one that all gauges show the measured characteristic to be in specification.

A1-5.2.1.2 A nonconforming item is taken to be one in which at least one gauge shows the measured characteristic to be outside of specification.

A1-5.2.2 It is then possible to define a set of α and β error rates for each gauge. Let α_1, α_2, …, α_n be the α values and β_1, β_2, …, β_n be the β values associated with the n different gauges.

A1-5.2.3 The overall α value, α_T, is calculated from the equation:

$$\alpha_T = \pi - \prod_{i-1}^{n} (1 - \alpha_i) \tag{9}$$

where:

$$\pi = \int_{-\infty}^{USL} f(x) \mathrm{d}\, x \text{ , and}$$

$f(x)$ = PDF of the characteristic being measured.

NOTE 2: This equation is based on the probability P that the item is conforming but that one or more gauges give a conforming result:

$\alpha_T = P$[Item is conforming, ≥1 gauges show nonconforming]

$= P$[Item is conforming]

– P[Item is conforming, All gauges show conforming]

A1-5.2.4 The overall β value, β_T, is calculated from the equation:

$$\beta_T = \prod_{i=1}^{n} \beta_i. \tag{10}$$

NOTE 3: This equation is based on the probability P that the item is nonconforming but that all gauges give a conforming result:

$\beta_T = P$[Item is nonconforming, All gauges show pass]

A1-5.3 *Extension to Multiple Inspections with the Same Metrology System*

A1-5.3.1 Multiple inspection with the same metrology system is a special case of inspection with multiple gauges. If the same measurement system is used to measure the item characteristic repeatedly, one merely lets $\alpha_i = \alpha$ and $\beta_i = \beta$ for all i, as the α and β error rates will not change for the same gauge.

A1-5.4 *Extension to Decisions Based on Multiple Characteristics*

A1-5.4.1 It is also possible to develop a model where a decision is based on more than one characteristic. As with the case of multiple gauges, several assumptions must be made.

A1-5.4.1.1 The characteristics being measured are independent or an independent combination of their values is used.

A1-5.4.1.2 All tests are performed before a decision to reject or pass is made.

A1-5.4.1.3 F(x) has been deconvolved from F·G.

A1-5.4.1.4 A conforming unit is defined as one in which all measured characteristics are shown to be within specification.

A1-5.4.1.5 A nonconforming unit is taken to be one in which at least one characteristic is outside of specification.

A1-5.4.2 It is then possible to define a set of α and β errors for each gauge. Let $\alpha_1, \alpha_2, \ldots, \alpha_n$ be the α values and $\beta_1, \beta_2, \ldots, \beta_n$ be the β values associated with the n different characteristics.

A1-5.4.3 The overall α value, α_T, is calculated from the equation:

$$\alpha_T = \prod_{i=1}^{n} \pi_i - \prod_{i=1}^{n} (1 - \alpha_i) \tag{11}$$

where:

$$\pi_i = \int_{-\infty}^{USL} f_i(x) \mathrm{d}x \text{ , and}$$

$f_i(x)$ = PDF of the characteristic i.

This equation is based on the probability P that all characteristics conform, but that at least one test failed:

$\alpha_T = P$[All characteristics conform, At least one test failed]

$= P$[All characteristics conform]

– P[All characteristics conform, All tests passed]

A1-5.4.4 The overall β value, β_T, is calculated from the equation:

$$\beta_T = \prod_{i-1}^{n} P_i - \prod_{i=1}^{n} (1 - \alpha_i) \tag{12}$$

where:

P_i = proportion of observations within specification for characteristic i.

This equation is based on the probability P that one or more characteristics are nonconforming but that all tests passed:

$\beta_T = P$[≥1 characteristic nonconforming, All tests passed]

$= P$[All pass]

$- P$[All characteristics conform, All tests passed]

RELATED INFORMATION 1
COST OF OWNERSHIP

NOTICE: This related information is not an official part of SEMI E35 and was derived from North American Metrics Committee. This related information was approved for publication by full letter ballot on December 10, 2004.

R1-1 COO Calculation Graphical Overview

R1-1.1 A discussion of COO is provided in this related information to supplement the presentation within the guideline.

R1-1.2 The COO calculation is shown graphically in Figure R1-1. This figure is not a flowchart, but rather is meant to illustrate the elements of the calculation.

R1-1.3 The left side of the diagram shows various cost factors, while the right side shows how they are incorporated in the calculation. The upper section is the determination of the number of pieces of equipment required to process the specified number of units. In the middle section, the fixed costs are converted to an annual basis and combined with the recurring costs. In the last section, the total cost is then divided by the number of good unit equivalents.

