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IPC-2511B

Generic Requirements for Implementation of Product Manufacturing Description Data and Transfer XML Schema Methodology

IPC-2511B

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A standard developed by IPC

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IPC-2511B

GenCAM

[MANGN]

Generic Requirements for Implementation of Product Manufacturing Description Data and Transfer XML Schema Methodology

A standard developed by the IPC Electronic Data Transfer Generic Requirements Task Group (2-11i) of the IPC Data Generation and Transfer Committee (2-10) of IPC.

The GenCAM format is intended to provide CAD-to-CAM, or CAM-to-CAM data transfer rules and parameters related to manufacturing printed boards and printed board assemblies.



Users of this standard are encouraged to participate in the development of future revisions.

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Acknowledgment

Any Standard involving a complex technology draws material from a vast number of sources. While the principal members of the IPC Electronic Data Transfer Generic Requirements Task Group of the IPC Data Generation and Transfer Committee are shown below, it is not possible to include all of those who assisted in the evolution of this standard. To each of them, the members of the IPC extend their gratitude.

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Generic Requirements for Implementation of Product Manufacturing Description Data and Transfer Methodology (MANGN)

1 SCOPE

This standard specifies the XML schema that represents the data file format used to describe printed board and printed board assembly products with details sufficient for tooling, manufacturing, assembly, inspection and testing requirements. This format may be used for transmitting information between a printed board designer and a manufacturing or assembly facility. The data is most useful when the manufacturing cycle includes computer-aided processes and numerical control machines.

The data can be defined in either English or International System of Units (SI) units.

1.1 GenCAM Focus

The GenCAM format requirements are provided in a series of standards focused on printed board manufacturing, assembly, inspection, and testing. This standard series consists of a generic standard (IPC-2511) which contains all the general requirements. There are seven sectional standards that are focused on the XML details necessary to accumulate information in the single GenCAM file, that addresses the needs of the manufacturing disciplines producing a particular product. The sectional standards (IPC-2512 through 2518) paraphrase the important requirements and provide suggested usage and examples for the topic covered by the sectional standard.

2 APPLICABLE DOCUMENTS

IPC-T-50	Terms and Definitions for Interconnecting and Packaging Electronic Circuits
IPC-2512	Sectional Requirements for Implementation of Administrative Methods for Manufacturing Data Description
IPC-2513	Sectional Requirements for Implementation of Drawing Methods for Manufacturing Data Description
IPC-2514	Sectional Requirements for Implementation of Printed Board Fabrication Data Description
IPC-2515	Sectional Requirements for Implementation of Bare Board Product Electrical Testing Data Description
IPC-2516	Sectional Requirements for Implementation of Assembled Board Product Manufacturing Data Description
IPC-2517	Sectional Requirements for Implementation of Assembly In-Circuit Testing Data Description
IPC-2518	Sectional Requirements for Implementation of Part List Product Data Description
IPC-2524	PWB Fabrication Data Quality Rating System
IPC-2525	Bareboard Electrical Test Quality Rating System
IPC-2526	Printed Board Assembly Data Quality Rating System

IPC-2527	In-Circuit Test Data Quality Rating System
IPC-2571	Generic Requirements for Electronics Manufacturing Supply Chain Communication – Product Data eXchange (PDX)
IPC-2576	Sectional Requirements for Electronics Manufacturing Supply Chain Communication of As-Built Product Data – Product Data eXchange (PDX)
IPC-2578	Sectional Requirements for Supply Chain Communication of Bill of Material and Product Design Configuration Data - Product Data eXchange (PDX)?
IPC-4101	Specification for Base Materials for Rigid Board and Multilayer Printed Boards
IPC-4103	Specification for Base Materials for High Speed/ High Frequency Applications
IPC-4104	Specification for High Density Interconnect (HDI) and Microvia Materials

2.1 Documentation Conventions

The XML file format standard and the XML Schema definition language standard, as defined by the World Wide Web Consortium (W3C), have been adopted by IPC for use in the IPC-2500 series of standards. As a consequence of this change the IPC-2511 document has undergone a significant rewrite. The underlying object model of the standard has changed very little, but the examples, definitions, and organization of information have been rewritten to using the new file format and a new notation for specifying the file format. An example will help illustrate why the object model has not changed significantly.

The first example demonstrates the IPC-2511A syntax for keyword statements:

```
GROUP: "bd1";
  LINEDESC: "Line9", 1.0, SQUARE , , CENTER, 8.0, 40.0,
            TP, BOTH, 2.5, 1.3;
```

Here is the same content using the XML syntax for elements and attributes:

```
<LineDesc id = "bd1:line9" width = "1.0" lineEnd = "SQUARE"
  type = "CENTER" space = "8.0" length = "40" lineMod = "TP"
  modEnd = "BOTH" dimA = "2.5" dimB = "1.3"/>
```

This next example demonstrates the use of a <linedesc_ref> parameter that references the element defined in the last example:

```
RECTCENTER: 2, 4, "bd1"."line9", , , (0,0);
```

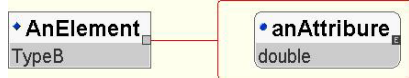
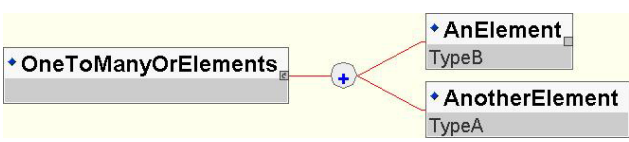
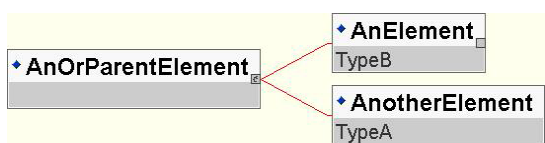
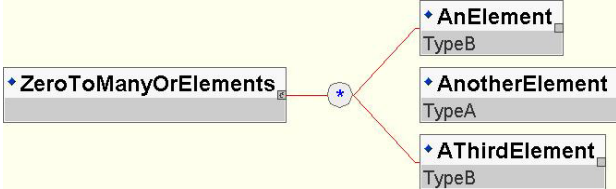
Here is the RECTCENTER example using the XML format of elements and attributes:

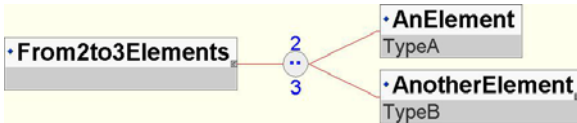
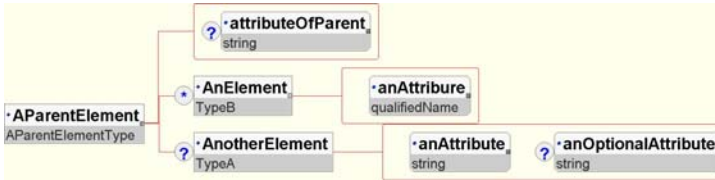
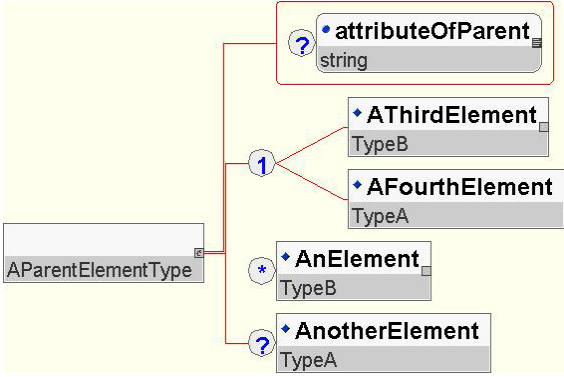
```
<RectCenter width = "4" height = "2" lineDescRef = "bd1:line9">
  <Place x = "0" y = "0"/>
</RectCenter>
```

Note that the information content is unchanged. There are a few organizational changes, but the primary change is just syntactical.

