EOS Industry Best Practices and special cases found during EFC visits

Document for customer / assembly sites to learn about EOS and prevent / overcome EOS related issues.

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1. EOS remarks

- General EOS definition: ‘Damage as result of an electrical condition applied to a semiconductor component that exceeds the limiting values’.
- Destructive levels are determined by the amount of energy applied in a certain amount of time.
- EOS damage itself is not a rootcause !
- EOS damage can be the result of consecutive failure mechanisms
- Extreme damage can cover up the rootcause evidence
- Any device can be damaged at some point.
- A device that can withstand all EOS treats is not feasible (due to costs and physical limitations/maximum ratings).
- For rootcause determination it is necessary to know as much as possible about the conditions whereby the device failed.

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2. ESD control in Assembly lines

The six basic principles of static control are:

1. Design in protection
2. Define the level of control needed in your environment
3. Identify and define the electrostatic protected areas (EPA)
4. Reduce electrostatic charge generation
5. Dissipate and neutralize
6. Protect products

The six key elements to ESD control program development and implementation are:

1. Establish an ESD Coordinator and ESD teams
2. Assess your organization, facility, processes and losses
3. Establish and document your ESD control program plan
4. Build justification to get the top management support
5. Develop and implement a training plan
6. Develop and implement a compliance verification plan

1. Basic ESD Control Procedures and Materials

Design in protection by designing products and assemblies to be as robust as reasonable from the effects of ESD.
Define the level of control needed in your environment.
Identify and define the electrostatic protected areas (EPAs), the areas in which you will be handling ESD sensitive parts (ESDS).
Reduce Electrostatic charge generation by reducing and eliminating static generating processes, keeping processes and materials at the same electrostatic potential, and by providing appropriate ground paths to reduce charge generation and accumulation.
Dissipate and neutralize by grounding, ionization, and the use of conductive and dissipative static control materials.
Protect products from ESD with proper grounding or shunting and the use of static control packaging and material handling products.

Which areas of our facility need ESD protection?"
This allows to define specific electrostatic protected areas (EPAs), the areas where sensitive parts are handled so the locations where ESD control needs to be implemented.

Typical facility areas requiring ESD protection:

1. Receiving
2. Inspection
3. Stores and warehouses
4. Assembly
5. Test and inspection
6. Research and development

7. Packaging
8. Field service repair
9. Offices and laboratories
10. Cleanrooms

2. Grounding

Grounding is especially important for effective ESD control; it should be clearly defined, and regularly evaluated.

The equipment grounding conductor provides a path to bring ESD protective materials and personnel to the same electrical potential. All conductors and dissipative materials in the environment, including personnel, must be bonded or electrically connected and attached to a known ground, or create an equipotential balance between all items and personnel. ESD protection can be maintained at a charge or potential above a "zero" voltage ground reference as long as all items in the system are at the same potential.
It is important to note that insulators, by definition non-conductors, cannot lose their electrostatic charge by attachment to ground.

This ESD common point ground should be properly identified. ESD Association standard ANSI/ESD S8.1 – Symbols, recommends the use of the symbol under to identify the common point ground.

The second step is to connect the common point ground to the equipment grounding conductor (AC ground) or the third wire (typically green) electrical ground connection. This is the preferred ground connection because all electrical equipment at the workstation is already connected to this ground. Connecting the ESD control materials or equipment to the equipment ground brings all components of the workstation to the same electrical potential.

3. Controlling Static on Personnel and Moving Equipment

People can be one of the prime generators of static electricity. The simple act of walking around or the motions required in repairing a circuit board can generate several thousand volts of electrostatic charge on the human body. If not properly controlled, this static charge can easily discharge into an ESD sensitive device.

a. Wrist Straps

Typically, wrist straps are the primary means of grounding personnel. When properly worn and connected to ground, a wrist strap keeps the person wearing it near ground potential. Because the person and other grounded objects in the work area are at or near the same potential, there can be no hazardous discharge between them. In addition, static charges are removed from the person to ground and do not accumulate. When personnel are seated on a chair which is not EPA appropriate, they are to be grounded using a wrist strap.

