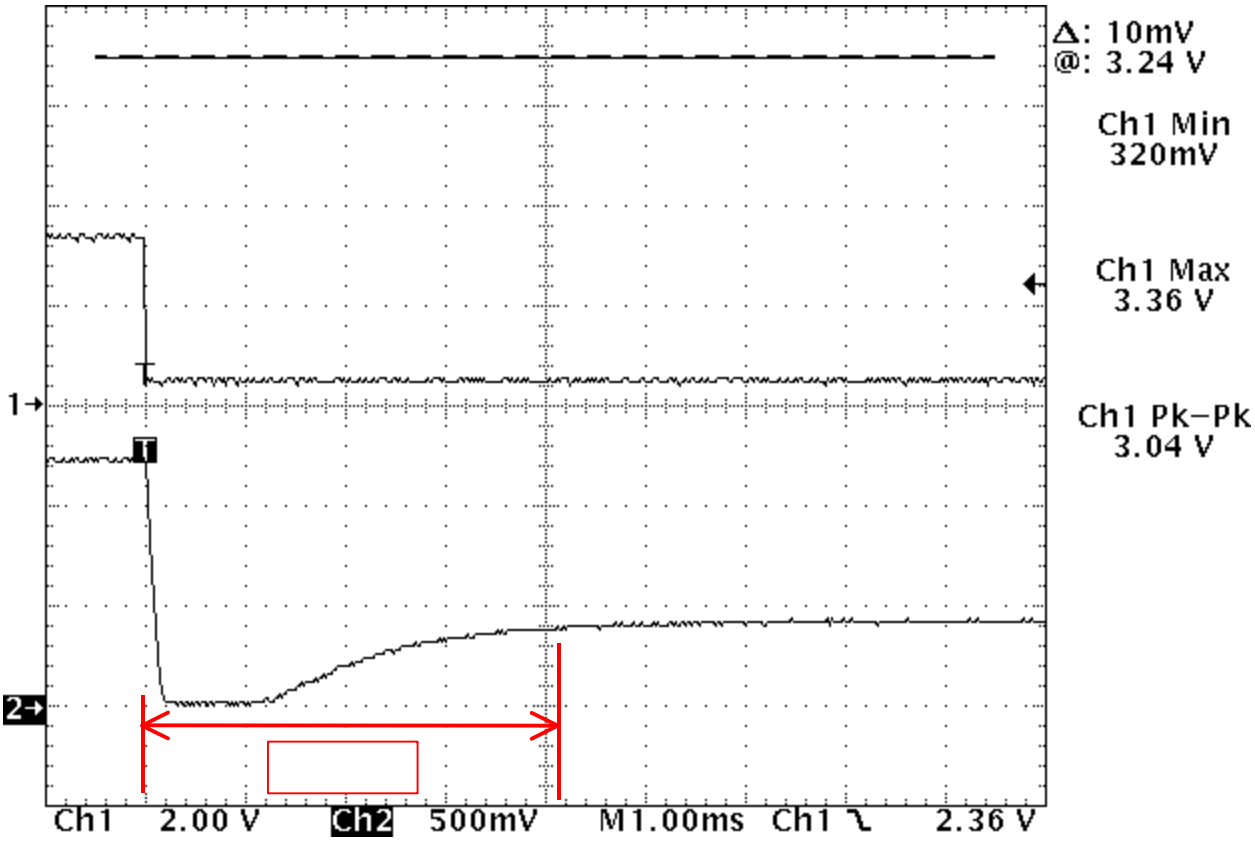
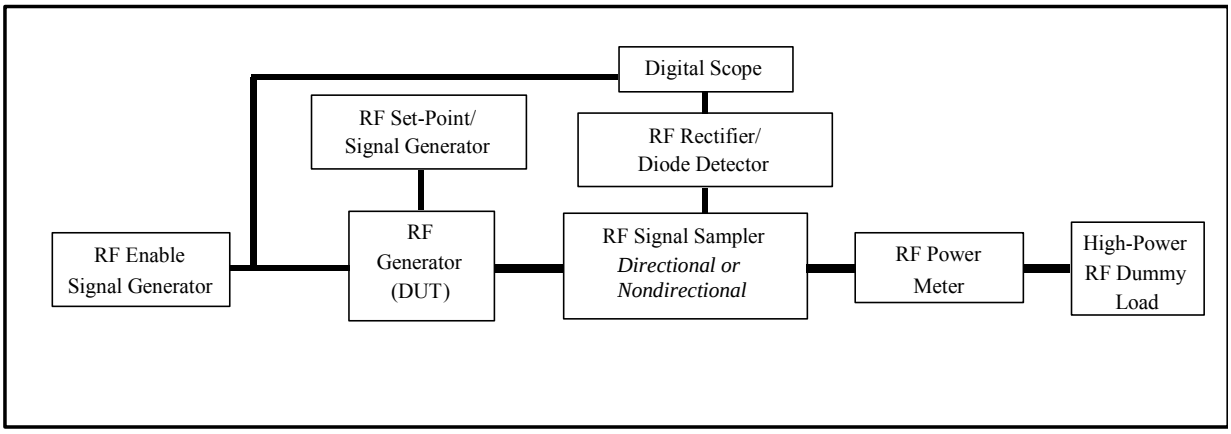


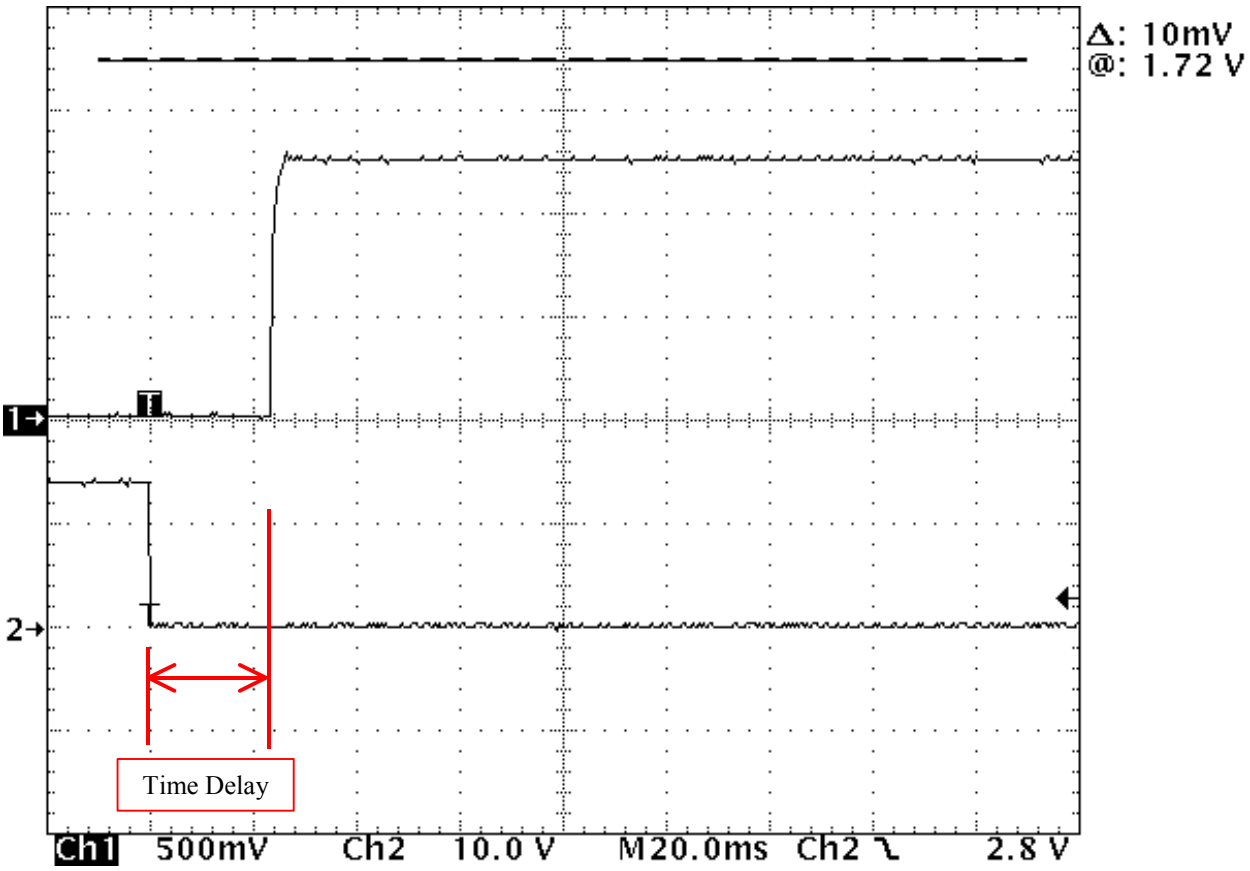
NOTE: These data are for conditions where the requested power went from 33% to 3% of the full power of the RF Generator being tested.

Figure 3
Example of Digital Oscilloscope Data that Shows the Transient Response of the RF Output Power (Lower Trace) Due to a Change in Set Point Signal (Upper Trace)



NOTE: If cable assemblies are used between the output of the RF Generator (DUT) and the High-Power Dummy Load, they shall have the same nominal impedance as the DUT and shall have a power handling capability that is consistent with the maximum output power of the RF Generator (DUT).

Figure 4
Schematic of the Test Setup for the Measuring the Transient Response of the RF Generator (DUT) as a Function of a Change in the RF Enable Signal



NOTE: These data are for conditions where the requested power went from 0% to 100% of the full power of the RF Generator being tested.

Figure 5
Example of Digital Oscilloscope Data that Shows the Transient Response and Time Delay of the RF Output Power (Upper Trace) Due to a Change in the RF Enable Signal (Lower Trace)

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.

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SEMI E136-1104
TEST METHOD FOR DETERMINING THE OUTPUT POWER OF RF GENERATORS USED IN SEMICONDUCTOR PROCESSING EQUIPMENT RF POWER DELIVERY SYSTEMS

This test method 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 July 11, 2004. Initially available at www.semi.org September 2004; to be published November 2004.

1 Purpose

1.1 The purpose of this test method is to provide an accurate method for measuring the output power of RF generators used in RF power delivery systems for semiconductor processing equipment to support SEMI E113.

2 Scope

2.1 This test method specifies the testing procedures and test equipment required for determining the true output power (i.e., heating power) output of RF generators. This test method uses a calorimetric power meter, which was calibrated previously using precise DC substitution techniques as a reference standard.

2.2 The primary focus for this test method is semiconductor processing equipment including, but not limited to, the following equipment types:

- Dry etch equipment, and
- Film deposition equipment (CVD and PVD).

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 test method is meant to provide a general means of measuring the true output power of RF generators operating over a wide range of frequency and power. Limitations in the frequency and power coverage of this method are determined by the individual system components chosen.

3.2 This test method assumes that the transmission system characteristic impedance is 50 Ω.

3.3 International, national, and local codes, regulations and laws should be consulted to ensure that the equipment and procedures meet regulatory requirements in each location.

3.4 Certain safety issues associated with the test procedures themselves are mentioned as a reminder that safety procedures are necessary for safe conduct of the test.

3.5 This standard does not address any safety or performance issues related to RF emissions or electrical codes (e.g., Underwriter's Laboratory, Inc. (UL), the National Electrical Code (NEC®), Federal Communications Commission (FCC)). It is the responsibility of the users of this standard to conform to the appropriate local codes and regulations as applied to this type of equipment, some of which are covered by referenced documents.

4 Referenced Standards

4.1 *SEMI Standards*

SEMI E113 — Specification for Semiconductor Processing Equipment RF Power Delivery Systems

SEMI E114 — Test Method for RF Cable Assemblies Used in Semiconductor Processing Equipment RF Power Delivery Systems

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

5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 *AC* — Alternating Current

5.1.2 *CVD* — Chemical Vapor Deposition

5.1.3 *DC* — Direct Current

5.1.4 *NIST* — National Institute for Standards and Technology

5.1.5 *PVD* — Physical Vapor Deposition

5.1.6 *RF* — Radio Frequency

5.1.7 *VSWR* — Voltage Standing Wave Ratio

5.2 *Definitions*

5.2.1 *cable assembly* — the section of cable (transmission line), including the connectors, used to

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connect various parts of the RF power delivery system.

5.2.2 *calorimeter* — an RF power measurement instrument using differential temperature and mass flow rate to determine true heating power.

5.2.3 *harmonic frequency* — the harmonic frequencies are defined as integer multiples of the fundamental frequency. For example, the second harmonic of 13.56 MHz is 27.12 MHz.

5.2.4 *RF generator* — a component in the RF power delivery system used to develop RF energy.

5.2.5 *RF termination* — a device for terminating RF transmission systems, and converting RF electrical energy into heat. RF terminations normally have values that are the same as the characteristic impedance of the transmission system.

5.2.6 *RF load* — another term used to describe an RF termination.

6 Test Apparatus

6.1 *Calorimetric Power Meter* — This instrument is designed to be used in conjunction with a high efficiency water-cooled RF termination, rated for the maximum power output of the RF generator. Typical calorimetric power meters use internal thermocouple- or thermistor-type temperature sensors, a precision coolant flow meter, and processing circuits for storage of calibration constants and coolant physical characteristics. Choose instruments capable of providing a power measurement accuracy of ± 1% after calibration at a specific power level.

6.2 *Water-Cooled RF Termination* — This device provides a low VSWR (i.e., high return loss) termination for the testing of the RF generator. Use an RF termination sized appropriately for the RF generator under test. Finally, use an RF termination capable of dissipating DC energy, without damage due to the effects of electrolysis. The return loss of the RF termination, including the interconnecting cable between the RF generator and the termination shall be no less than 30 dB. This return loss ensures maximum power transfer between the RF generator and the calorimeter.

NOTE 1: See Section 7 for safety-related recommendations related to RF terminations.

6.3 *Voltage and Current Meters* — These meters are used to measure the voltage and current presented to the calorimeter load during the DC calibration of the calorimeter. These instruments shall have a certificate indicating NIST traceability. Choose meters capable of voltage and current measurement accuracy of less than 0.2%.

6.4 *Calibration Power Supply* — This power supply is used as a source of clean DC energy for the purposes of calibrating the calorimetric power meter. Use a power supply sized for the calibration to be performed and that provides a very stable output at all levels.

6.5 *Cables and Connectors* — Various interconnecting cables are required to perform the tests outlined in this test method. These include low-loss cables to connect the DC power source to the measuring instrument and to the RF load, in addition to low-loss RF cables and connectors to connect the RF generator output to the load.

6.5.1 In order to keep cable losses to a minimum, minimize the lengths of interconnecting cables.

6.5.2 In addition, compensate for the losses associated with interconnecting cables used.

NOTE 2: For example, if 6 m (20 feet) of #10 AWG copper wire is used to connect the DC supply to the calorimeter, this wire will add approximately 0.04 Ω of resistance between the DC source and the 50 Ω termination. Using a DC supply voltage of 500 V terminated by 50 Ω (i.e., 5 kW), this will result in a loss of about 4 W in the copper wire.

6.5.3 Adjust the reading obtained by the calorimeter according to the cable loss value.

NOTE 3: For example, suppose that an RF generator, operating at 13.56 MHz and developing 3 kW is connected to the calorimeter through a 6 m (20-foot) length of RG-217/U coaxial cable. RG-217/U coaxial cable has a loss specification of 0.41 dB per 30 m (100 feet) of cable at 13.56 MHz. Therefore, for 6 m (20 feet) of cable, the loss would be approximately 0.41/5, or 0.082 dB. If the RF generator is developing 3 kW, this means that approximately 2.944 kW would appear at the calorimeter due to the cable loss.

7 Safety Precautions

NOTE 4: The tests described in this test method involve using low-output power test instrumentation (typically less than 10 mW).

7.1 Work should be conducted in accordance with local safety requirements and test device manufacturer's recommended safety procedures.

7.2 The area immediately surrounding the test setup should be kept free and clear of unnecessary equipment and materials.

7.3 Testing personnel should ensure they have

adequate lifting devices for large weights such as long RF cables and generators themselves.

7.4 Persons performing tests should determine which method of water cooling of the resistor in the RF termination is utilized by the test device manufacturer and should take steps to ensure safe use of the device.

7.4.1 Cooling-water flow rates should be appropriate to the test device manufacturer's recommendations for cooling of the power load level being tested. Consult the RF generator operating manual load specifications for this information.

7.4.2 An RF termination using internal resistor cooling only is highly recommended because such resistors (of the tubular ceramic, thin film type) are usually cooled by routing the coolant to the inside of the ceramic tube and away from the resistive film, thereby eliminating the possibility of electrolysis affecting the resistive film.

7.4.3 In an alternative method, the coolant is routed on both the inside and the outside of the resistor. While this method provides for more efficient cooling, the proximity of the coolant to the resistive film can potentially result in damage to the resistive film caused by electrolysis generated by the DC energy passing through the fluid in the termination.

7.4.3.1 For this reason, if an RF termination using both internal and external cooling is used, it is important to periodically check the resistor for damage due to electrolysis. This can be done easily by measuring the resistance of the load resistor using a simple digital multimeter.

7.4.3.2 With the RF termination disconnected from the RF cable, place one probe on the center conductor of the termination, and the other probe on the termination's outer conductor.

7.4.3.3 Measure the DC resistance of this path. If the DC resistance is more than 53 Ω, replace the resistor in the termination.

7.5 In order to prevent the possibility of ground loops between the RF generator and the calorimeter system, be sure to operate the calorimeter and the RF generator on the same AC supply.

8 Test Setup for RF Generator Power Output Test

8.1 The test setup for the RF generator output power test consists of the RF generator connected to the calorimeter power meter through a length of coaxial cable.

8.2 Prior to making any measurements, calibrate the calorimeter power meter using a source of stable DC energy.

9 Test Procedure for Determining RF Generator Output Power

9.1 Calorimetric power meters provide excellent reference standards for the measurement of RF energy in that they are capable of measuring the true heating power of a waveform, including any harmonic- or nonharmonic-related frequency components. The technique employed for this test is to first calibrate the calorimetric power meter with DC energy, which can be very precisely determined. Then, use two digital multimeters (e.g., Fluke™ 87 or equivalent) to determine the actual DC power applied to the calorimeter. Finally, once the DC calibration has been performed at a particular power level, connect the output of the RF generator under test to the calorimeter and measure the output power of the RF generator. The basic steps involved in the use of this system are outlined below.