In addition to the text based schema notation this document provides graphical representation of the structure of the new file format. The new diagrams are designed to effectively illustrate the structure and cardinality of elements and attributes that make up a GenCAM file. The notation in

the graphics does not provide a complete visualisation of the schema definition for the file format, but it does provide a good top down overview. Should there be any conflict between the graphical notation and the schema notation, the authoritative definition is the schema notation.. The following table provides an overview of the graphical notation used in the document.

This diagram depicts an element named <code>AnElement</code> that is of type <code>TypeB</code>. There is one attribute, named <code>anAttribute</code>, that is of type <code>double</code>. The attribute is required.	
Example: <pre><AnElement anAttribute="14.44e-3"/></pre> Note that all attribute values must be enclosed in quotes, regardless of type.	
This diagram depicts an element with two attributes. The attribute <code>anAttribute</code> is required. The "?" in the circle indicates that the second attribute, <code>anOptionalAttribute</code>, is optional. Both attributes are of type <code>string</code>.	
Examples: <pre><AnotherElement anAttribute="red" anOptionalAttribute="a string" /></pre> <pre><AnotherElement anAttribute="blue" /></pre>	
The element <code>OneToManyOrParentElement</code> is the parent of an unordered list of one or more instances of the elements <code>AnElement</code> and <code>AParentElement</code>. The "+" indicates the occurrence is one to many and the angled lines indicate this is a choice relationship (" ") between the children elements.	
< <code>OneToManyOrParentElement</code> >...	
The absence of an occurrence bubble declares that one and only one occurrence are allowed. The <code>AnOrParentElement</code> can have one of <code>AnElement</code> or <code>AnotherElement</code> as a child element.	
The "*" in the occurrence bubble indicates the choice is from 0 to many.	

This diagram depicts an element, From2to3Elements. The element has no type and no attributes. It can have from 2 to 3 subelements of either AnElement or AnotherElement.	 The diagram shows a box labeled 'From2to3Elements' connected to a central node with two paths. The top path leads to a box labeled 'AnElement' with 'TypeA' below it, and the bottom path leads to a box labeled 'AnotherElement' with 'TypeB' below it. The central node has a '2' on the top path and a '3' on the bottom path, indicating a range of 2 to 3 subelements.
This diagram depicts an element, AParentElement, of type AParentElementType. This element has one attribute, attributeOfParent, which is optional. The lines with square corners indicate that occurrences of AnElement and AnotherElement must appear in the order shown.	 The diagram shows a box labeled 'AParentElement' with 'AParentElementType' below it. It has an attribute box labeled 'attributeOfParent' with 'string' below it and a question mark in a circle. Below the element box are two subelement boxes: 'AnElement' with 'TypeB' and 'AnotherElement' with 'TypeA'. Lines with square corners connect the element box to these subelements. To the right, there are attribute boxes: 'anAttribute' with 'qualifiedName' and 'string', and 'anOptionalAttribute' with 'string' and a question mark in a circle.
This diagram depicts a type, AParentElementType, that contains a sequence starting with one of AThirdElement or AFourth element followed by 0-n AnElement and an optional final AnotherElement.	 The diagram shows a box labeled 'AParentElementType'. It has a sequence of subelements: first, a box labeled 'attributeOfParent' with 'string' and a question mark in a circle; then a box labeled '1' with two paths leading to 'AThirdElement' (TypeB) and 'AFourthElement' (TypeA); then a box labeled '*' with a path leading to 'AnElement' (TypeB); and finally a box labeled '?' with a path leading to 'AnotherElement' (TypeA).

3 REQUIREMENTS

The XML schema contained in this document describes the structure of a generic computer-aided manufacturing (GenCAM) exchange format. The document specifies data elements specifically designed to establish the information exchange related to the data needed by printed board manufacturing, assembly, inspection, and test.

The GenCAM XML schema defines the configuration of mandatory and optional elements, as well as mandatory and optional attributes. The top-level of the GenCAM schema contains forty-three elements. The schema notation specifies that the 43 top-level elements are required to appear in the order shown in Figure 1. The order of appearance in the file is significant. For instance, the appearance of graphics on a layer is dependent on the order of appearance in the file. The order is also important because elements often reference information that is defined elsewhere in the file in order to eliminate redundancy within the file. The file is structured to allow all references to be resolved in one pass.

An implementation of the XML schema must be able to facilitate the reading and writing of all characteristics defined within the requirements stated in this standard.

Each element has a specific function or task respectively. Accordingly, the information interchange for a specific purpose is possible only if that element is populated. The ability to select those characteristics that are appropriate for a given task makes the schema a robust methodology for defining only those areas and characteristics that is necessary to produce a given product. The following table lists the children elements of the GenCAM element.

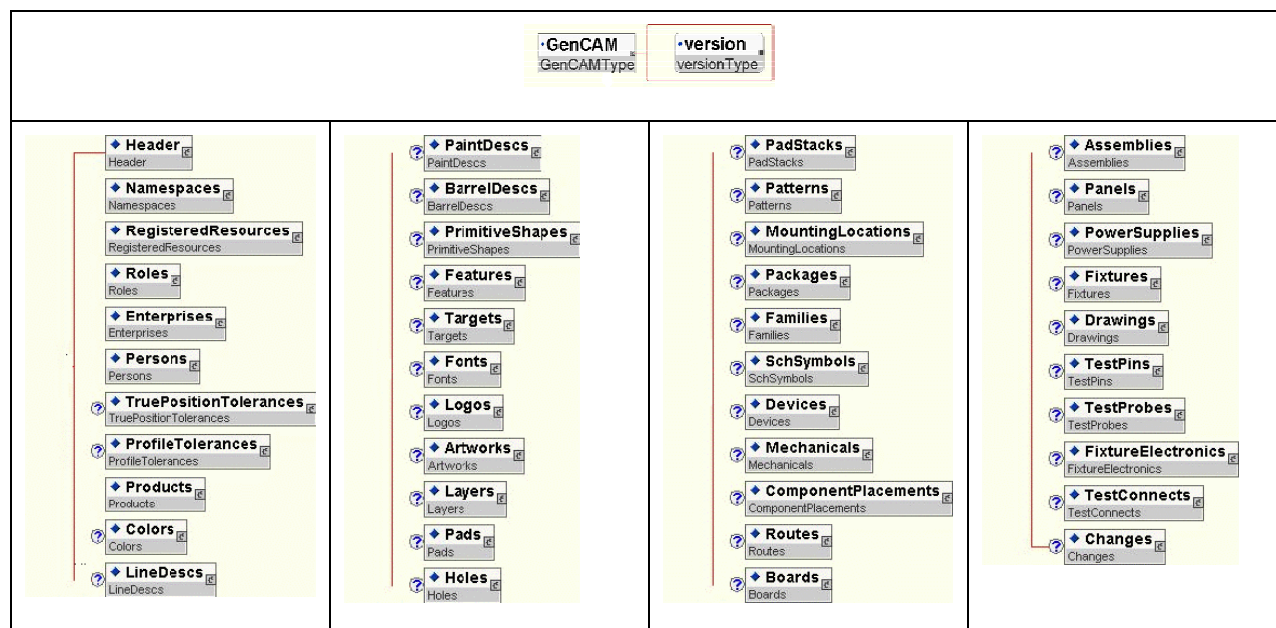


Figure 1 The GenCAM children element

3.1 Rules concerning the use of XML and XML Schema

The rules required to define syntax and semantics of the GenCAM file format notation have been simplified by the adoption of the W3C standards for XML Schema and XML file formats. These two standards are well specified by the W3C. The popularity of these standards has lead to the development of many commercial and open source software tools and libraries that conform to the W3C standards.