Wrist straps have two major components, the wristband that goes around the person's wrist and the ground cord that connects the wristband to the common point ground.
Wrist straps have several failure mechanisms and therefore should be tested on a regular basis. Either daily testing at specific test stations or using a continuous monitor at the workbench is recommended.

b. Floors, Floor Mats, Floor Finishes

A second method of grounding personnel is a Flooring/Footwear System using ESD flooring in conjunction with ESD control footwear or foot grounders. This combination of conductive or dissipative floor materials and footwear provides a safe ground path for the dissipation of electrostatic charge, thus reducing the charge accumulation on personnel. In addition to dissipating charge, some floor materials (and floor finishes) also reduce triboelectric charging. The use of a Flooring/Footwear System is especially appropriate in those areas where increased personnel mobility is necessary. In addition, floor materials can minimize charge accumulation on chairs, mobile equipment (such as carts and trolleys) and other objects that move across the floor. However, those items require dissipative or conductive casters or wheels to make electrical contact with the floor, and components to be electrically connected. When used as the personnel grounding system, the resistance to ground including the person, footwear and floor must be the same as specified for wrist straps (<35 megohms) and the accumulation body voltage in a standard walking voltage test must be less than 100 volts.

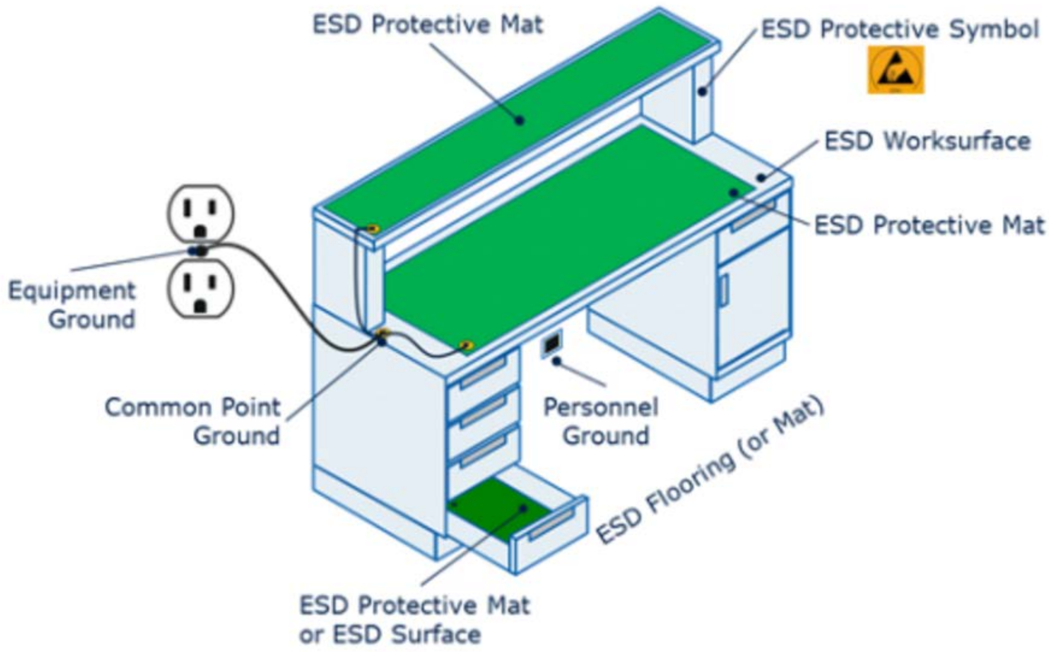
c. Shoes, Grounders, Casters

Used in combination with ESD flooring, static control shoes, foot grounders, casters and wheels provide the necessary electrical contact between the person or object and the flooring. Insulative footwear, casters, or wheels prevent static charges from flowing from the body or mobile equipment to the floor to ground and, therefore, have to be avoided.

d. Clothing

Clothing is a consideration in some ESD protective areas, especially in cleanrooms and very dry environments. Clothing materials, particularly those made of synthetic fabrics, can generate electrostatic charges that may discharge into ESDS or they may create electrostatic fields that may induce charges. Because clothing usually is electrically insulated or isolated from the body, charges on clothing fabrics are not necessarily dissipated to the skin and then to ground. Static control garments may suppress or otherwise affect an electric field from clothing worn underneath the garment.

e. Workstations and worksurfaces



An ESD protective workstation refers to the work area of a single individual that is constructed and equipped with materials and equipment to limit damage to ESD sensitive items. It may be a stand-alone station in a stockroom, warehouse, or assembly area. A workstation also may be located in a controlled area such as a cleanroom. The key ESD control elements comprising most workstations are a static dissipative worksurface, a means of grounding personnel (usually a wrist strap), a common point ground, and appropriate signage and labeling.