9.2 *Calibrate the Calorimeter* — Calibrate the calorimeter with the stable DC power supply, using the two digital multimeters to read the voltage and current applied to the calorimeter's RF load.

9.3 *Connections* — Connect the DC power supply, the digital multimeters, and the RF load according to Figures 1 and 2. Make the connections between the multimeters, the DC power supply, and the RF load using high-quality low-loss cable and high-quality corrosion-free cable terminations.

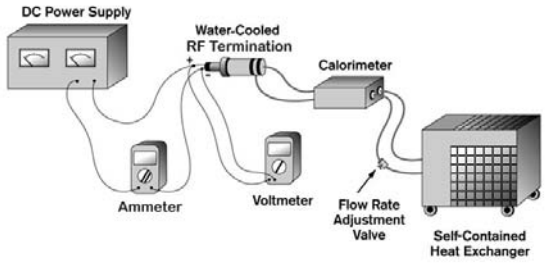

Figure 1
Calorimeter Calibration Configuration

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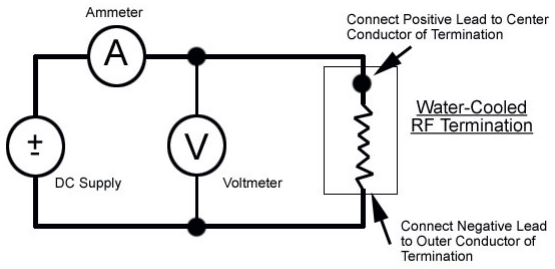

Figure 2
Calorimeter Calibration Connection Diagram

9.3.1 Use a calorimeter equipped with a coolant system.

NOTE 5: Most calorimeter systems use either a tap-water coolant system or a recirculating system of some type. Best results may be obtained through the use of a self-contained heat exchanger and coolant recirculating system.

9.3.2 Make all of the electrical and coolant connections to the calorimeter.

9.3.3 Apply main power to the calorimeter system and allow one hour for stabilization.

9.3.4 *Load Differential Temperature* — Most calorimeter systems will yield optimum performance when certain operating parameters relating to the differential temperature across the RF load and the flow rate are maintained. In most cases, a differential temperature of 2°C represents a good beginning point. The coolant flow rate may then be set to provide for this differential temperature.

9.3.4.1 The following formula may be used to arrive at the correct coolant flow rate.

$$Power = 69.32 \times \Delta T \times Flow\ Rate \quad (1)$$

where:
Power is in W,
ΔT is in °C, and
Flow Rate is in L/min.

9.3.4.2 Solving for flow rate yields:

$$Flow\ Rate = (Power / 69.32) / \Delta T \quad (2)$$

9.3.5 *Coolant Types* — In most cases, the coolant used in calorimetric power measurement systems is pure distilled water. In this case, most modern calorimeters will automatically correct for changes to the coolant physical characteristics (e.g., specific heat, specific gravity) as the coolant temperature changes.

9.3.5.1 If coolant other than pure water is used and the calorimeter chosen will not automatically compensate for changes to the coolant, adjust the power readings obtained for the effects of the coolant changes. Consult the calorimeter operating manual for specific details.

9.3.6 *Calorimeter Calibration* — Following the calorimeter warm-up, the device is ready for calibration.

9.3.6.1 With the calorimeter operating at the appropriate flow rate, apply DC power to the RF load, according to the voltage and current readings obtained with the two digital multimeters.

9.3.6.2 Multiply the voltage reading by the current reading to obtain the power applied to the load.

9.3.6.3 Allow 15 minutes for the calorimeter reading to stabilize.

9.3.6.4 Using the procedure in the calorimeter operating manual, set the calorimeter such that the calorimeter reading is exactly the same as that obtained using the voltage and current meters.

9.3.6.5 At this point, add any offsets that are associated with interconnecting cable losses, as outlined in Sections 6.5.2 and 6.5.3.

9.3.6.6 The calorimeter is now calibrated at this specific power level.

NOTE 6: If a new power level is selected, repeat this process in order to compensate for instrumentation linearity effects of the calorimeter.

9.3.7 *RF Generator Testing* — With the calorimeter calibrated at a particular power level, it is now possible to test the RF generator power output at this level.

9.3.8 *Connections* — Connect the RF generator output to the RF load according to Figure 3. Use cables and connectors between the RF generator output and the RF load of a high-quality, low-loss type. As outlined above, some power will be lost in the cables between the generator and the load. Add these losses as offsets to the calorimeter reading, in order to obtain the total power output of the generator. Base the losses upon cable length, cable type, and operating frequency. See SEMI E114 test method for details on cable loss compensation.

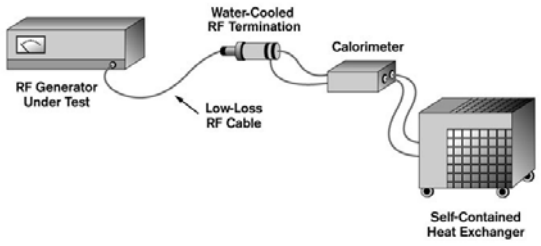

Figure 3
RF Generator Output Power Test

9.3.9 *Testing* — With the connections made according to Figure 2, apply main power to the RF generator and allow 15 minutes for stabilization. The power reading obtained on the calorimeter will represent the total power output of the RF generator, including harmonics.

9.3.9.1 Begin RF generator testing at a power level that represents 10% of the maximum output power of the RF generator.

9.3.9.2 Repeat the test at RF generator power levels of 40% of maximum, 70% of maximum, and maximum power.

9.3.9.3 Also, conduct tests corresponding to each range on the RF generator power output meter.

NOTE 7: Calibrate the calorimeter power meter to the DC standard at each power level used.

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SEMI E137-1104
GUIDE FOR FINAL ASSEMBLY, PACKAGING, TRANSPORTATION, UNPACKING, AND RELOCATION OF SEMICONDUCTOR MANUFACTURING EQUIPMENT

This guide 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.

NOTICE: This standard replaces SEMI E49.1, which has been removed from publication as of the November 2004 (1104) publication cycle.

1 Purpose

1.1 The objective of this document is to establish standard guidelines for activities specific to the final assembly, packaging, transportation, unpacking, and relocation of semiconductor manufacturing equipment (SME) to the cleanroom manufacturing area.

2 Scope

2.1 This standard has been developed as a guide for final assembly through relocation of SME, separate subassemblies, and components from the customer's loading dock/receiving area to their cleanroom manufacturing area for both high and ultrahigh purity applications.

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 Specific guidance associated with environment, health, and safety (EHS) concerns are not in the scope of this document.

NOTE 1: The SEMI EHS Technical Committee is working on a new related safety guideline document that provides EHS considerations for SME preparation, packaging, shipping, and handling including the handling of shipping and packaging materials.

3.2 Process specifications related to wafer particles and/or quality (e.g., ionic contamination) are not in the scope of this document. Parameters, such as particles per wafer pass (PWP), should be in the customer's specific equipment process performance specification.

4 Referenced Standards

4.1 *SEMI Standards*

SEMI C41 — Specifications and Guidelines for 2-Propanol

SEMI F63 — Guidelines for Ultrapure Water Used in Semiconductor Processing

4.2 *ISO Standard*[1]

ISO 14644-1 — Cleanrooms and Associated Controlled Environments, Part 1: Classification of Air Cleanliness

4.3 *APA − The Engineered Wood Association*[2]

NOTE 2: The APA − Engineered Wood Association was formerly known as the American Plywood Association.

PS 1 — Voluntary Product Standard for Construction and Industrial Plywood

4.4 *USA Department of Defense (DOD)*[3]

MIL-D-3464 — Military Specification – Desiccants, Activated, Bagged, Packaging Use and Static Dehumidification

MIL-PRF-131 — Performance Specification – Barrier Materials, Watervaporproof, Greaseproof, Flexible, Heat-sealable

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

2 APA-The Engineered Wood Association, 7011 So. 19th, Tacoma, WA 98466, (253) 565-6600, Fax: (253) 565-7265 Website: http://www.apawood.org

3 United States of America (USA) Department of Defense (DOD) ASSIST Quick-Search, Website:

http://www.dodssp.daps.mil/products.htm

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4.5 *Western Wood Products Association (WWPA)*[4]

Western Lumber Grading Rules (WLGR)

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

5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 DOD — Department of Defense

5.1.2 EPS — Expanded Polystyrene

5.1.3 IPA — Isopropyl Alcohol (2-propanol)

5.1.4 ISO — International Organization for Standardization

5.1.5 PO — Purchase Order

5.1.6 PWP — Particles Per Wafer Pass

5.1.7 SEMI — Semiconductor Equipment and Materials International

5.1.8 SME — Semiconductor Manufacturing Equipment

5.1.9 UPW — Ultrapure Water

5.1.10 USA — United States of America

5.1.11 WLGR — Western Lumber Grading Rules

5.1.12 WWPA — Western Wood Products Association

6 Cleaning and Wrapping Materials

6.1 For cleaning and triple wrap packaging, the following materials are recommended:

6.1.1 UPW (reference SEMI F63)

6.1.2 IPA (reference SEMI C41)

6.1.3 Ultralow particle generation, ultralow extractable ion level, polyester, ISO ST 14644-1 (subsequently called ISO) Class 5 cleanroom-compatible swabs and wipes with sealed edges

6.1.4 Ultralow particle generation, hydrocarbon-free, ultralow extractable ion level, ~150 μm (0.006 in.) thick, natural polyethylene film

6.1.5 Ultralow particle generation adhesive tape

4 Western Wood Products Association (WWPA), 522 SW Fifth Ave. Suite 500, Portland, Oregon 97204-2122, Tel: 503-224-3930, Fax: 503-224-3934, Website: http://www.wwpa.org

7 Assembly and Pre-Packaging Procedures

7.1 *Pre-Assembly*

7.1.1 Machining, sawing, welding, brazing, grinding, sanding, and other manufacturing operations incompatible with cleanrooms should be completed before components are brought into the clean assembly area.

7.1.2 All SME components should be vacuumed, blown off with filtered air, and cleaned with a solution of 10 to 70% IPA diluted in UPW using wipes and swabs immediately prior to being brought into the clean assembly area.

7.1.3 Cutting oils, lubricants, and solder flux should be removed before components are brought into the clean assembly area.

7.2 *Clean Assembly Area*

7.2.1 All components of the SME should be assembled in at least an ISO Class 6 or better (ISO Class 5 preferred) cleanroom.

7.2.2 A set of clean assembly tools should be maintained in the clean assembly area.

7.2.2.1 If this is not possible, tools should be vacuumed, blown off with filtered air, and cleaned with a solution of 10 to 70% IPA diluted in UPW using wipes and swabs immediately prior to each time they reenter the clean assembly area.

7.2.2.2 The assembly tools in the clean assembly area should be cleaned periodically and as needed if they become contaminated during usage.

7.3 *Pre-Packaging*

7.3.1 All SME with water (including UPW) or other liquids should be fully emptied and completely dried using dry, hydrocarbon-free air or nitrogen.

7.3.1.1 All SME with UPW that comes in direct contact with the production units (e.g., wafers) should have lines, baths, tanks, etc. flushed with a bacteria retardant (e.g., H_2O_2 solution, iodine/UPW solution) before emptying them fully.

7.3.2 All utility lines should be capped before and during shipment.

7.3.3 The SME with vacuum chambers should have these chambers and vacuum lines sealed and shipped under vacuum.

7.3.4 The SME should be clearly marked showing correct lifting points for removal from shipping container.

7.3.5 Following final assembly and test, all exposed surfaces should be thoroughly cleaned with a solution of 10 to 70% IPA diluted in UPW using wipes and swabs.

7.3.6 The SME should be inspected thoroughly for cleanliness.

7.3.6.1 The supplier should provide a copy of their inspection results (e.g., marked checklist) with the SME.

8 Triple Wrap Strategy

8.1 The following procedures support the strategy of totally enclosing and sealing the SME, separate subassemblies, or support components in three layers of protective wrapping (see Section 9) so that each layer forms a protective seal against moisture and particles.

8.2 Each individual wrap layer is intended to be removed at a specific stage of delivery and relocation (see Section 16) adhering to the following guidelines.

8.2.1 *Inner Wrap* — This inner wrap should stay with the SME, separate subassemblies, and components all the way into the final cleanroom or a staging area of the same cleanliness level for wipe down. The wrap should be cleaned prior to movement into the cleanroom.

8.2.2 *Middle Wrap* — This middle wrap should stay with the SME, separate subassemblies, and components until they reach at least an ISO Class 7 intermediate staging area. The wrap should be cleaned before leaving the customer's loading dock/receiving area and again before it is removed in the staging area.

8.2.3 *Outer Wrap* — This wrap is used to protect the SME, separate subassemblies, and components while in transit to the loading dock. While the SME, separate subassemblies, and components are on the customer's loading dock/receiving area, the outer shipping materials should be removed. The wrap should also be cleaned and removed.

9 Packaging Procedures

9.1 *Packaging in Clean Assembly Area* — The SME, separate subassemblies, and components should then be totally enclosed in a clean polyethylene inner wrap using tape as required.

9.1.1 A humidity indicator should be included inside of the initial wrapping layer.

9.1.2 If two sets of pallets are used, the inner pallet should also meet the requirements of Section 10.2 and should be enclosed with the SME, separate subassemblies, and components.

9.1.2.1 The inner pallet should be clearly marked showing correct lifting points for removal from shipping container.

9.2 *Packaging in Dedicated Clean Packaging Area* — After the inner (i.e., first) wrap is applied, the SME, separate subassemblies, and components should be relocated to a dedicated clean (ISO Class 7 or better) packaging area.

9.2.1 SME, separate subassemblies, and components should then be totally enclosed in two more independent layers (i.e., middle and outer wraps) of clean polyethylene film using tape as required.

9.2.2 After the SME, separate subassemblies, and components are triple wrapped, they should be placed on a pallet (see Sections 10 and 11) so that the triple wrapping is not damaged or violated.

9.2.2.1 The pallet should be movable (with SME, separate subassemblies, and components attached to it) with a conventional pallet jack or forklift.

9.2.2.2 The SME, separate subassemblies, and components should be capable of placement on and removal from the pallet with a conventional pallet jack or fork lift without compromising or tearing any of the triple wrapping.

9.3 After placement on the pallet, the SME, separate subassemblies, and components should be relocated to a separate crating area.

10 Crating Procedures

10.1 *Design*

10.1.1 The maximum outside crating dimensions should be sized not to exceed the maximum size requirements for method(s) of shipment (e.g., airfreight, air-ride trailers).

10.1.1.1 Crating shape and dimensions should be optimized to obtain transportation cost savings, when possible.

10.1.2 To ensure crate stability in transit, any crate over 1.2 m (48 in.) tall should be constructed so that the narrowest other dimension is no less than half the crate's height.

10.2 *Crating/Packaging Materials*

10.2.1 All wood products used should meet the regulatory requirements (e.g., heat treated wood regulations) of the country of delivery and any interim countries that the SME may be transported through.

10.2.2 Spruce, fir, or pine, Standard grade or better based on WWPA WLGR, or equivalent-strength softwoods available to the crating location should be used.

10.2.3 Plywood should be ≥3 ply for 1.0 to <1.3 cm (0.375 to <0.5 in.) in thickness and ≥5 ply for ≥1.3 cm (0.5 in.) in thickness.

10.2.4 Plywood grades should be C-D Exterior, C-D Plugged, or Sanded Shop-Cutting Panel ("Sanded Shop") with exterior glue based on APA − The Engineered Wood Association PS 1.

10.2.4.1 Floating decks may be "Underlayment" quality, when appropriate.

10.2.5 For SME, separate subassemblies, and components weighing ≤2500 kg (5,500 lb), the following materials should be used:

- ≥1 cm (0.375 in.) nominal thickness plywood for sides and covers,
- 2.5 × 10 cm (1 × 4 in.) nominal thickness wood for cleats,
- 1.3 cm (0.5 in.) nominal thickness plywood for decking, and
- 5 cm (2 in.) nominal thickness wood slabs for crate base.

10.2.6 For SME, separate subassemblies, and components weighing >2500 kg (5,500 lb), the following materials should be used:

- ≥1.3 cm (0.5 in.) nominal thickness plywood for sides and covers,
- 5 × 10 cm (2 × 4 in.) nominal thickness wood for cleats,
- 2.5 cm (1 in.) nominal thickness plywood for decking, and
- 5 cm (2 in.) nominal thickness wood slabs for crate base.

10.2.7 The following types and densities of cushion foam should be used, as required:

- Polyurethane foam 19 to 35 kg/m^3 (1.2 to 2.2 lb/ft^3)
- Polyethylene foam 16 to 32 kg/m^3 (1.0 to 2.0 lb/ft^3)
- Polyethylene foam 32 to 64 kg/m^3 (2.0 to 4.0 lb/ft^3)
- Polyethylene foam 64 to 96 kg/m^3 (4.0 to 6.0 lb/ft^3)

10.2.7.1 Faying (i.e., joining) surfaces of polyethylene cushion foam used for floating decks should be skived (i.e., skin removed) to ensure proper bonding.

10.2.8 Barrier bag material should comply with U.S. MIL-PRF-131 Class 2.

10.2.9 Desiccant (i.e., drying agent) should be nondusting type, clay or silica gel (e.g., U.S. MIL-D-3464, Type II, or commercial equivalent).

10.2.10 The following types of cushion wrapping materials should be used, as required:

- Polyethylene foam sheeting, 3 to 6 mm (0.125 to 0.25 in.) nominal thickness
- Polyethylene bubble pack cushioning

10.2.10.1 Loose-fill expanded polystyrene (EPS) or paper products should not be used.

10.2.11 When required due to shipment method (e.g., ocean), case line paper should be waterproof paper laminate (e.g., asphalt or blond laminate) with a 4.9/8.1/4.9 kg/100 m^2 (30/50/30 lb/3000 ft^2) minimum basis weight or equivalent.

10.2.12 Strapping material used should be commercial grade and type determined by SME weight and type.

10.2.13 Tilt indicators used should be low profile, disposable, and nonresettable.

10.2.14 Shock indicators used should be low profile, disposable, and nonresettable.

10.2.14.1 The specific shock indicators used should have an appropriate sensitivity based on the calculations and recommended ratings of the shock indicator supplier for the type of crating and SME sensitivity.