A GenCAM file begins with the `<GenCAM revision = "2.0">` tag and end with the `</GenCAM>` tag. The content between these tags must match the xsd definition of the GenCAM element as defined by the *GenCAM XML Schema*.

3.1.1 File Readability and Uniformity

A valid GenCAM file must conform to the *W3C Canonical XML* format. The format is defined by the <http://www.w3.org/TR/xml-c14n> specification. Software tools exist that will take malformed XML and automatically generate Canonical XML.

3.1.2 File Markers

An optional checksum can be appended following the `</GenCAM>` tag. The checksum is an MD5 message digest algorithm (see *Internet RFC 1321*: <http://www.ietf.org/rfc/rfc1321.txt>) that is

base64 encoded. The checksum starts with the "<" character of the <GenCAM> tag and ending with the ">" character of the closing </GenCAM> tag. The checksum followings immediately after the ">" character of the closing </GenCAM> tag.

The digest provides a 128-bit checksum of the GenCAM file contents. The MD5 signature must be base64 encoded (see *IETF RFC 1421* for the base64 algorithm) to convert the MD5 signature to an US-ASCII, base64 string. An end of line character will indicate the end of the base64 encoded MD5 signature.

3.1.3 File Extension

The file extension for a GenCAM file is ".gcx" (*GenCAM XML Schema*).

3.1.4 File Remarks

GenCAM permits file remarks using the standard XML commenting notation. They are only to be used to support debugging software. A parser may ignore and discard remarks when reading a GenCAM file. File remarks are never to be used to represent design or manufacturing information.

3.1.5 Character Set Definition

The XML standard uses the *Unicode* character set. This character set covers the character used in hundreds of written languages. The XML standard allows several of the Unicode encoding formats to be used in an XML file. This revision of IPC-2511 requires the use of the UTF-8 character encoding of the *Unicode* character set.

3.2 Data Organization and Identification Rules

The GenCAM standard uses a namespace mechanism for XML instance files that is similar to the XML namespace mechanism that was created for managing XML meta-data namespaces. The instance file namespace mechanism prevents collisions between the names used by the different products within a single file. This partitioning of namespaces is necessary because the GenCAM file may contain information describing an arbitrary collection of products. (Boards, assemblies, panels, and fixtures are products allowed in a GenCAM file.) For example, a file could contain descriptions for building multiple electronic assemblies that are manufactured on separate panels. This mechanism also prepares the way for a distributed database of GenCAM design data in which the data can be trusted to be universally unambiguous.

3.2.1 Naming elements within a GenCAM file

The concept of GROUP as defined in IPC-2511A was created to allow separation of namespaces in a GenCAM file. This capability was created to allow panel to be created that contain multiple boards. Since two boards may reuse the same identifier, e.g. "U1", "R1", it must be possible to separate names in the file into namespaces. The namespaces capability of the GROUP concept still exists in the XML release of GenCAM, but the implementation has been changed to make namespaces consistent with XML usage. The new implementation borrows the notation used by

XML namespaces. The new system simplifies managing names and makes the new GenCAM format consistent conventional XML usage.

There are two types of names used to name top-level objects (elements instances) in a GenCAM file. The first type of name is a `qualifiedName` type. This type includes a prefix in the name that corresponds to a namespace within the GenCAM file. The prefix and the globally unique identity of the `Namespace` are declared in the `Namespace` element. The second type of name is a `shortName` type. This type is required to be unique within the GenCAM file. The syntax restrictions on `shortNames` and `qualifiedNames` assure that all names will be unique as top-level names within a GenCAM file.

3.2.2 The use of XML elements and types

A comprehensive overview of XML Schema can be found in the *W3C XML Schema Primer*. This section briefly describes the decisions that were made in the development of the GenCAM schema. Reviewing the Primer is recommended prior to reading this section.

The XML Schema defines a namespace mechanism that can be used when defining element names. The W3C also provides a set of general purpose element and attribute types, such as `xsd:string`, `xsd:double`, and `xsd:datetime`. The GenCAM standard uses these standard types, but the GenCAM standard has been defined without the use of a namespace prefix for element names within a GenCAM file.

Each of the elements in the schema has a prefix `xsd:` which is associated with the XML Schema namespace through the declaration, `xmlns:xsd="http://www.w3.org/2000/08/XMLSchema"`, that appears in the schema element. The prefix `xsd:` is used by convention to denote the XML Schema namespace, although any prefix can be used. The same prefix, and hence the same association, also appears on the names of built-in simple types, e.g. `xsd:string`. The purpose of the association is to identify the elements and simple types as belonging to the vocabulary of the XML Schema language rather than the vocabulary of the schema author.

In XML Schema, there is a basic difference between complex types that allow elements in their content and may carry attributes, and simple types that cannot have element content and cannot carry attributes. There is also a major distinction between definitions that create new types (both simple and complex), and declarations that enable elements and attributes with specific names and types (both simple and complex) to appear in document instances.

New complex types are defined using the `complexType` element and such definitions typically contain a set of element declarations, element references, and attribute declarations. The declarations are not themselves types, but rather an association between a name and constraints that govern the appearance of that name in documents governed by the associated schema. Elements are declared using the element *"element"*, and attributes are declared using the element *"attribute"*.

3.2.3 GenCAM Attribute Base Types

The attribute basic types (SimpleTypes) provided by XML Schema are defined by the W3C. They are easy to distinguish from the IPC types because the W3C type is always prefixed with "xsd". The W3C datatypes are defined in *http://www.w3.org/2000/10/XMLSchema (XML Schema Part 2)*.

The following base attribute types are used to define attributes in the GenCAM schema. The `xsd:string` type is constrained to create GenCAM specific base types for special purpose strings, such as `qualifiedName` and `shortName`. The rules for special number types and the GenCAM date format are also defined.