The workstation provides a means for connecting all worksurfaces, fixtures, handling equipment, and grounding devices to a common point ground. In addition, there may be provision for connecting additional personnel grounding devices, equipment, and accessories such as constant or continuous monitors and ionizers.

Static protective worksurfaces with a resistance to ground of 1 megohm to 1 gigohm provide a surface that is at the same electrical potential as other ESD control items at the workstation. They also provide an electrical path to ground for the controlled dissipation of any static charges on materials that contact the surface. The worksurface also helps define a specific work area in which ESDS are to be handled. The worksurface is connected to the common point ground.

f. Continuous or Constant Monitors

Continuous (or constant) monitors are designed to provide ongoing testing of the wrist strap system. While a number of technologies are utilized, the goal remains consistent: electrical connections are tested between the ground point, ground cord, wristband and person's body while the wearer handles ESDS. Continuous monitors may also provide a monitoring circuit for the ESD worksurface or other equipment connection to the ground reference.

Typical test programs recommend that wrist straps that are used daily should be tested daily. However, if the products that are being produced are of such value that knowledge of a continuous, reliable ground is needed, and then continuous monitoring should be considered or even required.
Tools used for monitoring will need to be regularly checked (monitor schema needs to be available recorded). The actual status (last date proven to be ok) needs to be visible on the tool.

g. Production Equipment and Production Aids

Grounding is the primary means of controlling static charge on equipment and many production aids. Electrical equipment is required to be connected to the equipment ground (the green wire) in order to carry fault currents. This ground connection also will function for ESD control purposes. All electrical tools and equipment used to process ESD sensitive hardware require the 3 prong grounded type AC plug.
Hand tools that are not electrically powered, i.e., pliers, wire cutters, and tweezers, are usually grounded through the ESD worksurface and the grounded person using the conductive/dissipative tools.
Holding fixtures should be made of conductive or static dissipative materials when possible. Static dissipative materials are often suggested when very sensitive devices are being handled. A separate ground wire may be required for conductive or dissipative fixtures not in contact with an ESD worksurface or handled by a grounded person.
For those items that are composed of insulative materials, the use of ionization is required to control electrostatic charge generation and accumulation of static charges.

h. Gloves and Finger Cots

Certainly, grounded personnel handling ESDS should not be wearing gloves or finger cots made from insulative material. If gloves or finger cots are used, the material must be dissipative or conductive.
Gloves need to be clean and especially free from conductive particles (like metal or carbon particles).

i. Packaging and Handling

Inside the EPA packaging and material handing containers are to be low charging and be dissipative or conductive. Outside the EPA packaging and material handing containers are to also have a structure that provides electrostatic discharge shielding.

Direct protection of ESDS devices from electrostatic discharge is provided by packaging materials such as shielding bags, corrugated boxes, and rigid or semi-rigid plastic packages. The primary use of these items is to protect the product when it leaves the facility, usually when shipped to a customer. In addition, materials handling products such as tote boxes and other containers primarily provide protection during inter- or intra-facility transport.

The main ESD function of these packaging and materials handling products is to limit the possible impact of ESD from triboelectric charge generation, direct discharge, and in some cases electrostatic fields. The initial consideration is to have low charging materials in contact with ESD sensitive items. For example, the low charging property would control triboelectric charge resulting from sliding a board or component into the package or container. A second requirement is that the material can be grounded so that the resistance range must be conductive or dissipative. A third property required outside the EPA is to provide protection from direct electrostatic discharges that is discharge shielding.

Resistance or resistivity measurements help define the material's ability to provide electrostatic shielding or charge dissipation. Electrostatic shielding attenuates electrostatic fields on the surface of a package in order to prevent a difference in electrical potential from existing inside the package.

4. Ionization

Most static control programs also deal with isolated conductors that are not grounded, or insulating materials (e.g., most common plastics) that cannot be grounded.

Air ionization must be used to neutralize the static charge on insulated and isolated objects by producing a balanced source of positively and negatively charged ions. Whatever static charge is present on objects in the work environment will be reduced, neutralized by attracting opposite polarity charges from the air. Because it uses only the air that is already present in the work environment, air ionization may be employed even in cleanrooms.