10.2.14.2 Nondisposable (i.e., reusable), battery-operated, shock-measurement recording equipment may be used for SME more sensitive to handling, as required.

10.3 High-temperature and/or low-temperature indicators used should be disposable and nonresettable.

10.3.1.1 The specific temperature indicator(s) used should have an appropriate activation point based on the sensitivity of the SME to temperatures potentially encountered during shipment or storage.

10.3.1.2 Nondisposable (i.e., reusable), battery-operated, temperature-measurement recording equipment may be used for SME more sensitive to temperature, as required.

10.4 *Workmanship*

10.4.1 Crates should be free of cracked, damaged, or broken fasteners.

10.4.2 Nails should not be bent or driven to cause the wood to split.

10.4.3 Crates should not have exposed nails.

10.4.4 Crates should not have broken or split runners or skids.

10.4.5 Plywood should be cut square and to fit so that no edge of the plywood extends >1.6 mm (0.0625 in.) over or under the panel size, as determined by the cleat assembly.

10.4.6 The thickness of adjacent boards in a panel should match within a maximum tolerance of 1.6 mm (0.0625 in.).

11 Packing and Securing Procedures

11.1 All units of the SME should be adequately blocked and braced by foam or wood, if necessary to prevent shifting or movement during handling and transportation.

11.1.1 SME mainframes and some miscellaneous components may require special brackets for bracing.

11.2 All heavier items should be placed on the bottom of the crate with lighter and/or more fragile items placed near the top of the crate.

11.3 Crates should not be over packed.

11.4 All main SME components should be secured on a floating base with foam material of sufficient density to support the weight either in the deck or in the skid.

11.4.1 For SME that is deemed of lower-value and/or as less-sensitive to handling, a nonfloating base may be used. However, all other material requirements should remain the same.

11.5 The foot or base of the SME should be bolted against the crate's base, if possible.

11.6 For land and/or air shipment, the SME should be

- Wrapped with bubble pack,
- Wrapped with polyethylene stretch wrap, and
- Placed in a barrier bag.

11.7 For ocean shipment, the SME should be

- Wrapped with bubble pack,
- Wrapped with polyethylene stretch wrap,
- Placed in a barrier bag with activated desiccant distributed as evenly as possible between barrier bag and stretch wrap at the rate of 1 g/L (1 oz/ft^3) with the SME volume deducted from the air volume when calculating required amount of desiccant, up to a maximum of 9.1 kg (320 oz), and
- Vacuum sealed in the barrier bag in ≤5 minutes to minimize exposure of the desiccant to open air.

11.8 Feet or levelers from any frame or SME component should not be removed.

11.9 SME on casters (i.e., pivoting rollers) should be blocked up, keeping the casters clear of the crate, to prevent damage to casters and to keep them from wearing through the crate's base.

11.10 All support hardware or separate components (e.g., cables, spare parts) should be packaged in separate containers from the main unit.

12 Monitoring Device Installation Procedures

12.1 Shock indicators should be mounted on both one end and one side on the outside of the crate at a top corner.

12.1.1 Shock indicators should be glued to the crate and coated with lacquer so they cannot be peeled off or knocked off.

12.2 Additional disposable shock indicators should be mounted on both one end and one side inside of the crate at a top corner on the floating base, barrier bag, packing material, or SME itself for SME more sensitive to handling, as required.

12.2.1 If shock indicators are mounted inside of the crate, their locations should be marked on the outside of the crate.

12.2.2 Nondisposable shock-measurement recording equipment may be substituted.

12.3 Tilt indicators should be mounted on both the inside and the outside of the crate.

12.3.1 Tilt indicators on the outside should be glued to the crate and coated with lacquer so they cannot be peeled off or knocked off.

12.4 Disposable high-temperature and/or low-temperature indicators should be placed inside the crate for SME components sensitive to temperatures potentially encountered during shipment or storage.

12.4.1 Nondisposable temperature-measurement recording equipment may be substituted.

13 Marking and Labeling Procedures

13.1 The following markings should be applied to the crate using vinyl labels or by stencil:

- Delicate Instruments
- Do Not Drop
- Tilt Indicator Information
- Shock Indicator Information
- Temperature Indicator Information

- Fragile
- Keep Dry
- Any other markings as applicable (e.g., Center of Balance, Do Not Stack, Keep Upright, Do Not Freeze)

13.2 The following text should be applied by stencil with lettering height of ≥1.3 cm (0.5 in.):

- To/From information
- PO number
- Customer's SME identification number, if provided
- Box ___ of ___
- Tare weights
- Dimensions

13.3 No markings should appear on the crate other than information pertinent to the current shipment.

14 Packing List Procedures

14.1 The packing list should be affixed to exterior of the crate in a weatherproof holder.

14.2 The packing list should specify what component(s) of the SME each crate and container holds.

15 Transportation Procedures

15.1 For shipment over land, the SME should be transported in vehicles with air-ride suspension for all support axles (e.g., with air-ride trailers).

15.2 The trailer should have no holes to the exterior in the floor, walls, or roof.

15.3 Shipping containers should be secured using bars and/or straps connected to the trailer.

15.4 If a shipping container is neither a wooden crate nor a cardboard box (e.g., bubble pack), then transportation provider should supply and wrap the shipping container in clean protective covers and/or pads.

15.4.1 The transportation provider, supplier, and customer should keep the protective covers and/or pads on the shipping containers during all phases of loading, shipment, and unloading.

15.5 Shipping containers should not be stacked (i.e., top loaded).

16 Unloading, Unpacking, and Relocation Procedures

16.1 The supplier should provide their requirements to the customer for correctly unloading the SME from the vehicle, unpacking it, and relocating it from the loading dock/receiving area to its final location in the cleanroom.

16.2 The supplier should work with the customer and the movers to review and agree on their SME relocation plan.

16.3 The crating and the monitors should be inspected for any damage or indications of mishandling and conditions recorded.

16.4 The outer shipping materials (e.g., crates, bubble pack) should be carefully removed on the loading dock/receiving area to prevent damage to the triple wrapping.

16.5 The outer wrap should be cleaned and removed on the loading dock/receiving area.

16.6 The middle wrap should be cleaned before the SME, separate subassemblies, or support components leave the loading dock/receiving area.

16.7 The SME, separate subassemblies, or support components should be relocated to the at least ISO Class 7 intermediate staging area.

16.8 The middle wrap should be cleaned again before it is removed in the intermediate staging area.

16.9 The middle wrap should be carefully removed in the intermediate staging area.

16.10 The inner wrap should be cleaned before the SME, separate subassemblies, or support components leave the intermediate staging area.

16.11 The SME, separate subassemblies, or support components should be relocated to the final cleanroom or a final staging area of the same cleanliness level as the cleanroom.

16.12 The inner wrap should be cleaned again before it is removed in the final cleanroom or a final staging area of the same cleanliness level as the cleanroom.

16.13 The inner wrap should be carefully removed in the final cleanroom or a final staging area of the same cleanliness level as the cleanroom.

16.14 The humidity indicator should be inspected and the reading recorded.

16.15 If the inner wrap is removed in a final staging area, the SME, separate subassemblies, or support components should be relocated into the final cleanroom location for installation.

17 Inspection Procedures

17.1 The customer should inspect external surfaces of the SME, separate subassemblies, and/or support components for cleanliness after removal of the inner wrapping.

17.1.1 If the SME, separate subassemblies, or support components fail the cleanliness inspection, supplier should reclean the failed areas and pass a cleanliness reinspection prior to start of installation.

17.2 The customer should provide the supplier with a completed copy of their cleanliness inspection results.

18 Related Documents

Lin, Steve and Graves, Sarah, "Comparing The Molecular Contamination Contribution Of Clean Packaging Films," Micro, October, 1998. p. 95. http://www.micromagazine.com/archive/98/10/graves.html

Nappi, John J. Jr., "A Guide to Ultra Clean Film Packaging," Cleanroom News, Vol. 7, No. 1, August 2003. http://www.liberty-ind.com/newsletter_0503.htm

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SEMI E140-0305
GUIDE TO CALCULATE COST OF OWNERSHIP (COO) METRICS FOR GAS DELIVERY SYSTEMS

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.

1 Purpose

1.1 The purpose of this guide is to provide standard cost of ownership (COO) metrics for evaluating unit production cost effectiveness of gas delivery systems in the semiconductor industry.

1.2 This guide also illustrates how to apply the COO metrics to gas delivery systems. Users should be able to calculate the COO for any piece of gas delivery equipment using this guide.

NOTE 1: A spreadsheet (Microsoft® Excel) has been provided as an illustrative example.

1.3 The 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 COO calculator.

2 Scope

2.1 This guide defines a COO metric that can be applied to any gas delivery system. Some terms are specialized to integrated circuit wafer and device production, but may be adapted for other applications.

NOTICE: This guide does not purport to address safety issues, if any, 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.

3 Limitations

3.1 Effective building of a COO model requires identification of constraints and data values. Example data is provided in this document and may be updated periodically. Where possible, use direct values for inputs rather than deriving them from secondary models or using example values.

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

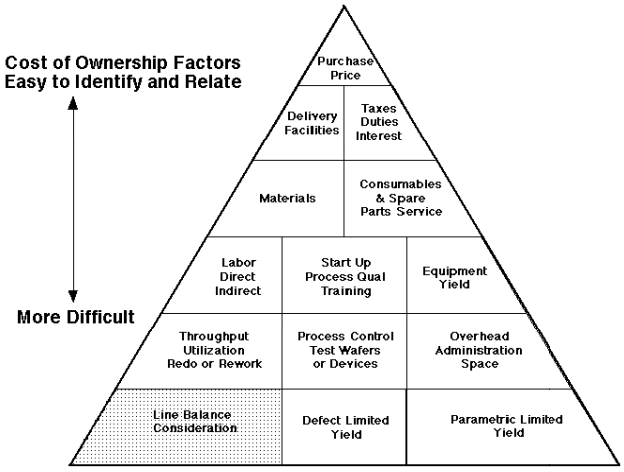

Figure 1
Relationship of Cost Factors to Difficulty of Collection and Validation

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.

4 Referenced Standards

4.1 *SEMI Standards*

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

SEMI E35 — Guide to Calculate Cost Of Ownership (COO) Metrics for Semiconductor Manufacturing Equipment

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

5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 *COO* — Cost of ownership

5.1.2 *CYL* — Cost of yield loss

5.1.3 *DLY* — Defect limited yield

5.1.4 *ER* — Equipment required (integer number)

5.1.5 *EY* — Equipment yield

5.1.6 *PLY* — Parametric limited yield

5.1.7 *PRY*— Product yield

5.1.8 *PU* — Production utilization (total)

5.1.9 *TP* — Throughput

5.2 Definitions

5.2.1 *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].

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

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

5.2.4 *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.

5.2.5 *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:

$$A = \left[Wt + 1/2\left(Ws - We\right)\right] \times \left[De + 1/2\left(Ds - De\right)\right] \quad (1)$$

$$= 1/4\left(We + Ws\right) \times \left(De + Ds\right)$$

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

5.2.6 *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.

5.2.7 *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 accumulated cost of manufacturing before the unit is lost. Therefore, CYL should be tracked as a separate cost for factory optimization.

5.2.8 *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.

5.2.9 *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.

5.2.10 *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.

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

5.2.12 *equipment throughput* — see throughput.

5.2.13 *equipment yield (EY)* — the percentage of units received by the piece of 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.

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

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

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

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

5.2.16 *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.

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

5.2.18 *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).

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

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

5.2.20 *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.

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

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

5.2.23 *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.

5.2.24 *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).

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

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

5.2.27 *test unit* — see monitor unit.

5.2.28 *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 nonproduct units is accounted for directly.

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

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

5.2.31 *yield* — see product yield.

6 Description of COO Model

6.1 *COO Model Calculation* — The formula for calculating COO is given in Equation 2.

$$COO = (F\$ + R\$ + Y\$) / (L \times TP \times PRY \times OU) \quad (2)$$

where

F$ = annualized fixed costs, $

R$ = annualized recurring costs, $

Y$ = annualized yield costs (CYL), $

L = lifetime of piece of equipment, yrs

TP = throughput, units/yr

PRY = product yield, dimensionless

OU = operational uptime, dimensionless

6.1.1 F$ is calculated by summing the fixed cost categories F_{ij} in Table 1 in SEMI E35.

6.1.2 R$ is calculated by summing the recurring cost categories R_{ij} in Table 2 in SEMI E35.

6.1.3 Y$ is calculated by summing the recurring scrap cost categories in Table 3 in SEMI E35.

6.1.4 The parameters L and TP are input directly into the model.

6.1.5 The model calculates PRY from user inputs on numbers of wafers lost due to EY, DLY, and PLY.

6.1.6 The model calculates OU from inputs for scheduled and unscheduled maintenance (including assists), standby time, qualification time, engineering time, and the scheduled production hours.

6.1.6.1 While the cost terms used specific currency units of dollars as an example, any currency may be used as long as it is applied consistently throughout the model.

RELATED INFORMATION 1
COST OF OWNERSHIP

NOTICE: This related information is not an official part of SEMI E140 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 Sample Input to Model

R1-1.1 To effectively illustrate use of the COO model, it was run with a hypothetical set of input data. This input data is listed in Table 1. When studying this example, the user should remember that parameter values are for the gas delivery system only, not the entire process piece of equipment.

R1-2 Sample Model Output

R1-2.1 The model calculates each term in the numerator of Equation 2 and then sums these results and divides by the denominator to get COO. To enhance the user's understanding of the components of COO, Tables 2, 3, 4, and 5 and the spreadsheet show interim results. For the set of inputs listed in Table 1, F$ are shown in Table 2, R$ are shown in Table 3, and Y$ are shown in Table 4. Each of these terms is calculated from the cost factors listed in SEMI E35. The italicized rows in Tables 2, 3, and 4 correspond to these cost factors and show the subtotal for that cost factor. The breakdown for each cost factor is shown in the rows below it.

R1-2.2 Tables 2, 3, and 4 show costs for years 1 through 7. The last year is based on user input. It is the longest of useful life or depreciable life. In the example shown, depreciable life was set to 7 years and useful life was set to 5 years. The depreciable life was deliberately made longer than the useful life to illustrate the feature of the spreadsheet that allows these two parameter values to differ. This often occurs in practice since a piece of equipment is sometimes "obsoleted" before it is fully depreciated. The user can enter any value up to 10 for these two parameters.

R1-2.3 Table 5 shows the COO results.

Table 1 Input Data for COO Model

Row [#1]	*Parameter*	*Units*	*Example Value*
TA8	*This Section Contains Equipment Procurement Cost Data*		
TA10	**Equipment Cost Data**		
TA11	For Straight Line Depreciation, input SLN. For Fixed Declining Balance Depreciation, input DB. For Double Declining Balance Depreciation, input DDB.	not applicable	SLN
TA12	Floor Space Rental Rate	$/m^2/yr	2691
TA13	Gas Box (or Stick or Component) Purchase Price	$	100,000
TA14	Gas Box (or Stick or Component) Depreciable Life (Must be 10 or Less)	yrs	7
TA15	Gas Box (or Stick or Component) Scrap Value	$	1,000
TA16	Gas Box (or Stick or Component) Useful Life (Must be 10 or Less)	yrs	5
TA17	Cost Foot Print or Floor Space Required for Gas Box (or Stick or Component)	m^2	0.23
TA18	Support Equipment Purchase Price	$	5,000
TA19	Support Equipment Depreciable Life (must be same as Gas Box Depreciable Life for purposes of COO)	yrs	7
TA20	Support Equipment Scrap Value	$	100
TA21	Support Equipment Useful Life (must be same as Gas Box Useful Life for purposes of COO)	yrs	5
TA22	Floor Space Required for Piece of Support Equipment	m^2	0.093
TA23	*This Section Contains Data Specific to the Process Equipment and Costs Specific to a Particular Fab*		
TA25	**Equipment-Specific Data**		
TA26	Equipment Throughput	wafers/hr	33

Row [#1]	*Parameter*	*Units*	*Example Value*
TA27	**Fab-Specific Data**		
TA28	Value of Wafer Entering Piece of Equipment	$/wafer	1,422
TA29	Value of Wafer Exiting Piece of Equipment	$/wafer	2,244
TA30	Cost of Test Wafer	$/wafer	500
TA31	Scheduled Production Hours per Year	hrs/yr	8,400
TA32	Inflation Rate	%	3
TA33	Burdened Equipment Engineering Salary	$/yr	111,000
TA34	Burdened Process Engineering Salary	$/yr	111,000
TA35	Burdened Supervision Salary	$/yr	111,000
TA36	Burdened Operator Rate	$/hr	25.00
TA37	Burdened Maintenance Technician Rate	$/hr	35.00
TA38	OEM Field Service Rate Billed to Fab	$/hr	175.00
TA39	OEM Field Process Rate Billed to Fab	$/hr	45.00
TA40	Electricity Charge	$/kWh	0.10
TA41	DI Water Charge	$/$m^3$	1.00
TA42	Chilled Water Charge	$/$m^3$	1.00
TA43	Purge Gas Charge	$/$m^3$	1.00
TA44	Waste/Exhaust Charge	$/$m^3$	1.00
TA45	This Section Contains Data Related to Equipment Installation		
TA47	**Initial Training Data (One-Time Training at Installation. On-Going Training is Accounted for under Maintenance.)**		
TA48	Time Required for Training	hrs/person	8.0
TA49	Hourly Rate Paid for Training	$/hr	200.00
TA50	Number of Equipment Engineers Trained	person	2.0
TA51	Number of Process Engineers Trained	person	2.0
TA52	Number of Supervisors Trained	person	2.0
TA53	Number of Operators Trained	person	6.0
TA54	Number of Maintenance Technicians Trained	person	6.0
TA55	Materials Consumed for Training	$	2,000
TA56	**Installation Data**		
TA57	Fab Costs Incurred to Move/Rearrange A Piece of Equipment to Accommodate Gas Box	$	30,000
TA58	Equipment Engineering Time Required for System Installation	hrs	200
TA59	Process Engineering Time Required for System Installation	hrs	2.0
TA60	Supervision Time Required for System Installation	hrs	2.0
TA61	Operator Time Required for System Installation	hrs	2.0
TA62	Maintenance Technician Time Required for System Installation	hrs	6.0
TA63	OEM Field Service Time Required for System Installation	hrs	6.0
TA64	OEM Field Process Time Required for System Installation	hrs	6.0
TA65	**Qualification Data**		
TA66	Equipment Engineering Time Required for System Prove-In	hrs	40.0
TA67	Process Engineering Time Required for System Prove-In	hrs	40.0
TA68	Supervision Time Required for System Prove-In	hrs	2.0
TA69	Operator Time Required for System Prove-In	hrs	2.0
TA70	Maintenance Technician Time Required for System Prove-In	hrs	2.0
TA71	OEM Field Service Time Required for System Prove-In	hrs	6.0
TA72	OEM Field Process Time Required for System Prove-In	hrs	6.0
TA73	Materials Consumed for System Prove-In	$	2,000