Basic Types Defined by W3C	
<code>xsd:string</code>	A W3C standard data type for a Unicode character string. The characters are from the UTF-8 character set as defined in http://www.ietf.org/rfc/rfc2279.txt .
<code>xsd:double</code>	A W3C standard data type for a binary floating point number. The W3C definition of <code>xsd:double</code> is in http://www.w3.org/TR/xmlschema-2/. The <code>xsd:double</code> is a number where the value can be positive, negative, integer or floating point, with at least 7 digits of precision. Numbers are assumed to be positive but can be explicitly designated as positive by preceding the number with a '+' (ASCII decimal 43) character. Negative numbers must be explicitly designated as negative by a preceding '-' (ASCII decimal 45) character. An internal representation of an IEEE double precision floating point number is assumed. This range of values for IEEE doubles is defined as $3.4 \times 10^{-38} \leq \text{value} \leq 3.4 \times 10^{38}$. The format for representing a double is the same as the format used in the computer languages C, Perl, Python, or TCL. For example, all the following are legal numbers: 1.005 0.01 .01 -2.334e-33 .224e-2
<code>xsd:nonNegativeInteger</code>	A W3C standard data type for non-negative integer numbers. The W3C definition of <code>xsd:nonNegativeInteger</code> is in http://www.w3.org/TR/xmlschema-2/. The range of values allowed are $0 \leq \text{value} \leq 2147483647$ (the non-negative values that fit in a 32 bit signed integer)
<code>xsd:positiveInteger</code>	A W3C standard data type for positive integer numbers. The W3C definition of <code>xsd:positiveInteger</code> is in http://www.w3.org/TR/xmlschema-2/. The range of values allowed are $1 \leq \text{value} \leq 2147483647$ (the positive values that fit in a 32 bit signed integer)

<code>xsd:dateTime</code>	The W3C standard data type for the current date and time is <code>xsd:dateTime</code>. (See http://www.w3.org/TR/NOTE-datetime-970915.html.) The following formats from the W3C specification are recommended for GenCAM: Complete date plus hours, minutes and seconds: YYYY-MM-DDThh:mm:ssTZD (e.g. 1997-07-16T19:20:30.4536+01:00) Complete date plus hours, minutes, seconds and a decimal fraction of a Second: YYYY-MM-DDThh:mm:ss.sTZD (e.g. 1997-07-16T19:20:30.45+01:00) where: YYYY = four-digit year MM = two-digit month (01=January, etc.) DD = two-digit day of month (01 through 31) hh = two digits of hour (00 through 23) (am/pm NOT allowed) mm = two digits of minute (00 through 59) ss = two digits of second (00 through 59) s = one or more digits representing a decimal fraction of a second TZD = time zone designator (Z or +hh:mm or -hh:mm)
<code>xsd:anyURI</code>	A W3C standard data type for hyperlinks. The W3C definition of <code>xsd:anyURI</code> is in http://www.w3.org/TR/xmlschema-2/ .
<code>xsd:unsignedByte</code>	The W3C standard for an unsigned byte (an unsigned 8 bit integer with a value between 0-255.) The W3C definition of <code>xsd:unsignedByte</code> is in http://www.w3.org/TR/xmlschema-2/ .
<code>xsd:base64Binary</code>	The data is encoded using base64. (see IETF <i>RFC 1421</i> for the base64 algorithm and http://www.w3.org/TR/xmlschema-2/#base64Binary)

Basic Types Defined by IPC	
qualifiedName	The <code>qualifiedName</code> data type is a data type defined for GenCAM. The type is a restricted <code>xsd:string</code> data type where the pattern of the string must match the regular expression "[a-zA-Z][a-zA-Z0-9_-]*.+". The definition of the <code>qualifiedName</code> data type is: <pre><xsd:simpleType name = "qualifiedName"> <xsd:restriction base = "xsd:string"> <xsd:pattern value = "[a-zA-Z][a-zA-Z0-9_-]*.+"/> </xsd:restriction> </xsd:simpleType></pre> An example of a string that matches the pattern is: "prefix:name". The "prefix" is a Namespace name. The "name" is the name of an object within the Namespace.
point	The <code>point</code> data type is a data type defined for GenCAM. This type is defined as an <code>xsd:simpleType</code> that consists of a list of two double separated by whitespace inside of a single string. The first double in the list is the X coordinate. The second double in the list is the Y coordinate. For example: p1="42.666 3.01e-1" would define X=42.666 and Y=3.01e-1
nonNegativeDouble	The <code>nonNegativeDouble</code> data type is defined for GenCAM. The type restricts an <code>xsd:double</code> to positive numbers, inclusive of 0. The non-negative range of values for IEEE doubles is defined as $0.0 \leq \text{value} \leq 3.4 \times 10^{38}$
pinName	The <code>pinName</code> data type is a data type defined for GenCAM. The type is a restricted <code>xsd:string</code>. The definition of the <code>pinName</code> data type is: <pre><xsd:simpleType name = "pinName"> <xsd:restriction base = "xsd:string"/> </xsd:simpleType></pre>
xpath	The <code>xpath</code> data type is a data type defined for GenCAM. The type is a restricted <code>xsd:string</code> data type where the pattern of the string must be a legal Xpath as defined in W3C http://www.w3.org/TR/xpath.
shortName	The <code>shortName</code> data type is a data type defined for GenCAM. The type is a restricted <code>xsd:string</code> data type where the pattern of the string must match the regular expression "[a-zA-Z][a-zA-Z0-9_-]*". The xsd definition of the <code>shortName</code> data type is: <pre><xsd:simpleType name = "shortName"> <xsd:restriction base = "xsd:string"> <xsd:pattern value = "[a-zA-Z][a-zA-Z0-9_-]*"/> </xsd:restriction> </xsd:simpleType></pre> An example of a string that matches the pattern is "bob_24".
contentType	The <code>contentType</code> data type is a restricted <code>xsd:string</code> type that matches IETF MIME type definitions. (e.g. text/html, application/postscript)

3.2.4 Coordinate System and Transformation Rules

Any geometry defined in a GenCAM file is defined in a Cartesian coordinate system. The x coordinates become more positive going from left to right (west to east). The y coordinates become more positive going from bottom to top (south to north). The primary side (TOP) of the board, coupon, or panel is in the x-y plane of the coordinate system with the primary side facing up .

Coordinates are defined by attributes of type `point`. The definition of a `point` is as follows:

```
<xsd:simpleType name = "point">
  <xsd:list>
    <xsd:simpleType>
      <xsd:restriction base = "xsd:double">
        <xsd:length value = "2"/>
      </xsd:restriction>
    </xsd:simpleType>
  </xsd:list>
</xsd:simpleType>
```

The definition of a Line element can be used to illustrate the use of two points.



An instance of a line would look as follows:

```
<Line startXY="1.0 2.0" endXY="4.0 5.0"/>
```

In this example the line begins at a coordinate of x=1.0 and y=2.0 and the line ends at a coordinate of x=4.0 and y=5.0.

The illustration in Figure 2 provides a perspective drawing of a board and a coordinate system. Each product in a GenCAM file is defined relative to a local coordinate system for the product. The point of origin of the product is located at (0,0) in the local coordinate system.