Air ionization is one component of a complete ESD control program, and not a substitute for grounding or other methods. Ionizers are used when it is not possible to properly ground everything and as backup to other static control methods. In cleanrooms, air ionization is one of the few methods of static control available.

5. Cleanrooms

Many objects integral to the semiconductor manufacturing process (quartz, glass, plastic, and ceramic) are inherently charge generating. Because these materials are insulators, this charge cannot be removed by grounding. Many static control materials contain carbon particles or surfactant additives that sometimes restrict their use in cleanrooms. In these circumstances, ionization and flooring/footwear grounding systems become key weapons against static charge.

6. Identification

A final element in an ESD control program is the use of appropriate symbols to identify ESD sensitive items, as well as specialty products intended to control ESD. The two most widely accepted symbols for identifying ESDS parts or ESD control protective materials are defined in ESD Association Standard ANSI/ESD S8.1 — ESD Awareness Symbols.

a. ESD Susceptibility Symbol

The ESD Susceptibility Symbol consists of a triangle, a reaching hand, and a slash through the reaching hand. The triangle means "caution" and the slash through the reaching hand means "Don't touch." Because of its broad usage, the hand in the triangle has become associated with ESD and the symbol literally translates to "ESD sensitive stuff, don't touch."

The ESD Susceptibility Symbol is applied directly to integrated circuits, boards, and assemblies that are ESD sensitive. It indicates that handling or use of this item may result in damage from ESD if proper precautions are not taken. Operators should be grounded prior to handling. If desired, the sensitivity level of the item may be added to the label.

b. ESD Protective Symbol

The ESD Protective Symbol consists of the reaching hand in the triangle. An arc around the triangle replaces the slash. This "umbrella" means protection. The symbol indicates ESD protective material. It is applied to mats, chairs, wrist straps, garments, packaging, and other items that provide ESD protection. It also may be used on equipment such as hand tools, conveyor belts, or automated handlers that is especially designed or modified to provide ESD control properties (low charging, conductive/dissipative resistance, and/or discharge shielding). Only bags with these symbols are ESD safe all other are not.

3. EOS rootcauses and Fishbone

a) EOS caused by external Electrical conditions

EOS damage is caused by an electrical overstress beyond the limiting values of a device. It results in thermal damage to a component’s circuitry. The amount of damage caused by EOS depends on the magnitude and duration of electrical transient pulse widths. We can broadly classify the duration of pulse widths into long >100 μs and short <100 μs types.

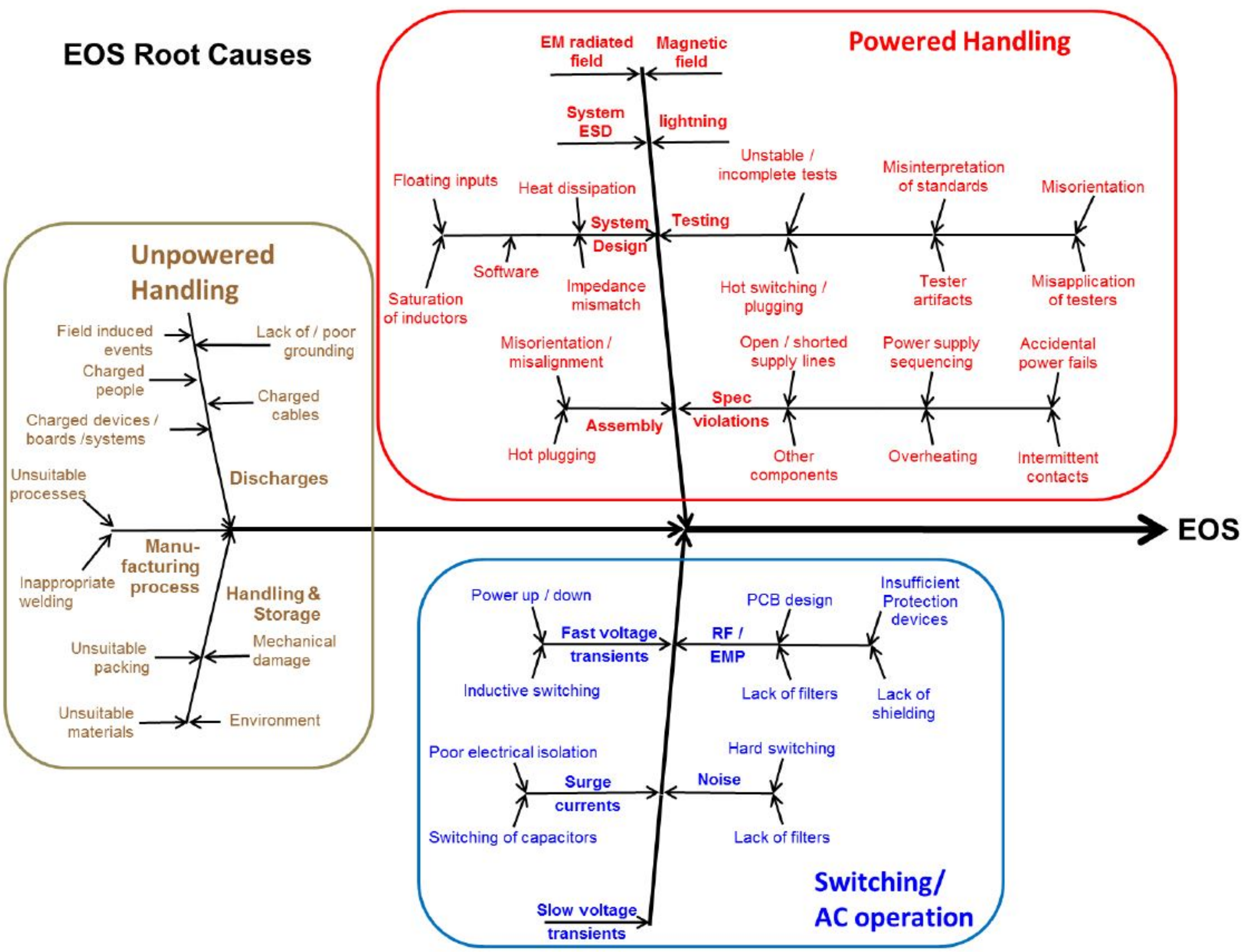
- For short pulse widths the most common failure mode is junction spiking.
- For long electrical pulse widths the most common failure modes are melted metallization that can include carbonized covering.