Row [#1]	*Parameter*	*Units*	*Example Value*
TA74	*This Section Contains Data for Routine Operation of the Piece of Equipment*		
TA76	**Materials Used During Operation of the Piece of Equipment**		
TA77	Unit Volume of Purge Gas Consumed	m^3/wafer	1.00×10^{-4}
TA78	Unit Volume of Waste Generated	m^3/wafer	2.00×10^{-4}
TA79	Test/Filler Wafers	number/wafer	1.00×10^{-6}
TA80	Electricity Consumed on an Ongoing Basis	kWh/wafer	0.067
TA81	DI Water Consumed on an Ongoing Basis	$/$m^3$	0.00
TA82	Chilled Water Consumed on an Ongoing Basis	$/$m^3$	0.00
TA83	**Consumables (Parts that are Worn Out During Normal Operation and Require Replacement after Less than One Year of Operation)**		
TA84	Consumable Purchase Price	$	1,200
TA85	Consumable Life	yrs	1.0
TA86	**Labor Required to Operate the Piece of Equipment**		
TA87	Operator	hrs/wafer	0.0033
TA88	**Labor Required to Support the Piece of Equipment**		
TA89	Equipment Engineering	hrs/wafer	0.0
TA90	Process Engineering	hrs/wafer	0.0
TA91	Supervision	hrs/wafer	0.0
TA92	Maintenance Technician	hrs/wafer	0.0
TA93	OEM Field Service	hrs/wafer	0.0
TA94	OEM Field Process	hrs/wafer	0.0
TA95	**Support Services**		
TA96	Annual ESH Charge	$/yr	500.00
TA97	Other Annual Charge	$/yr	100.00
TA98	*This Section Contains Data Related to Reliability, Availability, and Maintainability (RAM)*		
TA100	**RAM Data**		
TA101	Scheduled Maintenance Downtime	hrs/week	0.0
TA102	Mean Time Between Failure	hrs	4,200
TA103	Average Response Time	hrs	0.3
TA104	Mean Time to Repair	hrs	7.0
TA105	Mean Time to Test	hrs	0.3
TA106	Mean Time to Restart Production	hrs	1.3
TA108	Standby Time (independent of process equipment standby time)	hrs/week	0.0
TA109	Process Engineering Time	hrs/week	2.0
TA110	**Non-Personnel Maintenance Costs**		
TA111	Service Contract	$/yr	0.00
TA112	Spares Inventory Cost to Fab	$/yr	3,800
TA113	Repair Parts	$/maintenance event	5.0
TA114	Electricity Consumed Solely during Maintenance	kWh/maintenance event	1,000
TA115	**On-Going Training**		
TA116	Frequency of Training	events/yr	1.0
TA117	Time Required for Training	hrs/person	8.0
TA118	Hourly Rate Paid for Training Per Student	$/hr	200.00
TA119	Number of Equipment Engineers Trained	person	2.0
TA120	Number of Process Engineers Trained	person	2.0
TA121	Number of Supervisors Trained	person	0.0
TA122	Number of Operators Trained	person	6.0
TA123	Number of Maintenance Technicians Trained	person	6.0

Row [#1]	*Parameter*	*Units*	*Example Value*
TA124	Materials Consumed for Training	$	2,000
TA125	**Labor per Maintenance Event**		
TA126	Equipment Engineering Time Required per Maintenance Event	hrs/maintenance event	8.0
TA127	Process Engineering Time Required per Maintenance Event	hrs/maintenance event	1.0
TA128	Supervision Time Required per Maintenance Event	hrs/maintenance event	1.0
TA129	Operator Time Required per Maintenance Event	hrs/maintenance event	0.5
TA130	Maintenance Technician Time Required per Maintenance Event	hrs/maintenance event	0.5
TA131	OEM Field Service Time	hrs/maintenance event	8.0
TA132	OEM Field Process Time	hrs/maintenance event	0.0
TA133	**Equipment Requalification Costs**		
TA134	Equipment Engineering Time Required per Maintenance Event	hrs/maintenance event	1.5
TA135	Process Engineering Time Required per Maintenance Event	hrs/maintenance event	0.0
TA136	Supervision Time Required per Maintenance Event	hrs/maintenance event	0.0
TA137	Operator Time Required per Maintenance Event	hrs/maintenance event	0.0
TA138	Maintenance Technician Time Required per Maintenance Event	hrs/maintenance event	1.5
TA139	OEM Field Service Time Required per Maintenance Event	hrs/maintenance event	1.5
TA140	OEM Field Process Time Required per Maintenance Event	hrs/maintenance event	0.0
TA141	Number of Test Wafers Consumed	wafers/maintenance event	1.0
TA142	Other Consumables Required to Requalify A Piece of Equipment	$/maintenance event	100.00
TA143	*This Section Contains Data Related to Yield*		
TA145	*NOTE: Yield Costs are Only Those Caused by Gas Box Problems, Not Other Problems on the Piece of Equipment.*		
TA146	**Composite Yield**		
TA147	Equipment Yield	dimensionless	1.00
TA148	Probe Yield	dimensionless	1.00
TA149	**Inputs for Annualized Yield Costs**		
TA150	Number of Wafers Lost to Equipment Yield	wafer	0.0
TA151	Number of Equivalent Wafers Lost to Defect Limited Yield	wafer	0.0
TA152	Number of Equivalent Wafers Lost to Parametric Limited Yield	wafer	0.0

[#1] Row numbers begin with 8 to align with the corresponding rows in the sample spreadsheet. The row numbering convention is the Table number (using a lettering scheme to simplify the formulae) followed by the row in that table.

Table 2 Annualized Fixed Costs for the Input Data Listed in Table 1.

Row [#1]		*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Formula*
TB7	***Depreciation , $*** [#2]	14,843	14,843	14,843	14,843	14,843	14,843	14,843	=Σ(TB9:TB16)
TB9	***Gas Box***								
TB10	*Straight Line, $*	14,143	14,143	14,143	14,143	14,143	14,143	14,143	
TB11	*Fixed Declining Balance, $*	-	-	-	-	-	-	-	
TB12	*Double Declining Balance, $*	-	-	-	-	-	-	-	
TB13	***Support Equipment***								
TB14	*Straight Line, $*	700	700	700	700	700	700	700	
TB15	*Fixed Declining Balance, $*	-	-	-	-	-	-	-	
TB16	*Double Declining Balance, $*	-	-	-	-	-	-	-	
TB17	***System Qualification***	7,816	0	0	0	0	0	0	=Σ(TB18:TB25)
TB18	*Cost to Equipment Engineering, $*	2,135							=TA66 × TA33/52/40

Row [#1]		*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Formula*
TB19	*Cost to Process Engineering, $*	2,135							=TA67 × TA34/52/40
TB20	*Cost to Supervision, $*	107							=TA68 × TA35/52/40
TB21	*Cost to Operations, $*	50							=TA69 × TA36
TB22	*Cost to Maintenance, $*	70							=TA70 × TA37
TB23	*Cost of OEM Field Service Billed to Fab In Addition to Purchase Price, $*	1,050							=TA71 × TA38
TB24	*Cost of OEM Field Process Billed to Fab in Addition to Purchase Price, $*	270							=TA72 × TA39
TB25	*Materials Consumed, $*	2,000							=TA73
TB26	***Installation***	12,467	0	0	0	0	0	0	=Σ(TB27:TB33)
TB27	*Cost to Equipment Engineering, $*	10,673							=TA58 × TA33/52/40
TB28	*Cost to Process Engineering, $*	107							=TA59 × TA34/52/40
TB29	*Cost to Supervision, $*	107							=TA60 × TA35/52/40
TB30	*Cost to Operations, $*	50							=TA61 × TA36
TB31	*Cost to Maintenance, $*	210							=TA62 × TA37
TB32	*Cost of OEM Field Service Billed to Fab In Addition to Purchase Price, $*	1,050							=TA63 × TA38
TB33	*Cost of OEM Field Process Billed to Fab in Addition to Purchase Price, $*	270							=TA64 × TA39
TB34	***Training, $***	30,800	0	0	0	0	0	0	=Σ(TB35:TB36)
TB35	*Training Time Billed by OEM, $*	28,800							=TA48 × TA49 × Σ(TA50:TA54)
TB36	*Materials Consumed, $*	2,000							=TA55
TB37	***Moves & Rearrangements, $***	30,000	0	0	0	0	0	0	=TB38
TB38	*Moves & Rearrangements, $*	30,000							=TA57
TB39	***Floor Space, $***	875	875	875	875	875	0	0	=Σ(TB40:TB41)
TB40	*Gas Box, $*	625	625	625	625	625	0	0	=IF(TA16>=1, TA17 × TA12,0)
TB41	*Support Equipment, $*	250	250	250	250	250	0	0	=IF(TA21>=1, TA22 × TA12,0)
TB43	***Total Fixed Costs, $***	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	

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Row [#1]		*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Formula*
TB44	***Annual, $***	96,800	15,718	15,718	15,718	15,718	14,843	14,843	For Year n, sum the corresponding year's value from these rows: TB7+TB17+TB26+TB34+TB37+ TB39
TB45	***Cumulative, $***	96,800	112,518	128,236	143,954	159,672	174,515	189,358	=Σ(Year 1 value + Year 2 value + … + Year n value)

[#1] Row numbers begin with 7 to align with the corresponding rows in the sample spreadsheet. The row numbering convention is the Table number (using a lettering scheme to simplify the formulae) followed by the row in that table.
[#2] Depreciation formulas may be found in standard accounting textbooks.

Table 3 Annualized Recurring Costs for the Input Data Listed in Table 1.

Row [#1]		*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Formula*
TC7	***Material, $***	*2,079*	*2,141*	*2,206*	*2,272*	*2,340*	*0*	*0*	=Σ(TC8:TC11)
TC8	Test/Filler Wafers, $	139	143	147	151	156	0	0	=TA79 × TA26 × TA31 × TA30
TC9	Utilities, $	1,857	1,913	1,970	2,029	2,090	0	0	=(TA80 × TA40+TA81 × TA41+TA82 × TA42) × TA26 × TA31
TC10	Supplies, $	28	29	29	30	31	0	0	=TA77 × TA43 × TA26 × TA31
TC11	Waste Disposal, $	55	57	59	61	62	0	0	=TA76 × TA26 × TA31 × TA44
TC12	***Consumables, $***	*960*	*989*	*1,018*	*1,049*	*1,080*	*0*	*0*	=TC13
TC13	**Consumables, $**	960	989	1,018	1,049	1,080	0	0	=IF(TA85<TA16,TA84/TA16 × ROUNDUP ((TA16-TA85)/TA85,0),0)
TC14	***Maintenance, $***	*37,527*	*38,653*	*39,813*	*41,007*	*42,237*	*0*	*0*	=Σ(TC15:TC19)
TC15	Labor, $	4,717	4,859	5,005	5,155	5,309	0	0	=TA31/TA102 × (((TA126+TA134) × TA33/52/40) + ((TA127+TA135) × TA34/52/40) + ((TA128+TA136) × TA35/52/40) + ((TA129+TA139) × TA36) + ((TA130+TA138) × TA37) + ((TA131+TA139) × TA38) + ((TA132+TA140) × TA39))
TC16	Spare Parts, $	3,800	3,914	4,031	4,152	4,277	0	0	=TA112

Row [#1]		*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Formula*
TC17	Repair Parts, $	1,410	1,452	1,496	1,541	1,587	0	0	=TA31/TA102 × (TA113+TA114 × TA40+TA141 × TA30+TA141)
TC18	Service Contract, $	0	0	0	0	0	0	0	=TA111
TC19	Training, $	27,600	28,428	29,281	30,159	31,064	0	0	=(TA117 × TA118 × Σ(TA119:TA123) + TA124) × TA116
TC20	***Labor, $***	*22,869*	*23,555*	*24,262*	*24,990*	*25,739*	*0*	*0*	=TC21
TC21	Operations, $	22,869	23,555	24,262	24,990	25,739	0	0	=TA87 × TA36 × TA26 × TA31
TC22	***Support Personnel, $***	*0*	*0*	*0*	*0*	*0*	*0*	*0*	=Σ(TC23:TC28)
TC23	Equipment Engineering, $	0	0	0	0	0	0	0	=TA89 × TA26 × TA33
TC24	Process Engineering, $	0	0	0	0	0	0	0	=TA90 × TA26 × TA34
TC25	Supervision, $	0	0	0	0	0	0	0	=TA89 × TA26 × TA35
TC26	Maintenance, $	0	0	0	0	0	0	0	=TA92 × TA37 × TA26 × TA31
TC27	OEM Field Service, $	0	0	0	0	0	0	0	=TA93 × TA38 × TA26 × TA31
TC28	OEM Field Process, $	0	0	0	0	0	0	0	=TA94 × TA39 × TA26 × TA31
TC29	***Scrap, $***	*0*	*0*	*0*	*0*	*0*	*0*	*0*	=0 (These are accounted for in Y$.)
TC31	***Support Services, $***	*600*	*618*	*637*	*656*	*675*	*0*	*0*	=Σ(TC32:TC33)
TC32	ESH, $	500	515	530	546	563	0	0	=TA96
TC33	Other, $	100	103	106	109	113	0	0	=TA97
TC35	***Total Recurring Costs, $***	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	
TC36	***Annual, $***	*64,035*	*65,956*	*67,935*	*69,973*	*72,072*	*0*	*0*	=IF(TA16>=1, Σ(TC7 + TC12 + TC14 + TC20 + TC22 + TC29 + TC31),0)
TC37	***Cumulative, $***	*64,035*	*129,992*	*197,927*	*267,900*	*339,973*	*339,973*	*339,973*	=Σ(Year 1 value + Year 2 value + … + Year n value)

[#1] Row numbers begin with 8 to align with the corresponding rows in the sample spreadsheet. The row numbering convention is the Table number (using a lettering scheme to simplify the formulae) followed by the row in that table.

Table 4 Annualized Yield Costs for the Input Data Listed in Table 1.

Row [#1]		*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Formula*
TD16	Equipment Yield, $	0	0	0	0	0	0	0	=TA150 × TA28
TD17	Defect Limited Yield, $	0	0	0	0	0	0	0	=TA151 × TA29
TD18	Parametric Limited Yield, $	0	0	0	0	0	0	0	=TA152 × TA29
TD20	Total Yield Costs, $	0	0	0	0	0	0	0	
TD21	Annual, $	0	0	0	0	0	0	0	=IF(TA16>=1, Σ(TD16:TD18),0)

Row [#1]		*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Formula*
TD22	Cumulative, $	0	0	0	0	0	0	0	=Σ(Year 1 value = Year 2 value = … = Year n value)

[#1] Row numbers begin with 16 to align with the corresponding rows in the sample spreadsheet. The row numbering convention is the Table number (using a lettering scheme to simplify the formulae) followed by the row in that table.

Table 5 COO for the Input Data Listed in Table 1.

Row [#1]		*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Formula*
TE4	Fixed Costs, $	96,800	15,718	15,718	15,718	15,718	14,843	14,843	For Year n, =IF(TA14>=1,TB44 value for year n,"Asset Fully Depreciated")
TE5	Recurring Costs, $	64,035	65,956	67,935	69,973	72,072	Asset Retired	Asset Retired	For Year n, =IF(TA16>=1,TC36 value for year n,"Asset Retired")
TE6	Yield Costs, $	0	0	0	0	0	Asset Retired	Asset Retired	For Year n, =IF(TA16>=1,TC36 value for year n,"Asset Retired")
TE7	Total Costs, $	160,836	81,674	83,653	85,691	87,790	14,843	14,843	=Σ(TE4:TE6)
TE9	Cumulative Fixed Costs, $	96,800	112,518	128,236	143,954	159,672	174,515	189,358	=Year n value in row TB45
TE10	Cumulative Recurring Costs, $	64,035	129,992	197,927	267,900	339,973	339,973	339,973	=Year n value in row TC37
TE11	Cumulative Yield Costs, $	0	0	0	0	0	Asset Retired	Asset Retired	=Year n value in row TD22
TE12	Cumulative Total Costs, $	160,836	242,510	326,163	411,854	499,644	514,487	529,330 [#3]	=Σ(TE9:TE11)
TE24	Yearly Cost, $/wafer	0.5887	0.2990	0.3062	0.3137	0.3214	Asset Retired	Asset Retired	=IF(TA16>=1,TE7 / TA16/(TA26 × TA31)/(TA147 × TA148),"Asset Retired")
TE26	Cumulative Cost, $/wafer	0.5887	0.4439	0.3980	0.3769	0.3658	0.3767	0.3875 [#4]	=IF(TA16>=1,TE12/TA16/(TA26 × TA31)/(TA147 × TA148),TE12/TA16/TA16/(TA26 × TA31)/(TA147 × TA148))

[#1] Row numbers begin with 4 to align with the corresponding rows in the sample spreadsheet. The row numbering convention is the Table number (using a lettering scheme to simplify the formulae) followed by the row in that table.

[#2] For the results shown in the table, Useful Life of Piece of Equipment = 5 yrs; Depreciable Life of Piece of Equipment = 7 yrs; Tool Throughput = 33 wafers/hr = 277,200 wafers/yr; Equipment Utilization = 0.9855.

[#3] Total Cost = $529,330

[#4] Total COO = $0.3875/wafer. (The Cumulative Cost in the last year equals the Total COO.)

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SEMI E141-0705
GUIDE FOR SPECIFICATION OF ELLIPSOMETER EQUIPMENT FOR USE IN INTEGRATED METROLOGY

This standard was technically approved by the global Metrics Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on May 20, 2005. It was available at www.semi.org in June 2005 and on CD-ROM in July 2005.