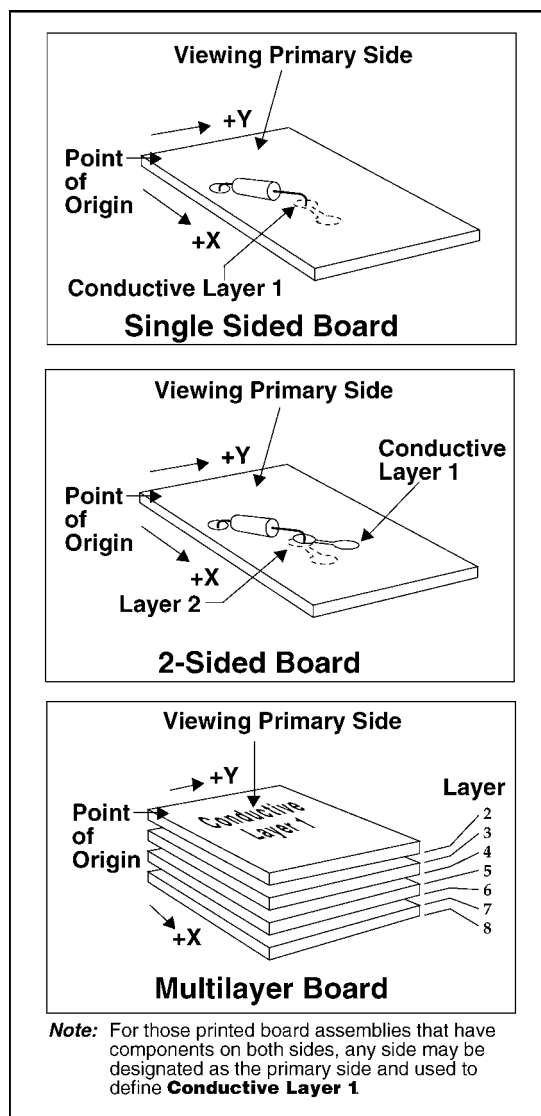


Figure 2 Printed board viewing

3.2.5 Transformation Characteristics

There are four types of transformations used in a GenCAM file. The most general, `Xform`, will be described first. The three additional types of transformations are constrained versions of the `Xform` transform (see table 1). The order of attributes does not define the execution order. The sequence of execution is to mirror, rotate, translate and then scale. The execution order of nested transformations starts at the origin of the outer most product definition and move up the tree of nested geometric elements.

Table 1 Types of Constrained Transformations

Transformation	x	y	rotation	mirror	scale
Xform	O	O	O	O	O
Place	O	O	O	O	
Position	O	O	O		
Offset	O	O			

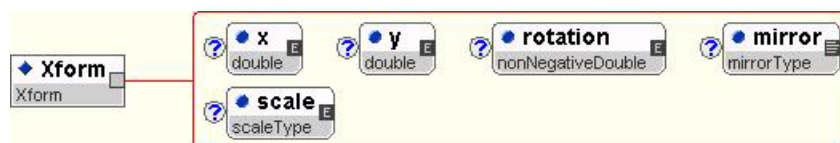
Note: Mandatory (M), Optional (O)

3.3 Elements used throughout the GenCAM Schema

Several elements are used frequently as children elements. These elements will be defined in this section. When the elements are subsequently used the definitions from this section apply.

3.3.1 The Xform Transformation

The `Xform` element defines a transformation that is used throughout this specification to define the location and orientation of physical features. Primitives in the GenCAM file are manipulated relative to their local Cartesian coordinate system by the values set in the transform. The `Xform` transform defines manipulation of placement, rotation, scaling, and mirror. (see Figure 3)

**Figure 3 Xform**

3.3.1.1 The x and y attribute

The `x` and `y` attributes are of type `xsd:double`. They define the `x` and `y` offset of a shape relative to the origin of a Cartesian coordinate system. The definition of shapes in GenCAM can be nested and the `x` and `y` attributes are always interpreted relative to the local coordinate system of the shape to which the transformation applies. The default value for `x` and `y` is 0.0.

3.3.1.2 The rotation attribute

The `rotation` attribute is of type `nonNegativeDouble` that defines the rotation of a shape about the local origin. The interpretation of the value is set globally in the GenCAM file to units of either degrees, or radians. The `Units` element in the `Header` element section specifies the units of measure. If the angle attribute setting for the file is "RADIANS" then the range of the rotation parameter is $0.0 \leq \text{number} \leq 6.28318... (2\pi)$. If the angle attribute setting for the file is "DEGREES" then the range of the rotation parameter is $0.0 \leq \text{number} \leq 360.0$. Positive rotation is always counter-clockwise as viewed from the board TOP (primary

side), even if the component being rotated is on the board BOTTOM (secondary side). Rotation defaults to 0.0, and can be applied to text, or any physical shape.

3.3.1.3 The mirror attribute

The `mirror` attribute is of type `mirrorType`. This type is an enumerated `xsd:string` type with a value of either MIRROR or NOMIRROR. The default value is NOMIRROR. When `mirror` is set to MIRROR it indicates that all `x` dimensions are set to a `-x` value. The proper interpretation of the `mirror` and `rotate` attributes are shown in Figure 4. The example shows a unique artwork (14-pin DIP device) placed on the top and bottom of a board at 90-degree rotations.

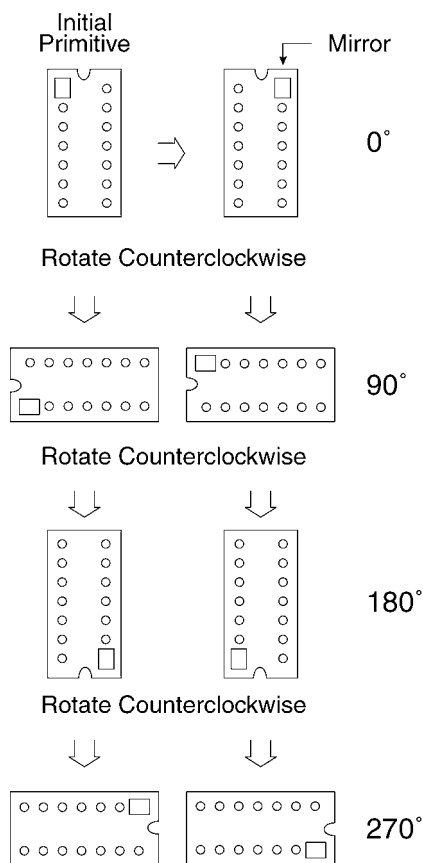


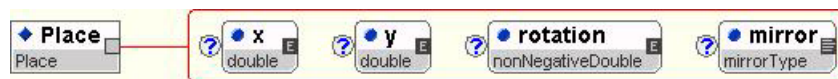
Figure 4 Mirror and Rotation Diagram

3.3.1.4 The scale attribute

The `scale` attribute is of data type `scaleType`. This is a nonNegativeDouble that must have a value greater than zero. All `x` and `y` dimensions of a geometry are multiplied by the `scale` attribute. The scale factor does not apply to angular values. The default value is 1.0.

3.3.2 The *Place* Transformation

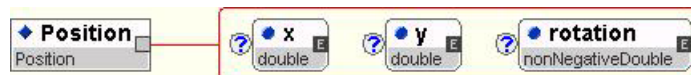
The `Place` transformation is identical to `Xform` with the `scale` attribute fixed at 1.0. The intent of `Place` is to prevent CAD or CAM systems from scaling those items where a change of scale is not appropriate.



The attributes are defined in 3.3.1.

3.3.3 The *Position* Transformation

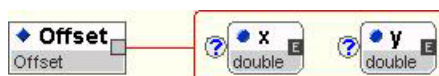
The `Position` transformation is identical to `Place` with the `mirror` attribute fixed as `NOMIRROR`. The intent of `Position` is to prevent CAD or CAM systems from scaling and mirroring those items where a change of scale or orientation is not appropriate.



The attributes are defined in 3.3.1.