- Open bond wires can be caused when exceeding the 1A range by long pulse.

b) EOS rootcauses

- Inadequate work procedures
- Lack of power line filters
- Lack of power supply over voltage protection circuits
- Lack of power supply grounding
- Loose connections causing intermitting events
- Hot switching effect
- Incorrect test sequence such as application of signal before powering up the device
- Application of excessive voltages to chip beyond product specification
- Charged cable connections
- Possible actions must be taken with respect to the conditions at the customer's side.

c) The EOS root cause fishbone diagram:



4. Special cases found during EFC visits at various customers

a. Use of non ESD safe components during assembly

Non ESD safe components should not be used…
IF this is not possible these components should be absolutely free of any charge when used during assembly.
Ionizers are a must to discharge (since isolative materials cannot be grounded to discharge).

Example non ESD safe components.

b. Non-equal length from pins sticking out from the PCB/application board

In case too long pins are sticking out from the PCB/Application board they may only be corrected/cut after the complete board is at 0V by sufficient time under an ionizer(s).
Risk is that for instance capacitors will discharge and (pre) damage board components (IC's).

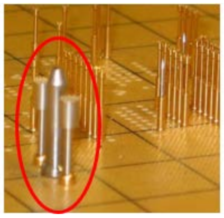
c. Ionizers before and after test

In many cases not all components can be properly discharged.
So always have an ionizer directly before boards are tested (at every test station).
Make sure boards stays long enough in the ionizer air flow until all components/100% discharged.
Also have an ionizer after test to 100% ensure no any voltage is left after test.

Example of a bulk capacitor directly after discharge in the application; some Voltage (up to 8V) can occur again (in about 30sec). If this discharges via an IC it might be (pre)damaged.

d. Testing

- Always contact ground first and last in order to minimize metal to metal contact issues



Elevated ground pin(s) in red oval

- Ensure proper testing of components and boards:
  - Check test programs for hot switching and incorrect test sequence
  - Solicit maximum specification ratings from manufacturers to ensure devices are not overstressed
  - Ensure reliability stress tests are properly designed, especially during burn-in.
  - Check for excessive noise levels
  - Use “transzorbs” to clamp voltage spikes

e. Laser marking placement (bulk) elcap

Lasers (especially during marking when high currents are used) can produce charges. So after usage of lasers an ionizer needs to be used to discharge products / application boards.