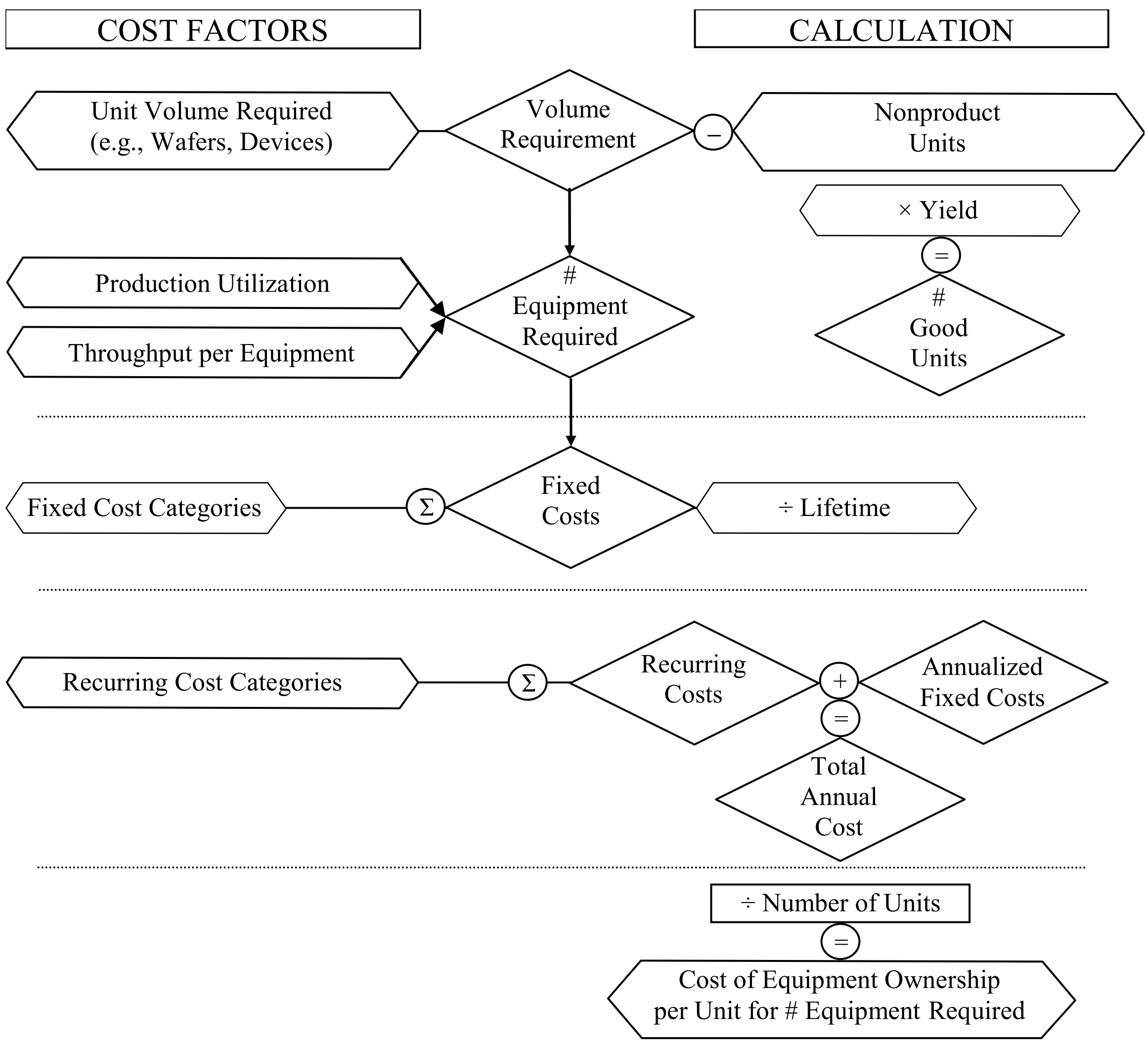

Figure R1-1
Cost of Equipment Ownership

RELATED INFORMATION 2
EXAMPLE VALUES TABLE

NOTICE: This related information is not an official part of SEMI E35 and is not intended to modify or supersede the official standard. It has been derived from multiple sources. Publication was authorized by vote of the SEMI Metrics Committee. These values are provided only as examples. Actual values should be determined by considering company experience, specific equipment characteristics, applications, process technology, product type, regional differences and analysis objectives. Determination of the suitability of the material is solely the responsibility of the user.

Example Values Description	*150 mm Example* #1	*200 mm Example* #2	*300 mm Example* #3
1. Fab Values			
Engineering Usage	0	0	0
Standby Time	0	0	0
Production Tests	127	14	14
MTTT	0.31	0.25	0.3
Whole Systems	NA	1	1
2. Scheduled Production			
Hours/Week/Shift	42	42	42
Shifts/Week	4	4	4
Hours/Day	24	24	24
Days/Year	350	365	365
Supplier Shifts/Week	NA	4	4
3. Labor and Salary Rates			
Engineering	$100,000	$111,000	$111,000
Supervision	$80,000	$111,000	$111,000
Operator/Hour	$26	$25	$25
Maintenance/Hour	$26	$30	$30
Productivity	80%	80%	80%
4. Space Rates in cost/m^2/year (cost/ft^2/year)			
Fed. Std 209E Class 1 or ISO Class 3	$3875 ($360)	$4306 ($400)	$4306 ($400)
Fed. Std 209E Class 10 or ISO Class 4	$2583 ($240)	$2691 ($250)	$2691 ($250)
Fed. Std 209E Class 100 or ISO Class 5	$1076 ($100)	$1076 ($100)	$1076 ($100)
Other	$538 ($50)	$538 ($50)	$538 ($50)
5. Wafer Costs			
Test Wafer	$5.50	$100	$500
Test Wafer Reuse Times[1]	1	10	10
Incoming Wafer	$250	$500	$1317
Completed Wafer	$500	$1000	$2034
6. Depreciation Values			
Life of Equipment Years	5	7	7
Depreciation Life Years	NA	5	5
Salvage Value	$0	$0	$0
Depreciation Method	Straight Line	Straight Line	Straight Line
7. Other Values			
Systems/Engineer	5	10	10
Systems/Supervisor	20	30	30
Systems/Operator	2	3	3
Defect Fault Probability	0.167	0.05	0.08

Example Values Description	*150 mm Example* [#1]	*200 mm Example* [#2]	*300 mm Example* [#3]
8. Installation Cost as Percent of Equipment Cost			
Lithography	NA	NA	8%
Metrology	NA	NA	5%
Other	NA	NA	12%

[#1] Derived from SEMATECH Cost of Ownership Rev. B December 1990.

[#2] Approved, Metrics Committee, July 11, 1995.

[#3] Derived from joint Selete and International 300mm Initiative (I300I) inputs, 1997.

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