3.3.4 The *Offset* Transformation

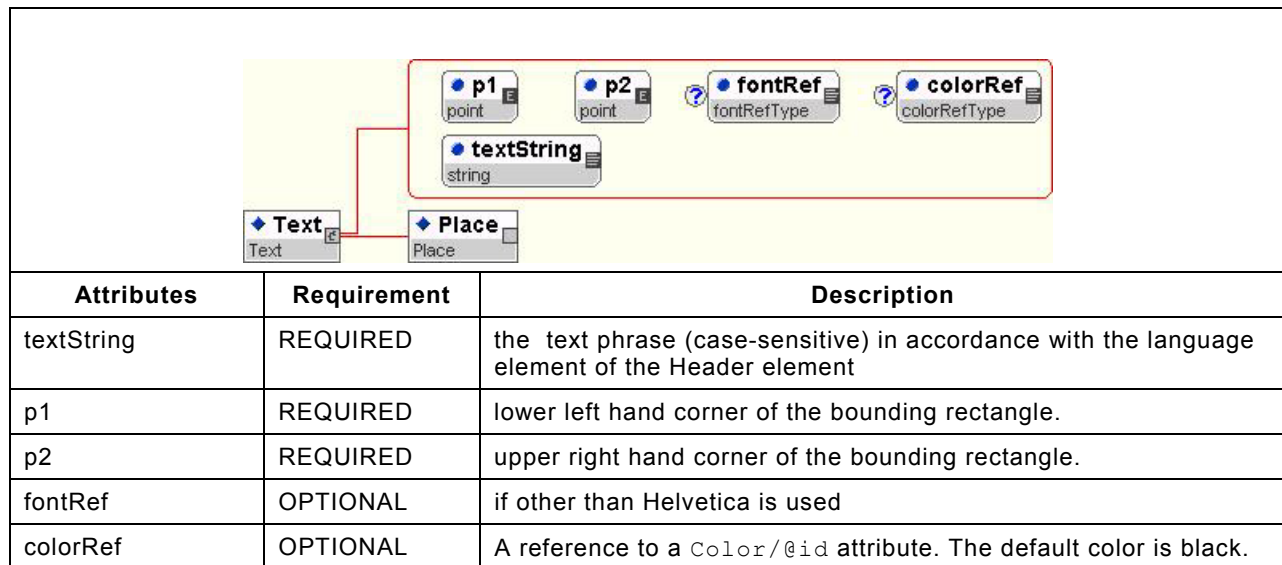
The `Offset` transformation is identical to `Position` with the `rotation` attribute set to 0.0. The intent of restricting the transformation to just `Offset` is to prevent CAD or CAM systems from scaling, mirroring and rotating those items where a change of scale, rotation, or orientation is not appropriate.



The attributes are defined in 3.3.1.

3.3.5 Text

When text is to be drawn on a product or a drawing the definition includes a bounding rectangle for the text. The lower xy coordinate `p1` and the upper xy coordinate `p2` define the bounding rectangle. All portions of the text, including the line width of the strokes of the text, must fit within the bounding rectangle. Any portion of a character exceeding the perimeter of the bounding rectangle will be clipped at the boundaries of the bounding rectangle.



The diagram and the description describe the general case for how text is to be draw. There are two variations on the Text type; TextNamedWithLayers and TextWithLayer. These types add additional attributes for some uses of Text. The id is added for Panel and Board because the Text is defined as a top-level element and as such needs to have an id. The layersRef attribute is added in places where the layer on which the Text is drawn is not managed by the containing element, or in the case of Drawing, where there isn't a layer required.

The content of Text/@string should be defined to be enclosed in the textbox as illustrated in Figure 5. This includes upper and lower case letters, as well as all line widths, line descriptions, and line ends. Anything outside the clipping box will be clipped. The clipping boundary is necessary because fonts vary between computer systems and application implementations.

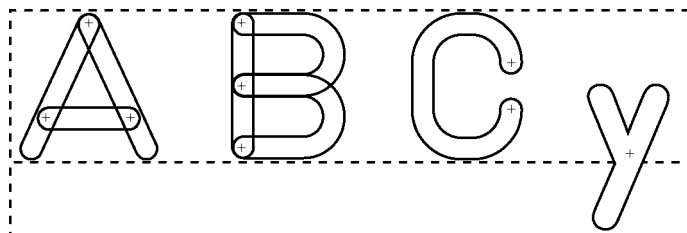


Figure 5 Bounding rectangle to round end character relationships

3.3.5.1 Text transformations

Text character dimensions are constrained by the bounding rectangle as illustrated in Figure 6. Character height is expressed in incremental units of the dimensional characteristics of the file, through the limits (xy coordinates) of the bounding rectangle. Both upper and lower case letters must be inside the bounding rectangle. Included in this requirement are the extensions of such descending letters as lower case "g", "q", "y", "j" and "p". The bounding rectangle of Text is defined relative to the local coordinate system. The Place transform is applied to the bounding rectangle and the text contained within the rectangle. The bounding rectangle is mirrored, then rotated, and then translated per the Place element within the Text element. The text is drawn relative to the bounding rectangle.

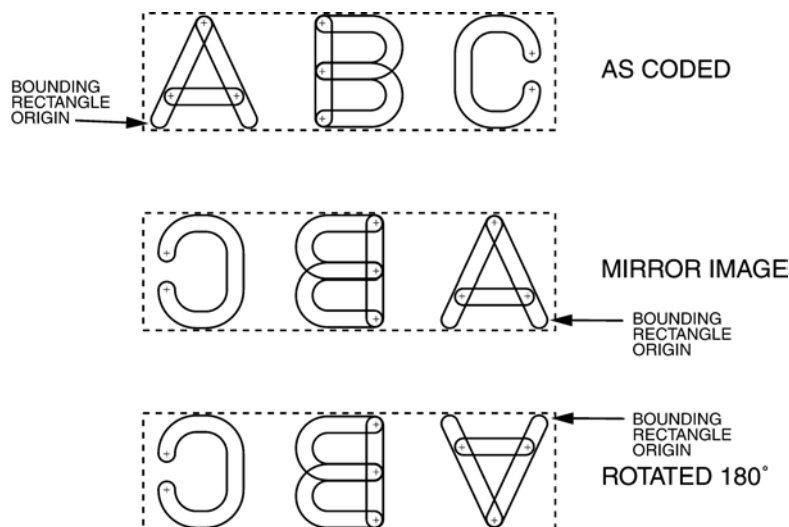


Figure 6 Text transformation examples

The bounding rectangle is rotated 30° about the lower xy coordinate. (see figure 7)

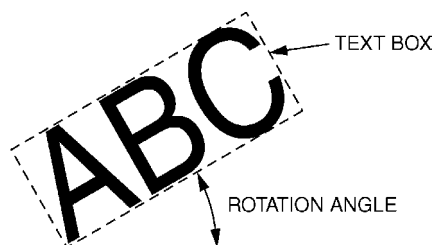


Figure 7 Rotation Angle

4 GenCAM XML Element Definitions

The remainder of the document will define and describe each of the elements that are found in the XML Schema for GenCAM. The order of the definitions is based on the order in which the elements will appear in the file. This order ensures that nothing is referenced prior to being defined. This also means that the interesting content, the product definitions and test configuration information will appear late in the file. The file order starts with elements that define reusable geometry objects. The elements used to define routes and mounting locations are next. This is followed by elements used to define packages, devices, and component placement. Finally, elements are defined that configure products.