1 Purpose

1.1 The application of integrated metrology is anticipated to become a key factor for advanced process control in future integrated circuit (IC) manufacturing. Important parameters, which are typically measured for the characterization and qualification of device manufacturing steps, are the thickness and the optical properties of fabricated layers and the critical dimensions (CD) of submicron structures. For the measurement principle of ellipsometry, which is commonly applied in both applications, different equipment and, hence, procedures and notations for data acquisition and modeling exist. If, therefore, ellipsometry is to be applied for integrated metrology equipment, the physical and the software integration into the equipment should be standardized to avoid efforts for specific installations depending on the equipment and fabrication environment.

1.2 The description of the mechanical integration of an ellipsometer into an equipment module (e.g. a front end module or an equipment chamber) comprises the

- specification of the ellipsometer equipment and the spatial arrangement of the ellipsometer modules and components,
- specification of the relative position of the ellipsometer equipment to the equipment module, and
- specification of the mechanical interfaces to the equipment module.

1.3 A prerequisite for a standardized software integration of an ellipsometer is the standardized notation of the layer counting method, the measurement parameters, the measurement data, and the measurement results. This document describes the position of the metrology equipment with respect to the sample. The position of the measurement position (i.e. the position of the measurement spot) refers to the description of the wafer surface coordinate system as described in SEMI M20.

1.4 The purpose of this standard is to provide a guide for a unique specification of the most commonly applied ellipsometer equipment, the comprised modules and components, and their spatial arrangement. In this standard, the notation for parameters required in data acquisition and modeling is specified, and a unique notation for remote access on measurement parameters, data, and results is provided. Derived from these definitions, the required parameters to identify the calibration status of an ellipsometer are specified. Additionally, recommendations for preferred physical units are given.

1.5 The standard is intended for use in integrated metrology, but may also be applicable for stand-alone metrology.

2 Scope

2.1 This standard covers reflection ellipsometric measurements in integrated metrology.

2.2 The standard covers the typical applications of ellipsometry, which are the determination of layer thickness and optical properties.

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 The standard is limited to the measurement technique of ellipsometry although definitions may be applicable to the measurement technique of polarimetry.

3.2 The standard is limited to the measurement of isotropic samples. It is limited to the application of Stokes vectors, Jones-, or Muller - matrix formalisms for the mathematical treatment of the sequence of optical components (see ¶7.6).

3.3 The ellipsometer equipment differs in the capability to measure all elements of the Stokes vector.

3.4 The ellipsometer equipment differs in the capability to measure the number of unknown optical properties of a sample and in their capability to measure critical dimension parameters.

3.5 This standard does not address the calibration procedures of ellipsometer equipment.

4 Referenced Standards and Documents

4.1 *SEMI Standards*

SEMI E30.5 — Specification for Metrology Specific Equipment Model (MSEM)

SEMI E89 — Guide for Measurement System Analysis (MSA)

SEMI E127 — Specification for Integrated Measurement Module Communications: Concepts, Behavior, and Services (IMMC)

SEMI M20 — Practice for Establishing a Wafer Coordinate System

SEMI MF576 — Test Method for Measurement of Insulator Thickness and Refractive Index on Silicon Substrates by Ellipsometry

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

5 Terminology

5.1 *Definitions*

5.1.1 *calibration* — set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards[1].

5.1.2 *ellipsometry* — a measurement method based on the principle of measuring the change of the polarization state of light after reflection from the sample surface. Ellipsometry is commonly applied for the measurement of layer thickness, refractive index and extinction coefficient, or critical dimensions.

5.1.3 *in situ measurement* — a measurement performed inside the processing chamber of an equipment. If a wafer is used for this measurement, the wafer typically can be fed back into the process flow. The measurement data is typically available within regular wafer-to-wafer processing time frame or within wafer processing time frame (e.g. when performing layer thickness measurements during plasma etching).

5.1.4 *in situ metrology* — the science of measurement referring to in situ measurements.

5.1.5 *in-line measurement* — a measurement performed inside any portion of an equipment or work cell except the processing chamber. If a wafer is used for this measurement, the wafer typically can be fed back into the process flow. The measurement data is typically available within regular wafer-to-wafer processing time frame (e.g. layer thickness measurements performed inside a cooling station of a cluster tool).

5.1.6 *in-line metrology* — the science of measurement referring to in-line measurements.

5.1.7 *integrated metrology* — the science of measurement using metrology equipment that is closely connected to an equipment or work cell, characterized by the capability to perform in-line and in situ measurements.

5.1.8 *layer thickness* — the metric distance between two interfaces.

5.1.9 *measurand* — particular quantity subject to measurement [1].

5.1.10 *measurement* — set of operations having the object of determining a value of a quantity[1].

1 *International vocabulary of basic and general terms in metrology,* Second Edition, ISBN 92-67-01075-1, International Organization for Standardization 1993.

5.1.11 *measuring instrument* — device intended to be used to make measurements, alone or in conjunction with supplementary device(s)[1].

5.1.12 *measuring system* — complete set of measuring instruments and other equipment assembled to carry out specified measurements[1].

5.1.13 *metrology* — the science of measurement[1]. In semiconductor manufacturing, metrology denotes the science of measurement to ascertain dimensions, quantity, or capacity; the techniques and procedures for using sensors and measurement equipment to determine physical and electrical properties in wafer processing[2].

5.1.14 *metrology equipment* — any equipment that collects and reports information on specific predetermined sites or features on a substrate with consistent data structure, or reports general information about the entire substrate[3].

6 Ellipsometer Equipment

6.1 *Ellipsometer Equipment Specification*

6.1.1 In the reflection ellipsometric measurement, a light beam with known state of polarization is directed towards a specular reflecting sample surface. The change in both the amplitude and phase of the oscillating parallel and perpendicular vector components of the electric field associated with the beam are measured after reflection from the surface as the complex amplitude reflectance ratio (i.e. a change in the polarization of the light beam occurs). There are several possible configurations for ellipsometer equipment, which can be described by the arrangement of modules that comprise the optical components required to perform the ellipsometric measurement. In addition, the optical components also induce changes in the polarization of the light beam.

6.1.2 For specification of the ellipsometer equipment, it is necessary to describe all modules and optical components included both in the measuring and in the reflection process from the sample system and their position within a coordinate system defined by the sample and the light beam. Additionally, information on the number of wavelengths used for measurement and the method of data acquisition must be provided. The following definitions are provided for ellipsometer equipment specification.

6.2 *Ellipsometer module definition (see Figure 1)*

6.2.1 *ellipsometer modules* — An ellipsometer consists of two modules, the polarizer module and the analyzer module. The modules comprise the components used to establish and analyze the state of polarization of the incident and reflected beam, respectively.

6.2.1.1 *polarizer module* — Arrangement of optical devices that generates a light beam of well-defined known state of polarization for interacting with the sample system. The polarizer module includes the polarizer device and the light source and may also include the compensator or modulator.

6.2.1.2 *analyzer module* — Arrangement of optical devices that allows measurement of the state of polarization of the light beam after reflection from the sample system. The analyzer module may also include the compensator or modulator, and the detector.

6.2.1.3 *incident beam* — The light beam that passes from the light source through the polarizer module on the sample surface.

6.2.1.4 *reflected beam* — The light beam that passes from the sample surface through the analyzer module.

6.2.1.5 *plane of incidence* — The plane spread by the incident and the reflected beam.

6.2.1.6 *angle of incidence* (Φ_0) — Angle between the incident beam and the normal vector of the sample surface.

6.3 *Ellipsometer component definition (see Figure 1)*

6.3.1 *ellipsometer component* — An optical device within the ellipsometer that intentionally changes the state of polarization during the measurement.

6.3.1.1 *polarizer (P)* — Component that transmits light with a preferred polarization axis (typically linearly polarized).

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2 *SEMATECH Official Dictionary, Rev 5.0,* SEMATECH Inc., 2004 (Available through www.sematech.org).

3 *SEMI International Standards: Compilation of terms*. March 2004 (Available through www.semi.org).

6.3.1.2 *rotating polarizer (RP)* — Component that transmits light with a preferred polarization axis (typically linearly polarized) and that is rotating during measurement.

6.3.1.3 *compensator (retarder) (C)* — Component that can add a phase shift between the components of the electric field (i.e. the field component parallel to the plane of incidence and perpendicular to the beam direction and the field component perpendicular to the plane of incidence and to the beam direction, respectively) (see ¶6.4.2.3–¶6.4.2.6).

6.3.1.4 *rotating compensator (retarder) (RC)* — A rotating component that can add a phase shift between the components of the electric field (i.e., the field component parallel to the plane of incidence and perpendicular to the beam direction and the field component perpendicular to the plane of incidence and to the beam direction, respectively) (see ¶6.4.2.3–¶6.4.2.6).

6.3.1.5 *birefringence modulator (BM)* — Component that can add a time-modulated phase shift between the components of the electric field (i.e. the field component parallel to the plane of incidence and perpendicular to the beam direction and the field component perpendicular to the plane of incidence and to the beam direction, respectively) (see ¶6.4.2.3–¶6.4.2.6). The photoelastic modulator (PEM) is a component of this type.

NOTE 1: A PEM is an electro-optical modulator made of a suitable birefringent material. By applying an external electric field to this material, its refractive index changes anisotropically, thus resulting in a phase shift of a transmitting light wave. By driving the electric field resonantly, the phase of one polarization component of the transmitting light wave will be delayed periodically.

6.3.1.6 *analyzer (A)* — Component that transmits light with a preferred polarization axis (typically linearly polarized).

6.3.1.7 *rotating analyzer (RA)* — Component that transmits light with a preferred polarization axis (typically linearly polarized) and that is rotating during measurement.

6.3.1.8 *sample (S)* — Material or layer system to be analyzed. The sample is the reflecting component that changes the state of polarization in a characteristic manner (typically, light is elliptically polarized after reflection) and that is to be evaluated.

6.4 *Ellipsometer Equipment Definition (see Figure 1)*

6.4.1 *sequence of ellipsometer components* — The first item to be described for the definition of ellipsometer equipment is the sequence of optical components beginning with the first component in the polarizer module after the light source and including all the optical components to the analyzer module before the detector element. For this definition, optical elements that do not intentionally affect the state of light polarization (e.g. the light source, the detector, or the spectrometer) are not listed.

6.4.1.1 The most commonly applied ellipsometer equipment is listed below.

6.4.1.1.1 *P C S A and P S C A* — Null Ellipsometer.

6.4.1.1.2 *P (C) S RA and P S (C) RA* — Rotating Analyzer Ellipsometer (with) without Compensator.

6.4.1.1.3 *RP (C) S A and RP S (C) A* — Rotating Polarizer Ellipsometer (with) without Compensator.

6.4.1.1.4 *P RC S A, P S RC A, and P RC S RC A* — Rotating Compensator Ellipsometer.

6.4.1.1.5 *P BM S A and P S BM A* — Birefringence Modulation Ellipsometer (sample configuration: P PEM S A or P S PEM A).

6.4.2 *position of ellipsometer components* — The second item to be described for the definition of ellipsometer equipment is the position of the optical components within this coordinate system. The ellipsometer setup uses a coordinate system defined by the sample surface and the light beam (see Figure 1).

6.4.2.1 *definition of the optical system of coordinates* — The optical system of coordinates is defined by the electromagnetic field components, described as complex numbers, and the wave vector.

6.4.2.2 *wave vector ($\underline{k}$)* — The vector indicates the propagation direction of a light beam. The magnitude is given by $|\underline{k}| = 2\pi/\lambda$, with λ being the wavelength of the light beam. The wave vector of the incident beam is $\underline{k}_i$ and that of the reflected beam is $\underline{k}_r$.

6.4.2.3 *electric field vector (E_{ip})* — Electric field strength of the incident beam parallel to the plane of incidence and perpendicular to the wave vector of the incident beam.

6.4.2.4 *electric field vector (E_{is})* — Electric field strength of the incident beam perpendicular to the plane of incidence and perpendicular to the wave vector of the incident beam.

6.4.2.5 *electric field vector (E_{rp})* — Electric field strength of the reflected beam parallel to the plane of incidence and perpendicular to the wave vector of the reflected beam.

6.4.2.6 *electric field vector (E_{rs})* — Electric field strength of the reflected beam perpendicular to the plane of incidence and perpendicular to the wave vector of the reflected beam.

6.4.2.7 *handedness of the coordinate system* — The vectors E_{ip}, E_{is}, and the wave vector $\underline{k}_i$ of the incident beam as well as the vectors E_{rp}, E_{rs}, and the wave vector $\underline{k}_r$ of the reflected beam span a right-handed coordinate system (see Figure 1).

6.4.2.8 *description of the component position* — The positions of the ellipsometer components are described by the following angles, which are specified counterclockwise relative to E_{ip} and E_{rp}, respectively.

6.4.2.8.1 *polarizer azimuth (α_P)* — Angle between the plane of incidence and the polarization axis of the light emerging the polarizer (see Figure 1).

6.4.2.8.2 *compensator azimuth (α_C)* — Angle between the plane of incidence and the fast axis of the compensator crystal. If a compensator consists of multiple anisotropic crystals, the axis is defined as the effective axis when the output is modeled by a single anisotropic crystal (see Figure 1).

6.4.2.8.3 *PEM azimuth (α_{PEM})* — The PEM azimuth denotes the same angle as α_C for an electronically phase modulated compensator.

6.4.2.8.4 *analyzer azimuth (α_A)* — The analyzer azimuth denotes the angle between the plane of incidence and the polarization axis of the light emerging the analyzer (see Figure 1).

6.4.3 *description of the angle of incidence* — The third item to be described for the definition of ellipsometer equipment is the number of angles of incidence.

6.4.3.1 *single-angle ellipsometer (SAE)* — With the single-angle ellipsometer, the ellipsometric measurement is performed at a single angle of incidence.

6.4.3.2 *multiple-angle ellipsometer (MAE)* — With the multiple-angle ellipsometer, the ellipsometric measurement is performed at different angles of incidence.

6.4.4 *description of measurement wavelength* (λ) — The fourth item to be described for the definition of ellipsometer equipment is the number of wavelengths used for measurement.

6.4.4.1 *single-wavelength ellipsometer (SWE)* — With the single-wavelength ellipsometer, one discrete wavelength is used in the measurement.

6.4.4.2 *multiple-wavelengths ellipsometer (MWE)* — With the multiple-wavelengths ellipsometer, several discrete wavelengths are used in the measurement.

6.4.4.3 *spectroscopic ellipsometer (SE)* — With the spectroscopic ellipsometer many (at least 10) different wavelengths are used in the measurement.

6.4.5 *description of the data acquisition method* — The fifth item to be described for the specification of ellipsometer equipment is the data acquisition method.

6.4.5.1 *scanning data acquisition* — In scanning data acquisition, the state of polarization is measured wavelength by wavelength for different positions of one or more optical components.

6.4.5.2 *parallel data acquisition* — In parallel data acquisition, the state of polarization is measured by simultaneously varying one or more parameters of the ellipsometer equipment for a defined position of one or more optical components, e.g. simultaneously measuring the state of polarization for different wavelengths or at different angles of incidence.

NOTE 2: In the literature, the terms TM (transverse magnetic) and TE (transverse electric) are also used to denote *p* and *s* polarizations, respectively. The TM polarization denotes that the magnetic field vector is perpendicular to the plane of incidence, while the TE polarization denotes that the electric field vector is perpendicular to the plane of incidence.

7 Definitions for Modeling the Reflection from a Sample Surface

7.1 *Analysis of Ellipsometric Measurements*

7.1.1 For the analysis of ellipsometric measurements an optical model describing the optical parameters and layer thickness values of the sample must be provided. The optical model is regarded as part of the necessary substrate data set[4]. The objective of the ellipsometric measurement is to determine the value of at least one parameter within the optical model such that the measurand calculated from the optical model is in optimum consistency with the measurand (raw data value[1]) determined in the measurement. For a correct optical model and in the absence of measurement errors, the measurand calculated from the optical model coincides with the measurand (raw data value[1]) determined in the measurement.

7.1.2 The set of adjusted parameter values is the measurement result (i.e. the converted measurement data[1] determined by the ellipsometric measurement). In some special cases the measurement result can be calculated from the measurands or raw data analytically.

7.1.3 Typically, in ellipsometry the analysis is performed by calculating the expected value of the measurand (i.e. raw data value from the parameter values provided in the optical model). The parameter values of interest within the optical model are then intentionally adjusted in a manner such that optimum consistency between the calculated and measured value of the measurand (i.e. the raw data value is obtained). The adjusted parameter values are the measurement result (i.e. the converted measurement data).

7.2 *Definition of the Optical Parameters* — The optical parameters are used as substrate data set and the optimized parameter values after measurement and analysis denote the measurement result (i.e. the converted measurement data).

7.2.1 *layer index (i)* — The layer index i identifies the layer for remote access. The index i = *'a'* describes the ambient medium (n_a, k_a). The index i = *'s'* describes the substrate medium (n_s, k_s). The intermediate layers are numbered in the direction from the substrate to the ambient (i.e. $i = 1$ denotes the first layer on the substrate) (see Figure 2).

7.2.2 n_i — Denotes the refractive index of layer i being a positive real number.

7.2.3 k_i — Denotes the extinction coefficient of layer i. The value of the extinction coefficient k_i must be set as a positive number $|k_i|$ for better readability in programs and printouts, independently of the notation of the complex refractive index and complex dielectric function (see ¶¶7.2.4, 7.2.6, and 7.2.7).

NOTE 3: The extinction coefficient k describes absorbing media if $|k| > 0$ and transparent media if $|k| = 0$. The absorption coefficient α and the absorption index κ are also two common optical parameters used for describing absorbing media. The extinction coefficient k is related to the absorption coefficient α by $\alpha = 4\pi k/\lambda$ and to the absorption index κ by $\kappa = k/n$.

7.2.4 N_i — Denotes the complex refractive index of layer i. Depending on the physical notation the complex refractive index is calculated by $N_i = n_i - j\,k_i$ or $N_i = n_i + j\,k_i$ (see ¶7.2.3).

7.2.5 $\varepsilon_i = N_i^2$ — Complex dielectric function of layer i.

7.2.6 $\varepsilon_{1i} = n_i^2 - k_i^2$ — Real part of the dielectric function of layer i.