f. Sufficient discharging after testing

If boards are not (completely) discharged after test discharges may take place during a next assembly phase causing (pre)damage to board components.
The last step of a test-routine must consist a discharge step.
After test there always needs to be an ionizer to discharge completely, even when a discharge step is implemented in the testprogram.

g. Repair station ESD conditions

All ESD precautions needs to be taken for assembly lines but also for locations where repairs are performed from a certain assembly line.
In repair stations exact the same ESD conditions need to be there.

h. Conductive contamination

Metal particles (e.g. scraping remains of application enclosures, insertion of frame parts) Particles can be transported though gloves and become stuck at the printed circuit board surface. At appliance of power foreign conductive particles can cause leakage paths / shorts resulting in EOS.

Cleaning from work surfaces should be performed daily and gloves should be new or regularly washed.

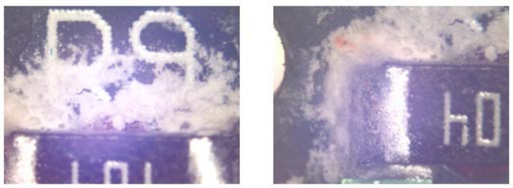
i. Flux cleaning

Left over Flux can create high ion concentrations at boards leading to:

- unwanted electrical path/contacts between components on the board
- corrosion from components on the board

Remaining flux from soldering needs to be removed after the soldering process has been completed.

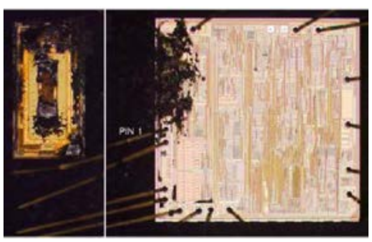
This applies also to so called “no clean flux” since it is known by now that even for this kind of flux still too much flux and because of that ions remain on boards.



Concentrated flux remnants.

j. Insufficient Surge Protection

Due to a too low rating for the external MOSFET massive EOS occurred. By changing from 600V to 650V external MOSFET the EOS was solved and the Surge rating went op 3 times higher (1,1 KV → 3,5KV; not leading to fails anymore).



k. Usage isolated tools (line and repair stations)

Isolated tools (so non ESD safe) can/will have very high charges (over 2-3KV), so always ESD safe tools need to be used.

Normal tools which can be bought in a normal construction market may not be used: all tools need to be ESD safe!

5. Further information/links

- NXP all documentation: http://www.nxp.com/support/documentation:DOCUMENTATION
- NXP datasheets (search for product):

http://www.nxp.com/search?client=search_documents&site=nxp_en&lang_cd=en&ulang=en&output=xml_no_dtd&proxystylesheet=nxp_search_style_fe&filter=0&getfields=*&rc=1&ie=UTF-8&ulang=en&access=p&sort=date:D:L:d1&entqr=3&entqrm=0&oe=UTF-8&ud=1&q=+inmeta:Asset_Type%3DDocuments+inmeta:type%3DData%2520Sheets&dnavs=inmeta:Asset_Type%3DDocuments+inmeta:type%3DData%2520Sheets

- NXP Application notes (search for product): http://www.nxp.com/search?client=search_documents&site=nxp_en&lang_cd=en&ulang=en&output=xml_no_dtd&proxystylesheet=nxp_search_style_fe&filter=0&getfields=*&rc=1&ie=UTF-8&ulang=en&access=p&sort=date:D:L:d1&entqr=3&entqrm=0&oe=UTF-8&ud=1&q=+inmeta:Asset_Type%3DDocuments+inmeta:type%3DApplication%2520Notes&dnavs=inmeta:Asset_Type%3DDocuments+inmeta:type%3DApplication%2520Notes

- NXP user manuals (search for product): http://www.nxp.com/search?client=search_documents&site=nxp_en&lang_cd=en&ulang=en&output=xml_no_dtd&proxystylesheet=nxp_search_style_fe&filter=0&getfields=*&rc=1&ie=UTF-8&ulang=en&access=p&sort=date:D:L:d1&entqr=3&entqrm=0&oe=UTF-8&ud=1&q=+inmeta:Asset_Type%3DDocuments+inmeta:type%3DUsers%2520Guides&dnavs=inmeta:Asset_Type%3DDocuments+inmeta:type%3DUsers%2520Guides

- EOS/ESD Association - esda.org: https://www.esda.org/about-esd/esd-fundamentals including Chinese translated documents