The following table is provided as a convenient reference. It summarizes the instructions and definitions for frequently used elements. Consult this table for the definition of any element stub that is not defined for a diagram. Only the stubs of these elements will appear in the element diagrams defined throughout this document. When a stub for the elements, or the substitution elements is present the note in the second column applies. This note references the section of the document where the stub is fully defined. The definitions will not be repeated or referenced in the remainder of this document.

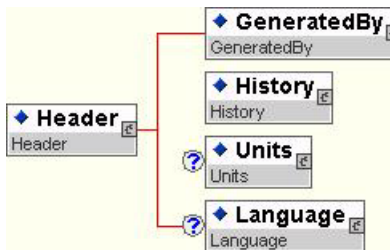
	The elements that can be substituted for the ClosedShape element are defined in the table of <i>ClosedShape Substitution Elements</i> defined in Section 4.17
	The transformation defined by the Offset element is to be applied shape element containing the Offset element prior to drawing containing shape. The attributes of the Offset are defined in Section 3.3.4
	The transformation defined by the Place element is to be applied shape element containing the Place element prior to drawing containing shape. The attributes of the Place are defined in Section 3.3.2
	The elements that can be substituted for the PolygonBuilder element are defined in the table of <i>PolygonBuilder Substitution Elements</i> defined in Section 4.16
	The elements that can be substituted for the PolylineBuilder element are defined in the table of <i>PolylineBuilder Substitution Elements</i> defined in Section 4.18
	The transformation defined by the Position element is to be applied shape element containing the Position element prior to drawing containing shape. The attributes of the Position are defined in Section 3.3.3
	The elements that can be substituted for the ShapeBuilder element are defined in the table of <i>ShapeBuilder Substitution Elements</i> defined in Section 4.19
	The definition of the Text element is in Section 3.3.6
	The transformation defined by the Xform element is to be applied shape element containing the Xform element prior to drawing containing shape. The attributes of the Xform are defined in Section 3.3.1

4.1 GenCAM

The top-level element in a GenCAM file is the `GenCAM` element. The `version` attribute of the `GenCAM` element is shown in Figure 1. This is a string data type that must match the regular expression pattern `'B-2.[0-9]+'`. The version number encodes the version of the standard to which the file data conforms. It is a mandatory attribute used to maintain the relationship between the information represented in the file and the specific release of the standard. GenCAM instance files that conform to the base document for the "B" revision of IPC-2511 must set the version attribute to "B-2.0". When industry requests for extensions or corrections to this base document are created through the release of addendum the new revision of the file format will be indicated by incrementing the least significant digit of the revision number, e.g., "B-2.1", "B-2.2". A future release of this base document would increment the letter and the most significant number in the version attribute, e.g., "C-3.0".

4.2 Header

The `Header` element is mandatory in a GenCAM file. `Header` has four elements that must appear in the order specified in the diagram. The `Language` and `Units` sub-elements are optional and have default values.



4.2.1 GeneratedBy

The `GeneratedBy` element defines the characteristics of what system generated the file according to the following requirements. The `GeneratedBy` element has two attributes and a sub-element. The attributes and sub-elements of a `GeneratedBy` element are defined as follows:

<pre> graph LR GeneratedBy[GeneratedBy] --> softwarePackage[softwarePackage] GeneratedBy --> revision[revision] GeneratedBy --> Certification[Certification] Certification --> certificationStatus[certificationStatus] Certification --> certificationCategory[certificationCategory] certificationStatus --- ReqCertStatus[+] certificationCategory --- ReqCertCategory[+] </pre>		
Attributes	Requirement	Description
softwarePackage	REQUIRED	A string describing the software package and platform i.e., "Mentor Board Station"
revision	REQUIRED	A string information providing the revision of the software package, i.e., "3.4"
certicationStatus	REQUIRED	An enumerated string of any of the fixed field characteristics: ALPHA BETA SELFTEST CERTIFIED

certificationCategory	OPTIONAL	Relates to the type of equipment being certified and the functions that it performs. It can be one or more of the following: GENERALASSEMBLY ASSEMBLYPANEL ASSEMBLYPREPTOOLS GLUEDOT SOLDERSTENCILPASTE COMPONENTPLACEMENT MECHANICALHARDWARE ASSEMBLYFIXTUREGENERATION ASSEMBLYTESTGENERATION ASSEMBLYTESTFIXTUREGENERATION PHOTOTOOLS BOARDFABRICATION BOARDPANEL BOARDFIXTUREGENERATION BOARDTESTGENERATION FABRICATIONDRAWING ASSEMBLYDRAWING SCHEMATICDRAWINGS DETAILEDDRAWING SPECSOURCECONTROLDRAWING SINGLEBOARDPARTSLIST MULTIBOARDPARTSLIST
-----------------------	----------	--

4.2.2 Units

The `Units` element defines the unit of measure for length and angle used throughout the GenCAM file. The attributes of a `Units` element are defined as follows:

		
Attributes	Requirement	Description
length	DEFAULT	Defines the unit of length for the file as one of: MM UM INCH. The default is MM
angle	DEFAULT	Defines the angular unit of measure as one of: DEGREES RADIANS The range of values for angle measure is defined as follows: RADIANS: 0.0 <= number <= 2π DEGREES: 0.0 <= number <= 360.0 The default is DEGREES

4.2.3 History

The `History` element provides a sequential change number for the GenCAM file. The number is changed every time the controlled version of the GenCAM file is modified. Only the file owner is allowed to change the value of `History/@number`. The attributes of a `History` element are defined as follows:

Attributes	Requirement	Description
number	REQUIRED	The revision number of the GenCAM file. The content of this number is defined and controlled by the file owner.
origination	REQUIRED	The timestamp recorded when the GenCAM file was first created.
lastChange	REQUIRED	The timestamp recorded when the History number was last incremented.
externalConfigurationControlEntryPoint	OPTIONAL	A URI referencing a configuration control system that "owns" the GenCAM file contents.

4.2.4 FileRevision

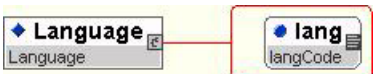
The `FileRevision` element tracks changes to the GenCAM file. The revision identifier does not necessarily track the revision of the product. The purpose of the `FileRevision` is to track which software tools were used to make changes to the file and the sequence in which the changes were made.

Attributes	Requirement	Description
modificationTime	REQUIRED	The timestamp of when the software saved the revision of the file.
fileRevisionId	REQUIRED	An identifier for the revision. This value may be supplied by a revision control system such as RCS, CVS, or SCCS.
comment	REQUIRED	A short description of the revision, such as a changes statement entered by RCS or SCCS.

label	OPTIONAL	A label that can be applied to a branch head. The label can be used to associate a file revision of special
softwarePackage	REQUIRED	The software package that wrote this revision of the file.
revision	REQUIRED	The revision of the software that wrote the file.