7.2.7 ε_{2i} — Imaginary part of the dielectric function of layer i. Depending on the physical notation, the imaginary part of the dielectric function is calculated by $\varepsilon_{2i} = -2n_ik_i$ or $\varepsilon_{2i} = 2n_ik_i$ (see ¶7.2.4, ¶7.2.5). The value of the imaginary part of the dielectric function ε_{2i} must be set as a positive number $|\varepsilon_{2i}|$ for better readability in programs and printouts, independently of the notation of the complex refractive index and complex dielectric function (see ¶¶7.2.3, 7.2.4, and 7.2.5).

7.2.8 t_i — Metric thickness of the layer i. The method for counting is identical as for the refractive indices, but no thickness is provided for the ambient and the substrate.

7.3 *ambient medium* — The modeling always requires a semi-infinite space (or material) for the incident and the reflected beam that is not part of the sample. The ambient is the propagation medium immediately before and after reflection at the sample surface. In many cases the ambient medium is air or vacuum with $n_a = 1$ and $k_a = 0$.

4 Terminology here is as defined in SEMI E127.

7.4 *material and layer definition* — the optical properties of a material determine how the complex refractive index N_i is given as a function of wavelength and environmental parameters (e.g., temperature). A layer consists of a single material or a combination of several materials with a metric thickness t_i. This definition also applies to complex structures as index gradients, interfaces, and roughness that can be modeled as a series of layers.

7.5 *substrate medium* — Lowest (see ¶7.2.1) material involved in the reflection with a complex refractive index N_s. A sample has only one substrate material, which is treated as semi-infinite.

7.6 *Ellipsometric Measurand (raw data set)* [5, 6, 7, 8, 9]

7.6.1 $r_p = E_{rp}/E_{ip}$ — Complex amplitude reflection coefficient parallel to the plane of incidence.

7.6.2 $r_s = E_{rs}/E_{is}$ — Complex amplitude reflection coefficient perpendicular to the plane of incidence.

7.6.3 $\rho = r_p/r_s = \tan \Psi \cdot e^{j\Delta}$ — Ratio of the complex amplitude reflection coefficients.

7.6.4 δ_p — Phase shift of E_{rp} relative to E_{ip}.

7.6.5 δ_s — Phase shift of E_{rs} relative to E_{is}.

7.6.6 $\Delta = \delta_p - \delta_s$ — Phase shift between *p* and *s* components of the electric field strength.

7.6.7 $\tan \Psi = |r_p| / |r_s|$ — Ratio of the absolute values of the amplitude reflection coefficients.

7.6.8 S_x — Stokes parameters (x = 0, 1, 2, 3).

NOTE 4: The four Stokes parameters describe the polarization ellipse using the physical dimension of energy. The four Stokes parameters involve three independent parameters that are necessary to describe the polarization ellipse. For totally polarized light, the Stokes parameters describe a sphere with the radius S_0 and represent the parameters Ψ and Δ in a Cartesian coordinate system: $S_0^2 = S_1^2 + S_2^2 + S_3^2$. The parameter S_0 is proportional to the energy of the light wave. For elliptically and totally polarized light, the Stokes parameters are calculated from the parameters Ψ and Δ as follows: $S_1 = -S_0 \cos 2\Psi$, $S_2 = S_0 \sin 2\Psi \cos \Delta$, and $S_3 = S_0 \sin 2\Psi \sin \Delta$. The Stokes vector, consists of four vector components, which are the Stokes parameters.

7.6.9 $s_x = S_x/S_0$ — normalized Stokes parameters (x = 1, 2, 3).

NOTE 5: The normalized Stokes parameters are calculated from the Stokes parameters as follows: $s_1 = S_1/S_0$, $s_2 = S_2/S_0$, and $s_3 = S_3/S_0$.

7.6.10 The results are typically given as $[\Psi, \Delta](\phi_0, \lambda, \xi)$, $[\tan \Psi, \cos \Delta](\phi_0, \lambda, \xi)$, $[s1, s2, s3](\phi_0, \lambda, \xi)$ dependent on the measurement angle of incidence ϕ_0, and the wavelength λ (see ¶3.4). The parameter array ξ provides all environmental conditions (influence quantities) relevant for the measurement. All relevant parameters shall be provided in SI units. At least the sample temperature must be specified, but additional parameters (e.g. ambient pressure, measurement time, sample orientation, the measurement position[10], composition, and strain) may have to be added.

7.7 *Qualification of Ellipsometric Data*

7.7.1 The qualification of an ellipsometer is verified by measuring certified reference samples and test procedures [11, 12, 13, 14].

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5 Born, M.; Wolf, E.: "Principles of Optics: Electromagnetic Theory of Propagation, Interference and Diffraction of Light", Cambridge University Press, ISBN 0521642221.

6 Azzam, R. M. A., Bashara, N. M.: "Ellipsometry and Polarized Light", Elsevier Science Publishers B. V., ISBN 0444870164.

7 Tompkins, H. G.; McGahan W.A.: "Spectroscopic Ellipsometry and Reflectometry: A User's Guide", Wiley-Interscience, ISBN 0471181722.

8 Muller, R. H.: "Definitions and Conventions in Ellipsometry", Surface Science Vol. 16 (1969), pp. 14-33.

9 Röseler, A.: Infrared Spectroscopic Ellipsometry, Akademie Verlag Berlin, ISBN 3-05-500623-2.

10 See SEMI M20.

11 See SEMI E89-1104E.

12 See SEMI MF576.

13 *Metrology Tool Gauge Study Procedure for the International 300 mm Initiative (I300I)*, Technology Transfer # 97063295A-XFR, International 300 mm Initiative, June 15, 1997.

14 Eastman, S. A.: *Evaluating Automated Wafer Measurement Instruments.* Technology Transfer # 94112638A-XFR; SEMATECH February 28, 1995.

NOTE 6: The reference samples are typically certified thickness standards using reference materials. For thickness measurements typical samples are thermal oxides on silicon ranging from 4 nm to 800 nm. For refractive index measurements, the reference sample thickness is typically in the range from 80 nm to 500 nm.

NOTE 7: SEMI MF576-01 was originally published by ASTM International as ASTM F 576-78. It was formally approved by ASTM balloting procedures and adhered to ASTM patent requirements. Though ownership of this standard has been transferred to SEMI, it has not been formally approved by SEMI balloting procedures and does not adhere either to SEMI Regulations dealing with patents or to SEMI Editorial Guidelines. It was available at www.semi.org, last published by ASTM International as ASTM F 576-01. Hence in SEMI MF576-01, the notation for parameters required in data acquisition and modeling is aligned but could not retroactively be fully harmonized with the definitions specified in the presented guide. This does not constitute any constraints since these few parameters may easily be superseded by the newer definitions provided.

7.7.2 Whenever the thickness and refractive index measurement (if performed) is within specified limits for the reference sample, the ellipsometer is defined as qualified and hence capable of measuring the respective type of sample.

7.7.3 The qualification status of an ellipsometer is defined and must be specified by providing the following parameters: (1) the relevant parameters for sample identification, (2) the relevant optical parameters of the sample, (3) the expected measurement result, (4) the actual measurement result, (5) the tolerated deviation between the actual and the expected measurement result, (6) all relevant parameters of the ellipsometer system (e.g. all relevant parameters of the positions of the optical components) the angle of incidence, and (7) all relevant environmental parameters.

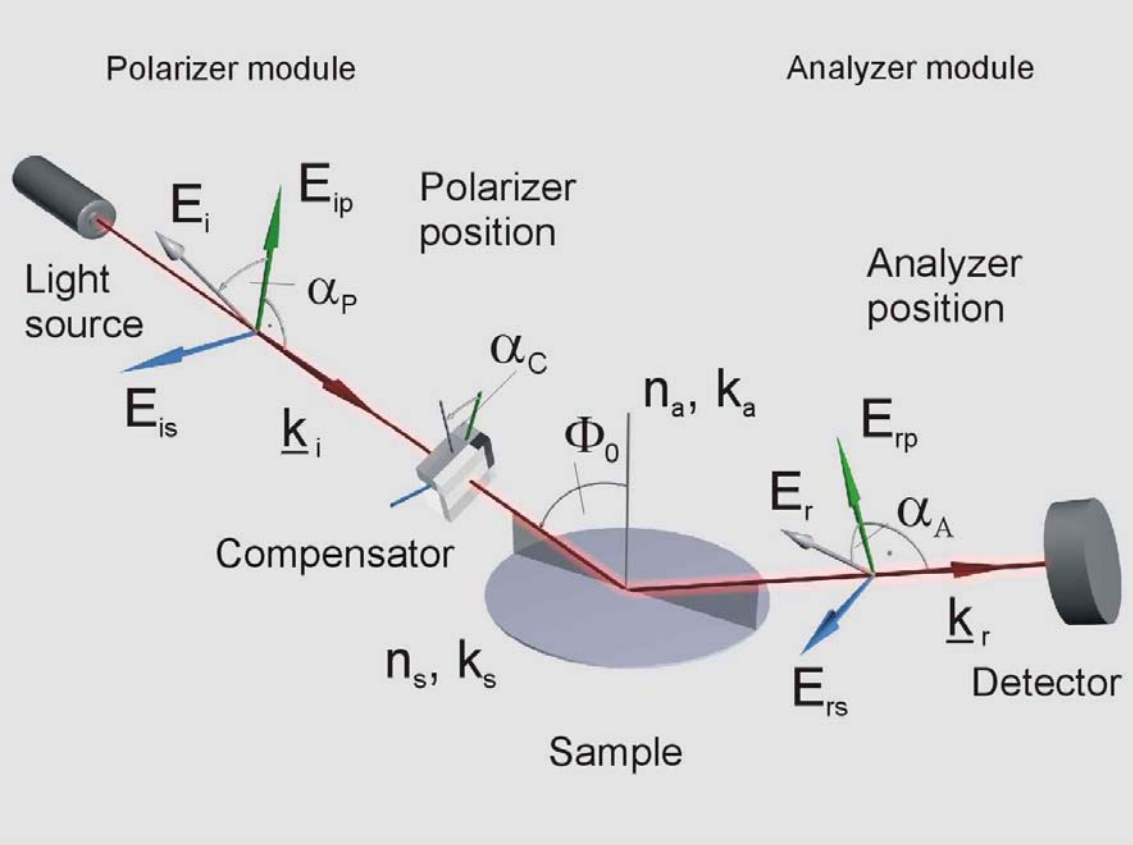
7.7.4 *Recommended Units and Symbols* — The units as listed in Table 1 are recommended for the description of the listed parameter.

Table 1 Recommended Units

Physical Quantity	*Symbol*	*Unit(s)*
Metric thickness	t	µm, nm, Å
Wavelength	λ	µm, nm, Å
Photon energy	E	eV
Wave number	ν	cm^{-1}
Angles	ψ, Δ, $\Phi_0, \alpha_p, \alpha_c, \alpha_{PEM}, \alpha_A$	° or deg (360° are a full circle)
Electric field vectors	E_{ip}, E_{is}, E_{rp}, E_{rs}	V/m
Optical parameters (refractive indices)	N, n, k	no unit
Complex dielectric function	ε	no unit
Pseudo ε	$<\varepsilon>$	no unit

[#1] See SEMI E30.5 for the preferred thickness unit (Å).

[#2] The pseudo dielectric constant <ε> is calculated from the raw data set using a sample model consisting of only the ambient and substrate without layers.



$$\rho = \frac{E_{rp} \cdot E_{is}}{E_{ip} \cdot E_{rs}} = \frac{r_p}{r_s} = \tan\Psi \cdot e^{j\Delta}; \qquad \Delta = \delta_p - \delta_s$$

NOTE: The P C S A configuration is shown for a single-wavelength ellipsometer. For other configurations, see ¶6.4.1.

Figure 1
Schematic of an Ellipsometer System

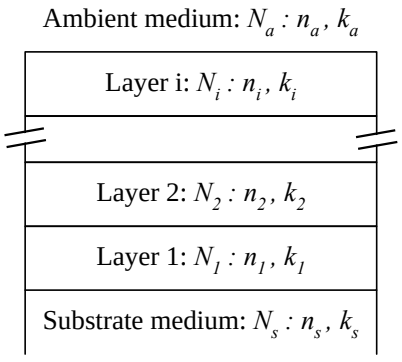


Figure 2
Illustration of the Layer Counting Principle

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SEMI INTERNATIONAL STANDARDS

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Semiconductor Equipment and Materials International

SEMI E4-0699
SEMI EQUIPMENT COMMUNICATIONS STANDARD 1 MESSAGE TRANSFER (SECS-I)

This standard was technically approved by the Global Information & Control Committee and is the direct responsibility of the North American Information & Control Committee. Current edition approved by the North American Regional Standards Committee on February 28, 1999. Initially available at www.semi.org May 1999; to be published June 1999. Originally published in 1980; previously published January 1999.

1 Introduction

1.1 *Revision History* — This is the first major revision since the original release of SECS-I in 1980. Very little of the original intent of SECS-I has been altered, although there are a few significant additions. The changes are summarized in Appendix 1. This specification has been developed in cooperation with the Japan Electronic Industry Development Association Committee 12 on Equipment Communications.

1.2 *Scope* — The SECS-I standard defines a communication interface suitable for the exchange of messages between semiconductor processing equipment and a host. Semiconductor processing equipment includes equipment intended for wafer manufacturing, wafer processing, process measuring, assembly and packaging. A host is a computer or network of computers which exchange information with the equipment to accomplish manufacturing. This standard includes the description of the physical connector, signal levels, data rate and logical protocols required to exchange messages between the host and equipment over a serial point-to-point data path. This standard does not define the data contained within a message. The meaning of messages must be determined through some message content standard such as SEMI Equipment Communications Standard E5 (SECS-II).

1.3 *Intent* — This standard provides a means for independent manufacturers to produce equipment and/or hosts which can be connected without requiring specific knowledge of each other.

1.3.1 *Layered Protocol* — The SECS-I protocol can be thought of as a layered protocol used for point-to-point communication. The levels within SECS-I are the physical link, block transfer protocol, and message protocol. (See Related Information R1-1.1.)

1.3.2 *Speed* — It is not the intent of this standard to meet the communication needs of all possible applications. For example, the speed of RS-232 may be insufficient to meet the needs of transferring mass amounts of data or programs in a short period of time, such as might be required by high speed functional test applications.

1.3.3 *Network Support* — The method by which blocks of data are routed to a piece of equipment or find their way back to the proper host application is not specified by SECS-I. In a network, the roles of host and equipment might be assumed by any party in the network. In this situation, one end of the communications link must assume the role of the equipment and the other the role of the host.

1.4 *Applicable Documents*

1.4.1 *Electronics Industries Association Standards*[1]

EIA RS-232-C — Interface between Data Terminal Equipment and Data Communication Equipment Employing Serial Binary Data Interchange

EIA RS-269-B — Synchronous Signaling Rates for Data Transmission

EIA RS-334 — Signal Quality at Interface Between Data Processing Terminal Equipment and Synchronous Communication Equipment for Serial Data Transmission

EIA RS-422 — Electrical Characteristics of Balanced Voltage Digital Interface Circuits

EIA RS-423 — Electrical Characteristics of Unbalanced Voltage Digital Interface Circuits

1.4.2 *European Computer Manufacturing Association*[2]

ECMA/TC24/82/18 — "Network Layer Principles," Final Draft (April, 1982)

1.4.3 *Japanese Industrial Standards Committees*[3]

JIS C 6361 — "The Interface between Data Circuit Terminating Equipment (DCE) and Data Terminal Equipment (DTE) (25-pin Interface)"

1.4.4 *International Organization for Standardization*[4]

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[1] *EIA Engineering Department, Standards Sales Office, 2001 Eye Street, N.W., Washington, D.C. 20006*

[2] *European Computer Manufacturing Association, 114 Rue du Rhone, 1204 Geneva, Switzerland*

[3] *Japanese Standards Association, 1-24, Akasaka 4 Chome, Minato-ku, Tokyo 107, Japan*

[4] *ANSI, 1430 Broadway, New York, NY 10018*

SEMI E4-0699 © SEMI 1980, 1999

ISO 2110-1980 — Data Communications, Interface Connectors and Pin Assignment

1.4.5 *SEMI Specifications*

SEMI E5 — SEMI Equipment Communications Standard 2 — Message Content (SECS-II)

SEMI E6 — SEMI Facilities Interface Specification Format

1.5 *Overview of SECS-I* — The SECS-I standard defines point-to-point communication of data utilizing a subset of the international standard known in the U.S.A. as EIA RS-232-C and in Japan as JIS C 6361 for the connector and voltage levels. The actual transmission consists of 8-bit bytes sent serially with one start and one stop bit. The communication is bidirectional and asynchronous, but flows in one direction at a time. The direction is established by special characters and a handshake, after which the data itself is sent. Data is sent in blocks of 254 bytes or less. Each block consists of a 10-byte header followed by data. A message is a complete unit of communication in one direction and consists of 1 to 32,767 blocks. Each block header contains information for identifying the block as part of a specific message. Messages are paired by a request and its reply which together are called a transaction.

1.6 *Structure of Document* — This document is divided into sections which correspond to major aspects of the standard. The sections outline requirements as well as implications of the requirements. The standard may be implemented in a variety of ways, depending upon the computer environment where it is placed. Implementation is not part of the standard. Information which may be useful for implementation is included in the form of Related Information.

2 Terminology

2.1 The following brief definitions refer to sections providing further information.

2.1.1 *ACK* — "Correct Reception" handshake code. (See Section 5.2.)

2.1.2 *application software* — the software performing the specific task of the equipment or the host.

2.1.3 *block* — header plus up to 244 bytes of data. (See Sections 1.5, 6.7.)

2.1.4 *block length* — the number of bytes sent in the block transfer protocol. (See Section 5.6.)

2.1.5 *block number* — a 15-bit field in the header for numbering blocks in a message. (See Sections 6.7.)

2.1.6 *character* — a byte sent on the SECS-I serial line. (See Section 4.1.)

2.1.7 *checksum* — a 16-bit number used to detect transmission errors. (See Section 5.7.)

2.1.8 *communication failure* — a failure in the communication link resulting from a failed send. (See Section 5.4.)

2.1.9 *device ID* — a 15-bit field in the header used to identify the equipment. (See Section 6.3.)

2.1.10 *E-bit* — a bit in the header identifying the last block of a message. (See Section 6.6.)

2.1.11 *ENQ* — "Request to Send" handshake code. (See Section 5.2.)

2.1.12 *EOT* — "Ready to Receive" handshake code. (See Section 5.2.)

2.1.13 *equipment* — the intelligent system which communicates with a host.

2.1.14 *expected block* — the block of a message which is expected by the message protocol. (See Section 7.4.4.)

2.1.15 *header* — a 10-byte data element used by the message and transaction protocols. (See Section 6.)

2.1.16 *host* — the intelligent system which communicates with the equipment.

2.1.17 *length byte* — the character used to establish the block length during transmission. (See Section 5.6.)

2.1.18 *line control* — a portion of the block transfer protocol. (See Section 5.8.2.)

2.1.19 *master* — the block transfer designation for the equipment. (See Section 5.5.)

2.1.20 *message* — a complete unit of communication. (See Section 7.)

2.1.21 *message ID* — a 15-bit field in the header used in the process of message identification. (See Sections 6.5, 7.3.1.)

2.1.22 *multi-block message* — a message sent in more than one block. (See Sections 6.7, 7.2.2.)

2.1.23 *NAK* — "lncorrect Reception" handshake code. (See Section 5.2.)

2.1.24 *open message* — a multi-block message for which not all of the blocks have been received. (See Section 7.4.4.)

2.1.25 *open transaction* — a transaction in progress. (See Section 7.3.)

2.1.26 *primary message* — a message with an odd numbered message ID. Also the first message of a transaction. (See Section 6.5.)

2.1.27 *primary/secondary attribute* — the least significant bit of the lower message ID which indicates whether a block belongs to a primary or secondary message.

2.1.28 *R-bit* — a bit in the header signifying the direction of the message. (See Section 6.2.)

2.1.29 *receiver* — the end of the SECS-I link receiving a message. (See Section 5.8.4.)

2.1.30 *reply* — the particular secondary message corresponding to a primary message. (See Section 7.3.)

2.1.31 *reply linking* — the process of forming a transaction out of a primary and a secondary message. (See Section 7.3.1.)

2.1.32 *retry count* — the number of unsuccessful attempts to send a block in the block transfer protocol. (See Section 5.4.)

2.1.33 *RTY* — the retry limit or the number of times the block transfer protocol will attempt to retry sending a block before declaring a failed send. (See Section 5.4.)

2.1.34 *secondary message* — a message with an even numbered message ID. Also the second message of a transaction. (See Section 6.5.2.)

2.1.35 *sender* — the end of the SECS-I link sending message. (See Section 5.8.3.)

2.1.36 *slave* — the block transfer designation for the host (See Section 5.5.)

2.1.37 *system bytes* — a 4-byte field in the header used for message identification. (See Section 6.8.)

2.1.38 *T1* — receive inter-character timeout in the block transfer protocol. (See Section 5.3.1.)

2.1.39 *T2* — protocol timeout in the block transfer protocol. (See Section 5.3.2.)

2.1.40 *T3* — reply timeout in the message protocol. (See Sections 5, 7.3.2)

2.1.41 *T4* — inter-block timeout in the message protocol. (See Section 7.4.3.)

2.1.42 *transaction* — a primary message and its associated secondary message, if any. (See Section 7.3.)

2.1.43 *W-bit* — a bit in the header signifying that a reply is expected. (See Section 6.4.)

3 Coupling

3.1 Coupling refers to the physical interface at the equipment. The host will provide compatible signals at this point. No restrictions are implied for any interface other than for equipment covered by this standard.

3.2 *Electrical Interface* — The connection will include a serial interface according to EIA Standard RS-232-C for interface Type E, full duplex communication, modified by the deletions, additions and exceptions described in this section.

3.2.1 *Connector* — Either the 9-pin or 25-pin connector described in the EIA RS232 may be used. In the case of the 25-pin connector a female connector will be mounted on the equipment and a male connector will be mounted on the cable from the host. In the case of the 9-pin connector the male connector will be mounted on the equipment and a female connector will be mounted on the cable. The connector on the equipment will have female 4-40 threaded jack screw locks.

NOTE: Suitable 25-pin connectors known as Type "D" are similar to Amphenol MIN RAC 17 series with jack screw locks. Suitable 9-pin connector is also Type "D" with jackscrew locks. It is the type commonly implemented on desktop and notebook PCs.

3.2.2 *Signal Pins* — Pins on the connector have functions as defined in Table 1. Pins 1, 2, 3, and 7 of the 25-pin connector or pins 3, 2, and 5 of the 9-pin connector are required for all equipment complying with SECS-I. When using a 25-pin connector, the two power supply pins, 18 and 25, are optional as indicated. Any other pins, if used, shall comply with the RS-232-C standard.

Table 1 Signal Connections

25-Pin	*9-Pin*	*RS-232-C Circuit*	*Circuit Description*
1	--	AA	Shield
2	3	BA	Data from Equipment
3	2	BB	Data to Equipment
7	5	AB	Signal Ground
18	--	--	+12 to +15 volts (opt for the 25-pin connector)
25	--	--	-12 to -15 volts (opt for the 25-pin connector)

3.2.3 *Logic Levels* — For the signal pins 2 and 3, the logic 1 level will be a voltage less than -3 volts and the logic 0 level will be a voltage greater than +3 volts. Voltages will never exceed ± 25 volts. These values correspond to those specified by the RS-232-C standard.

3.2.4 *Power Supplies* — When using a 25-pin connector, pins 18 and 25 are optional power supplies for driving external isolation circuits. When provided, both shall be present and must be able to supply at least 50 mA. (See Related Information R1-2 for example use.)

3.3 *Data Rate* — The supported data rates on signal pins shall be 9600, 4800, 2400, 1200, and 300 baud. The same data rate shall apply for data sent to and from the equipment. The data rate shall be controlled to better than 0.5%. (See RS-269-B and RS-334.) Optional rates of 19,200 and 150 baud may be supplied if desired.

3.4 *Physical Medium* — The connection with the host may involve any medium that provides the required RS-232-C quality, signal levels and data rate at the equipment connector. The quality of signal should be such that the effective bit error rate is less than 1×10^{-6}. This rate can be achieved easily with hardwired systems. The distance limits specified in RS-232-C apply only to systems using the wiring technique described in RS-232-C. Since any method may be used in SECS-I as long as RS-232-C signals are supplied at the connector, the distance and isolation is dependent upon the design of the physical medium which is external to the SECS-I standard. (See Related Information R1-2.)

4 Character Structure

4.1 *Characters* — Data will be transmitted or received in a serial bit stream of 10 bits per character at one of the specified data rates. The standard character has one start bit (0), 8 data bits and one stop bit (1). All bit transmissions are of the same duration. The 8 data bits are numbered from 1 to 8 in the order sent (see Figure 1). The timing between characters is asynchronous with respect to the data rate. The 8 data bits may be any arbitrary code. The eight data bits will hereafter be referred to as a byte.

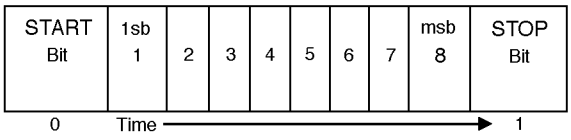

Figure 1

Character Structure

4.2 *Weighted Codes* — For bytes having weighted codes, bit one is the least significant and bit eight is the most significant. The most common weighted code is binary.

4.3 *Non-Weighted Codes* — For codes without numeric value such as ASCII, the bit numbers will be used as the entry into a standard code table for interpretation of the code. SECS-I performs no parity or other verification of the contents of individual bytes.

5 Block Transfer Protocol

5.1 The procedure used by the serial line to establish the direction of communication and provide the environment for passing message blocks is called the block transfer protocol. Most of the protocol is accomplished with a handshake of single bytes. When both ends of the line try to send at the same time, a condition known as line contention exists. The protocol resolves contention by forcing one end of the line, designated as the slave (always the host), to postpone its transmission and enter the receive mode. Retransmission of blocks is used to correct communication errors. The block transfer protocol is shown in flow chart form in Figure 2, and described below. Additional information is also contained in Related Information R1-3 and R1-4.

5.2 *Handshake Bytes* — The four standard handshake codes used in the block transfer protocol are shown in Table 2. The three letter names, ENQ, EOT, ACK, and NAK correspond to the ASCII code having the same pattern.

Table 2 Handshake Codes

Name	*Codeb8 b7.....b1*	*Function*
ENQ	00000101	Request to Send
EOT	00000100	Ready to Receive
ACK	00000110	Correct Reception
NAK	00010101	Incorrect Reception

5.3 *Timeout Parameters* — Timeouts are used to detect communications failures. A timeout occurs when the measured time between two events exceeds a predetermined limit. Generally, the length of time that must pass before it can be assumed that an error has occurred depends upon the particular systems involved. The time required in one situation might be excessively long in another. Thus, the timeout values must be "tuned" to meet the application. In the block transfer protocol, there are two situations requiring timeout values. The two timeout values are called parameters T1 and T2.

5.3.1 *Inter-Character Timeout, T1* — The inter-character timeout, T1, limits the time between receipt of characters within a block after the length byte has been received and until the receipt of the second checksum byte.

5.3.2 *Protocol Timeout, T2* — The protocol timeout, T2, limits the time between sending ENQ and receiving EOT, sending EOT and receiving the length byte, and sending the second checksum byte and receiving any character.

5.4 *Retry Limit, RTY* — The retry limit, RTY, is the maximum number of times the Block Transfer Protocol will attempt to retry sending a block before declaring a failed send. (See Section 5.8.2.)

5.5 *Master/Slave* — The master/slave parameter is used in the resolution of contention (see Section 5.8.2). The host is designated as the slave. The equipment is desig-nated as the master. This convention is based upon the assumption that the equipment is less able to store messages than the host.

5.6 *Block Lengths* — The unsigned integer value of the first byte sent after receipt of EOT is the length of the block being sent. The length includes all the bytes sent after the length byte, excluding the 2 bytes of the checksum. The maximum block length allowed by SECS-I is 254 bytes, and the minimum is 10 bytes.

5.7 *Checksum* — The checksum is calculated as the numeric sum of the unsigned binary values of all the bytes after the length byte and before the checksum in a single block. The checksum is sent as 16 bits in two bytes following the last byte of the block data. The high order eight bits of the checksum will be sent first, followed by the low order eight bits. The checksum is used by the receiver to check for transmission errors. The receiver performs the same checksum calculation on the received header and data.

5.8 *Algorithm* — The operation of the block transfer protocol is best understood by following the logic flow in Figure 2. This flow chart depicts the operation of the five states of the protocol - Receive, Idle, Send Line Control, and Completion. The flow chart shown in Figure 2 is not meant to imply that a particular implementation is required under this standard. However, any SECS-I block transfer protocol implementation must include all the logic described in Figure 2. The same algorithm is executed on each end of the SECS-I communications link.

5.8.1 *Idle State* — Both ends of the communications link are assumed to start in the Idle state. There are two primary activities of the protocol signified by the two exits from the Idle state. These are:

A. SEND — a message block is to be sent.

B. RECEIVE — the other end of the communications link has a message block to send

5.8.2 *Line Control* — The line control section establishes the transmission direction, resolves contention, and handles retries. When an ENQ is received in the Idle state, the Line Control responds with an EOT if the Block Transfer Protocol is ready to receive. The Block Transfer Protocol then goes to the Receive state. If a message block is to be sent, then an ENQ is sent. If an EOT is received in response to the ENQ within the time limit T2, the Block Transfer Protocol goes to the Send state.

5.8.2.1 If the slave receives an ENQ in response to the ENQ, contention has occurred. The slave postpones the send of its block until it receives a block from the master. The slave prepares to receive the incoming block and sends an EOT. When the block transfer protocol returns to the Idle state, the postponed block Send may be sent as if it were a new send request. After a master sends an ENQ, it can ignore all characters except an EOT. After a slave sends at ENQ, it can ignore all characters except an ENQ or EOT.

5.8.2.2 When the time between sending ENQ and receiving EOT exceeds T2, or the time between sending the second checksum byte and receiving any character exceeds T2, or a non-ACK character is received within time T2 after sending the second checksum byte, the Line Control will increment the retry count ("tries" in the flowchart). If the retry count does not exceed the value of the RTY parameter, then the Block Transfer Protocol will retry sending the block beginning with ENQ. If the retry count does exceed the value of the RTY parameter, then a failed send has occurred.

5.8.3 *Send* — Once a send state is established, the first byte sent is the length, N, of the data in the block. After N more bytes have been sent, the two bytes of the checksum are sent. The sender computes the checksum based on the data in the block and the block header, but not the length byte. When the sender receives the ACK before time T2, the block is deemed properly sent. However, if the sender receives a non-ACK character before time T2, or no character within time T2, it returns to the line control state for a possible retry. In the Send state, characters received prior to sending the last checksum byte can be ignored.

5.8.4 *Receive* — Once a receive state is established, the first byte received is the length byte, N. The receiver counts and saves the following N + 2 bytes. The last two bytes are the checksum. The receiver compares the two checksum bytes against its own computation of the checksum. In a good block, the computed and received checksum are the same.

5.8.5 *Receive Completion* — After a block is correctly received, an ACK character is sent and the message protocol is notified that a block has been received. If T2 is exceeded while waiting for the length character, or Tl is exceeded between characters being received, then an NAK is sent. If the length byte is invalid or if the received checksum does not agree with the computed checksum, the receiver continues to listen for characters to ensure that the sender is finished sending. This is detected when the inter-character time exceeds T1, at which point the receive is aborted and a NAK is sent. In

any case when an NAK is sent, the receiver may discard any data it has received for the block. The receiver returns immediately to the Idle state after sending an ACK or NAK.

5.8.6 *Send Completion* — After the second checksum byte is sent, if an ACK is received within time T2, the message protocol is notified that the send was successful. If a failed send occurs, the message protocol is informed of the failure. Application-level software must take the possibility of a send failure into account.

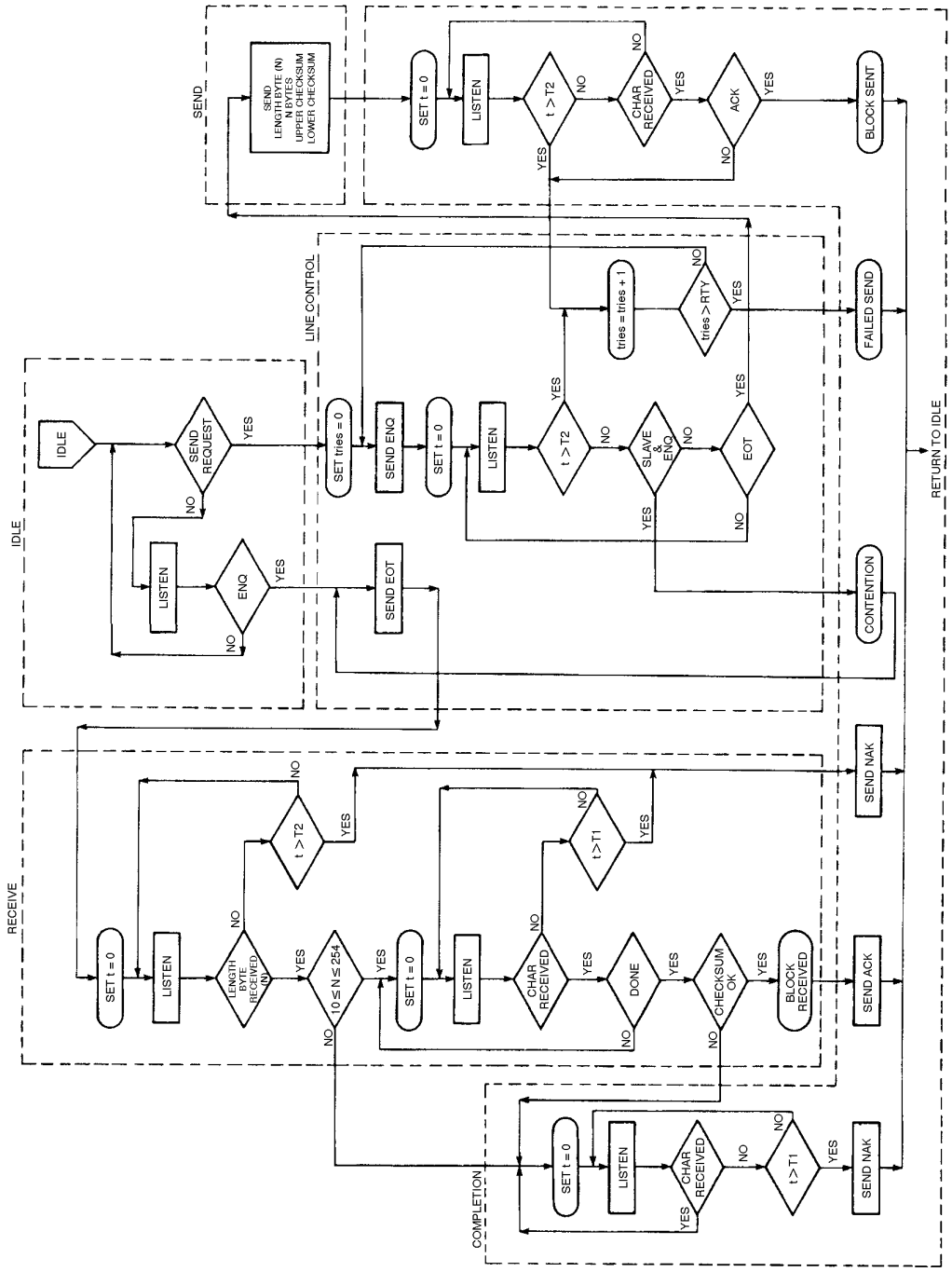

Figure 2

Block Transfer Protocol

6 Header Structure

6.1 The operation of all communications functions above the block transfer protocol is linked to information contained in a 10-byte data element called the header. The header is always the first 10 bytes of every block sent by the block transfer protocol. The information in the header is also used by the message protocol (see Section 7). The fixed format of the header is described in this section. The general header structure is shown in Figure 3.

NOTE: The header also contains information required by SECS-II.

6.2 *Reverse Bit (R-Bit)* — The reverse bit (R-bit) signifies the direction of a message. The R-bit is set to 0 for messages to the equipment and set to 1 for messages to the host. The R-bit is included in the header so that the direction of the message is contained in every block.

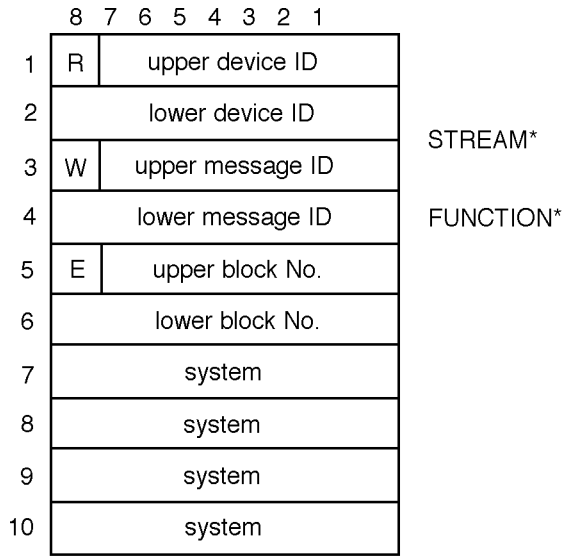

Figure 3

Block Header Structure

Table 3 Influence of the R-BIT

R-Bit	*Device ID*	*Message Direction*
0	Destination	Host to Equipment
1	Source	Equipment to Host

6.3 *Device ID* — The device ID defines the source or destination of the message depending upon the value of the R-bit as shown in Table 3. Device identification is a property of the equipment and must be settable according to Section 8. The host can view the device ID as a logical identifier connected with a physical device within the equipment. The host has no device ID.

6.4 *Wait Bit (W-Bit)* — The wait bit (W-bit) is used to indicate that the sender of a primary message expects a reply. A value of one in the W-bit means that a reply is expected. A value of zero in the W-bit means that no reply is expected. The W-bit must be set to zero in all secondary messages. For multi-block messages, the sender must ensure that the W-bit is the same in every block of the message.

6.5 *Message ID* — The message ID identifies the format and content of the message being sent (the particular message is one of many possible for the device in question). The exact message content is equipment-dependent. The upper message ID is the most significant portion of the ID.

6.5.1 *Primary Message* — A primary message is defined as any odd numbered message. An odd numbered message will have bit 1 of the lower message ID set to 1.

6.5.2 *Secondary Message* — A secondary message is defined as any even numbered message. An even-numbered message will have bit 1 of the lower message ID set to 0.

NOTE: In SECS-II, byte three of the header (excluding the W-bit) is known as the stream, and byte four of the header is known as the function. See SECS-II for more information.

6.6 *End Bit (E-Bit)* — The end bit (E-bit) is used to determine if a block is the last block of a message. A value of one in the E-bit means that the block is the last block. A value of zero means that more blocks are to follow.

6.7 *Block Number* — A message sent as more than one block is called a multi-block message. The first block is given a block number of one, and the block number is incremented by one for each subsequent block until the entire message is sent. The blocks of a multi-block message are sent in order. In a single-block message, the block number must have a value of zero or one. The maximum block number is 32,767. The upper block number is the most significant portion of the block number. (See also 7.2.)

6.8 *System Bytes* — The system bytes in the header of each message for a given device ID must satisfy the following requirements. (For a further discussion of system bytes, see Related Information R1-5.)

6.8.1 *Distinction* — The system bytes of a primary message must be distinct from those of all currently open transactions initiated from the same end of the communications link. They must also be distinct from those of the most recently completed transaction. (See Section 7.3.) They must also be distinct from any system bytes of blocks that were not successfully sent since the last successful block send.

6.8.2 *Reply Message* — The system bytes of the reply message are required to be the same as the system bytes of the corresponding primary message.

6.8.3 *Multi-Block Messages* — The system bytes of all blocks of a multi-block message must be the same.

7 Message Protocol

7.1 A message is a complete unit of communication in one direction. The message protocol uses the services of the block transfer protocol to send and receive messages. The message consists of the message data together with the following information from the header — R-bit, device ID, W-bit, message ID, and system bytes.

7.2 *Message Send* — When a message is ready to be sent, the message send protocol performs the functions described below. A block send failure terminates the message protocol action on that message.

7.2.1 *Message Length* — The maximum data length in a single block of a message is 244 bytes. The maximum number of blocks that can be sent in a multi-block message is 32,767, and so the maximum data length allowed in one message is 244 × 32,767 bytes.

7.2.2 *Message Blocking* — Message blocking is the division of the message data into blocks to be sent to the Block Transfer Protocol. For best performance, it is recommended, but not required, that the sender fill all blocks of a multi-block message, except possibly the last block, with the maximum 254 bytes. The receiver of a multi-block message should be able to accept any block size from 11 to 254 bytes, and should not require consecutive blocks necessarily to be the same size.

7.2.2.1 Certain older implementations may impose application-specific requirements on block sizes for certain incoming messages. Beginning with the 1988 revision of the standard, new applications may not impose application-specific requirements on incoming block sizes. Applications implemented before 1988 may impose such requirements.

NOTE: In SECS-II, certain messages are defined as single-block messages and must be sent as a single block in SECS-I.

7.2.3 *Header* — The message protocol must establish the header in each block of the message according to the requirements of Section 6.

7.2.4 *Interleaving Messages* — This standard allows, but does not require, the support of more than one concurrent open transaction. This standard allows, but does not require, the support of interleaving the blocks of different multi-block messages. (See documentation requirements in 9.)

7.3 *Transactions* — A transaction is a primary message and an optional corresponding secondary message is called the reply. A transaction is opened when a primary message is ready to be sent. A transaction is closed when the last block of a primary message requesting no reply has been sent, or when the last block of the reply has been received.

7.3.1 *Reply Linking* — When a reply is expected for a primary message, the message protocol starts the reply timer for the transaction after the last block of the message is successfully sent. When a primary message is sent for which a reply is requested, an expected block is established for the message receive algorithm. (See Section 7.4.) The expected block will have the complement of the R-bit, will have the same device ID, will be the first block of a secondary message, and will have the same system bytes as those of the given primary message.

NOTE: In SECS-II, the reply will have the same upper message ID (stream), and the lower message ID (function) will either be one greater than that of the corresponding primary message, or it will be zero.

7.3.2 *Reply Timeout, T3* — The reply timeout, T3, is a limit on the length of time that the message protocol is willing to wait after the last block of a primary message has been sent and before the arrival of the first block of the reply. If the first block of the reply does not arrive within the T3 limit, the expected block is removed from the list of expected blocks, and the transaction is aborted. A timer, called the reply timer, is used to measure the time between the last block of the primary message and the first block of its reply. Each open transaction for which a reply is expected requires a separate reply timer.

7.4 *Message Receive* — Each block successfully received by the block transfer protocol is passed to the message protocol. It is the task of the message protocol to identify the blocks and assemble them into the proper message.

7.4.1 *Routing Error* — When a piece of equipment receives a block of data which has a device ID in the block header which does not match its own device ID and it has no other knowledge of this device ID, it can assume that the block was sent in error.

7.4.2 *Duplicate Block Detection* — A duplicate block is a block which is exactly the same as the previous block received by the Block Transfer Protocol. This may occur when the receiver has sent an ACK but, for some reason, the ACK did not arrive in time at the sender, causing a send retry. A duplicate block is detected by the SECS-I message protocol by comparing the full 10-byte header of a block currently received by the block transfer protocol with the header of the last block accepted as non-duplicate by the message protocol. If the headers are identical, the new block is a duplicate and should be discarded. If the headers are different, the new block is a non-duplicate. The header of the non-duplicate block saved for comparison with the next block passed on by the block transfer protocol, and the block containing the header is further processed by the message receive algorithm.

NOTE: Some implementations which follow the 1980 version of SECS-I may not provide the unique headers required for duplicate block detection. An option for disabling the duplicate block detection is required to be compatible with these systems.

7.4.3 *Inter-Block Timeout T4* — The time interval between the successful receipt of a block in a multiblock message, and the successful receipt of the subsequent block of the same message, is limited to time T4. If this time is exceeded, the message is cancelled and the transaction is aborted. A time called the inter-block timer is used to measure the time between block arrivals in the message protocol. There must be one inter-block timer for each open multi-block message currently being received by the protocol. As each successive block of a message is received, the corresponding inter-block timer is reset.

7.4.4 *Algorithm* — When a block arrives at the message protocol, a combination of all the bytes in the header is used to determine what to do with the block. The operation of the message receive algorithm is to be understood by following the logic flow in Figure 4. The flow chart shown in Figure 4 and the description of the algorithm below are not meant to imply that particular implementation is required under this standard. However, any SECS-I message protocol implementation must include all the logic shown in Figure 4 on page 11.

7.4.4.1 The description of the message protocol uses the concepts of an expected block. When a (properly routed and non-duplicate) block is received by the message protocol, the first determination is whether the block is one of the expected blocks or not. In order to determine if a block is one of the expected blocks, the header information is compared with the header information in a list of expected blocks.

7.4.4.2 If the block is not one of the expected blocks, it must be the first block of a primary message, otherwise the block has been sent in error and can be discarded. If the block is the first block of a primary message, and it is not the last block of the message (E-bit = 0), an inter-block timer for the given message is established and set, and the expected block for the given message is set to have the same R-bit, device ID, system bytes, W-bit, message ID, and a block number one greater than that of the block just received.

7.4.4.3 If the block is one of the expected blocks, then it is either the first block of a reply message or it is part of an open message.

7.4.4.4 If the block is the first block of a reply message, the reply timer for the given message is cancelled. For the first block of a reply message, the expected block will have block number one (or possibly zero if the reply is a single block message) and will be a secondary message, but the full message ID is undetermined. (See Section 7.3.1.)

7.4.4.5 If the block is the last block of the given message (E-bit = 1), the message is complete. If the message is a primary message for which a reply is requested (W-bit = 1), the system bytes are saved for sending with the reply message. (See Section 7.2.3.)

7.4.4.6 If the block is not the last block of the message (E-bit = 0), then the inter-block timer for the given message is reset, and the (next) expected block for the given message is set to have the same R-bit, device ID, system bytes, W-bit, message ID, and a block number one greater than that of the block just received.

8 Parameter Setting

8.1 The eight protocol parameters are listed in Table 4. The selection of baud rate should be based on system performance. The value of the device ID is determined by the particular system requirements and is generally unique within one factory. The values of the next five parameters are determined by the performance characteristics of the host system and the baud rate of the communication channel. The first seven parameters must be adjustable by the user. All parameters must be stored in such a manner that the settings will be retained if the power fails or if the system software is reloaded. The range and resolution of protocol parameters must be at least as shown in Table 4. The M/S parameter is set to master in the equipment and to slave in the host.

Table 4 Protocol Parameters

Symbol	*Parameter Name*	*Typical Function*	*Typical Value*	*Range*	*Resolution*
BAUD	Baud Rate	Sets serial line speed	9600	300 - 9600	see Section 3.3
DEVID	Device ID	Identifier assigned to the equipment	—	0 - 32767	1
T1	Inter-Character Timeout	Detects an interruption between characters	0.5 sec.	0.1-10 sec.	0.1 sec.
T2	Protocol Timeout	Detects a lack of protocol response	10 sec.	0.2-25 sec.	0.2 sec.
T3	Reply Timeout	Detects a lack of reply message	45 sec.	1-120 sec.	1 sec.
T4	Inter-Block Timeout	Detects an interruption in a multi-block message	45 sec.	1-120 sec.	1 sec.
RTY	Retry Limit	The maximum number of send retries allowed	3	0 - 31	1
M/S	Master Slave	Contention resolution	—	—	—

9 Documentation

9.1 For equipment or host to comply with SECS-I, a document is required containing the following information. (See also SEMI E6, Facilities Interface Specifications Guideline and Format.)

1. Method for setting all the parameters in Table 4.
2. Range allowed and resolution for each parameter in Table 4.
3. Compatibility with duplicate block detection and the method for enabling and disabling the same if present (see Section 7.4.2).
4. Maximum expected inter-character, protocol, reply, and inter-block delays generated under normal operating conditions.
5. Whether multi-block messages are supported as a receiver.
6. Whether multi-block messages are used as a sender.
7. Whether there is a limit to the size of a message received and, if so, what the limit is.
8. Maximum expected size of a message being sent.
9. Whether message interleaving is supported as a receiver.
10. Whether message interleaving is used as a sender.
11. Number of device ID's supported on the port.
12. Maximum number of supported concurrent open transactions.

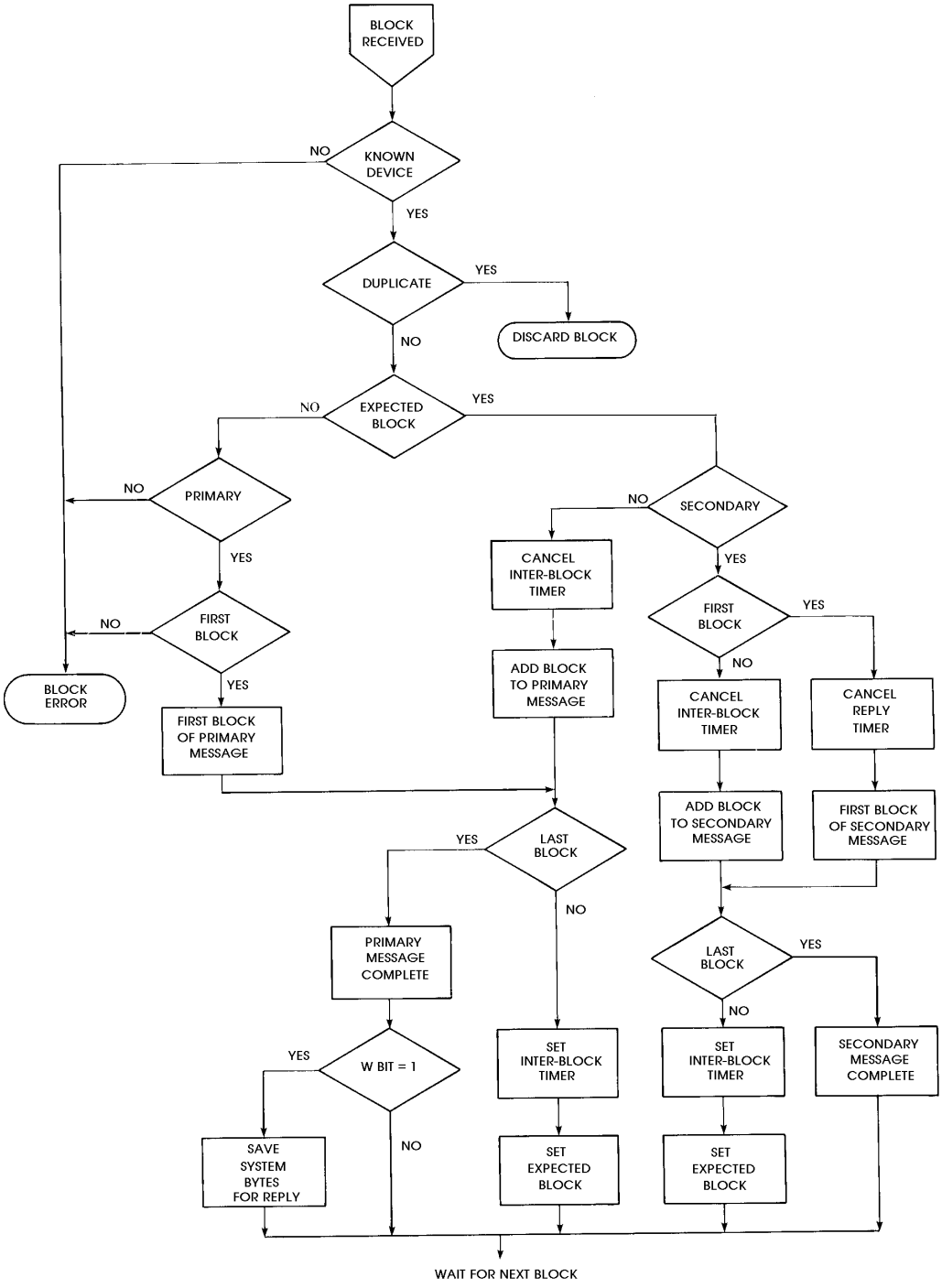

Figure 4

Message Receive Algorithm

SEMI E4-0699 © SEMI 1980, 1999

APPENDIX 1

A1-1 Differences from SECS-I 1980

This appendix describes the major differences between this version of the standard and the version originally adopted in 1980.

A1-1.1 *Signal Connections* — The required voltage levels for pins 18 and 25 on the 25 pin "D" connector are now optional.

A1-1.2 *Data Rate* — The 150 baud data rate has been made optional.

A1-1.3 *Timeout Parameters* — The T4 timeout, which limits the inter-block arrival time of multi-block messages, has been added. Use of the T3 timeout has been clarified.

A1-1.4 *Time Before Length Byte* — The protocol time with limit T2 is now used while waiting for the length byte after sending an EOT.

A1-1.5 *Block Send Acknowledgment* — Any character other than an ACK received after sending the second checksum byte is treated as an NAK.

A1-1.6 *Illegal Block Lengths and Bad Checksums* — An NAK code is sent for an illegal block length or for a bad checksum, but only after waiting for the sender to stop sending by forcing an inter-character (T1) timeout.

A1-1.7 *Block Number* — The wording describing the block number has been clarified to say that the value, zero, is allowed only for single block messages.

A1-1.8 *System Bytes* — The handling of the system bytes for secondary messages sent by a host is now the same as for the equipment. Also, specific functional requirements have been added for the content of the system bytes field.

A1-1.9 *Duplicate Blocks* — A mechanism for the detection of duplicate blocks has been added.

A1-1.10 *Messages* — The discussion of message assembly from blocks has been clarified and expanded.

A1-1.11 *Transactions* — The discussion of transaction handling and reply linking has been moved from SECS-II and expanded.

A1-1.12 *Appendix* — Parts of the Appendix have been moved to a new section called Related Information to distinguish the content from the standard itself. The general node transaction flow chart has been moved from the Appendix in SECS-II to the Related Information in SECS-I.

A1-1.13 *Titles* — The title of SECS-I has been changed from "Data Link" to "Message Transfer." This phrase more accurately covers the content of the standard and avoids confusion with other uses of the term "data link." The title of the "Data Link" section of SECS-I has been changed to "Block Transfer." The "Data Link Control" portion of the Block Transfer Protocol has been retitled "Line Control."

A1-1.14 *W-Bit* — The W-bit is now required to be set consistently in all blocks.

A1-1.15 *Documentation* — A section has been added on the documentation required for compliance with the standard.