4.2.5 Language

The `Language` element declares the written language used in the GenCAM file. The only parameter of a `Language` element is defined as follows:

		
Attributes	Requirement	Description
lang	REQUIRED	Internet Engineering Task Force (IETF) defines language codes in http://www.ietf.org/rfc/rfc1766.txt. (See the IETF for the full specification of the requirements.) The basic format is a language tag with an optional country code suffix. The syntax defined by RFC-1766 is: The syntax of this tag in RFC-822 EBNF is: <pre> Language-Tag = Primary-tag * ("-" Subtag) Primary-tag = 1*8ALPHA Subtag = 1*8ALPHA </pre> This means the value can be a string of up to 8 ASCII alphabetic characters followed by zero or more optional "-" characters that are followed by a string of up to 8 alphabetic characters Some Examples: <pre> <Language lang="zh" /> - uses Chinese <Language lang="en" /> - uses English <Language lang="fi" /> - uses Finnish <Language lang="fr" /> - uses French <Language lang="ge" /> - uses German <Language lang="ja" /> - uses Japanese <Language lang="ko" /> - uses Korean <Language lang="pt" /> - uses Portuguese <Language lang="ru" /> - uses Russian <Language lang="es" /> - uses Spanish <Language lang="sv" /> - uses Swedish <Language lang="no-bokmaal" /> - one of two official versions of Norwegian </pre> The first part half of the tag is the language code as defined in ISO-639. The code values are accessible from http://www.oasis-open.org/cover/iso639a.html. The interpretation of the codes are case insensitive, but lowercase is the preferred notation according to the IETF. The remainder of the code define the country and region of dialect. The country codes are defined in ISO-3166.

4.3 Namespaces

Namespaces are used to eliminate the naming conflicts that are introduced by the reuse of names in the definition of products. (For example, a reference designator of "U1" and "R1" is likely to appear in many products.) The **Namespaces** mechanism can be used to guarantee that names used in the declaration of product will be universally unique. The **Namespaces** element defines the list of **Namespace** elements that will be used in the GenCAM file.



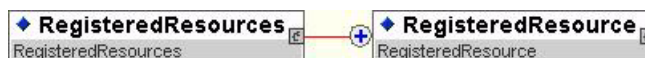
4.3.1 Namespace

A **Namespace** associates a short prefix with a long, globally unique identifier. It is possible to eliminate conflicts caused when two products defined in a GenCAM file share a common base name by using a separate prefix for the name used in each product in the GenCAM file. The globally unique identifier extends this conflict resolution to ensure the names are also globally unique.

Attributes	Requirement	Description
prefix	OPTIONAL	All prefix strings (the character sequence before the ':' in a qualifiedName) are declared as Namespace prefixes. For example, in the definition of a Device the id and packageRef attributes use qualifiedName types. <pre><Device id="dev1:LM555" packageRef="pk:8pinDIP"...></pre> The "dev1" string in id and the "pk" string in packageRef are prefix strings. All such prefix strings used in a GenCAM file must be declared as a Namespace.
uri	REQUIRED	The URI of a GenCAM namespace is an abbreviation of the namespace URI, just as XML name-space prefixes are abbreviations of XML name-space uri. The full name of the GenCAM object is a concatenation of the URI with the string following the ':' in the qualifiedName.
description	REQUIRED	A description of the source of the GenCAM name-space can be added to assist in understanding the source of the names used in the GenCAM file.

4.4 RegisteredResources

The `RegisteredResources` element defines a list of all `RegisteredResource` elements used within the GenCAM file.

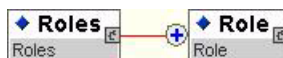


4.4.1 RegisteredResource

Attributes	Requirement	Description
id	REQUIRED	The <code>id</code> attribute is referenced from elements within the GenCAM file. A referencing element points to the <code>RegisteredResource</code> <code>id</code> to define the allowed values and data types for an associated attribute in the referencing element. The <code>RegisteredResource</code> defines attribute characteristics that are within the control of other IPC committees. The definition pointed to by the <code>url</code> attribute may include a list of the allowed enumerated value or minimum and maximum range for the values of the <code>RegisteredResource</code> .
url	REQUIRED	The <code>url</code> attribute contains a URL for the definition of the <code>RegisteredResource</code> .
description	OPTIONAL	A description of the local interpretation of a <code>RegisteredResource</code> can be added to the definition.

4.5 Roles

The `Roles` element defines a list of all `Role` elements used within the GenCAM file.



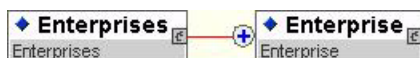
4.5.1 Role

A `Role` element declares a type of activity within an `Enterprise`. The attribute values of the `Role` based on the requirements of the activities performed by the role.

Attributes	Requirement	Description
<code>id</code>	REQUIRED	The <code>id</code> uniquely identifies a role type used by the enterprise. The <code>id</code> is a <code>shortName</code> data type (a restricted <code>xsd:string</code>) that must be unique within the global (top-level) namespace of the GenCAM file. The standard IPC role types are defined as follows: SENDER – Identifies the person sending out the GenCAM file. OWNER – Identifies the person who maintains the configuration management of the GenCAM file and has the right to increment the file history number of the GenCAM file. RECEIVER – Identifies the person receiving the GenCAM file. DESIGNER – Identifies the designer of the product described in the GenCAM file. ENGINEER – Identifies the engineer who is responsible for the product described in the GenCAM file. BUYER – Identifies the person who is responsible for payment. CUSTOMERSERVICE – Identifies the customer service representative who is responsible for the account. DELIVERTO – Identifies the person in the receiving department who takes possession of the shipment in the name of the enterprise. BILLTO – Identifies the person in the billing or purchasing department to whom the billing should be addressed.
<code>description</code>	OPTIONAL	The <code>description</code> attribute defines a role within an enterprise. (The description is optional if the IPC definition is to be used.)
<code>publicKey</code>	OPTIONAL	The <code>publicKey</code> attribute of a role holds the public encryption key if one exists for the role. The key is base64 encoded. (see IETF <i>RFC 1421</i> for the base64 algorithm) If a role <code>publicKey</code> is present it can be used instead of a <code>Person/@publicKey</code> to encrypt data. The role's <code>publicKey</code> is used to encrypt data so only that someone with access to the role's private key can access the data.
<code>authority</code>	OPTIONAL	The access level associated with this role as defined by the system referenced by <code>externalConfigurationControlEntryPoint</code>

4.6 Enterprises

The `Enterprises` element defines a list of all `Enterprise` elements used within the GenCAM file.



4.6.1 Enterprise

The `Enterprise` element provides information about an enterprise that will be referenced within the GenCAM file. The attributes of the `Enterprise` element are defined as follows:

Attributes	Requirement	Description
<code>id</code>	REQUIRED	The <code>id</code> uniquely identifies an enterprise throughout the GenCAM file. The <code>id</code> is a <code>shortName</code> data type (a restricted <code>xsd:string</code>) that must be unique within the global (top-level) namespace of the GenCAM file. (Suggest "XYZ", "ACME"...)
<code>name</code>	REQUIRED	The full name of the enterprise.
<code>address1</code>	OPTIONAL	The street address of the enterprise.
<code>address2</code>	OPTIONAL	Additional address information for the enterprise.
<code>city</code>	OPTIONAL	The city.
<code>stateProvince</code>	OPTIONAL	The state or province.
<code>country</code>	DEFAULT	The two-letter ISO country code from the ISO 3166 standard. (See ftp://info.ripe.net/iso3166-countrycodes). The default country is "us"
<code>postalCode</code>	OPTIONAL	The postal code.
<code>phone</code>	OPTIONAL	The phone number.
<code>fax</code>	OPTIONAL	The phone number of the fax machine.
<code>email</code>	OPTIONAL	The email address.
<code>url</code>	OPTIONAL	The Internet HTTP Web address of the enterprise.
<code>code</code>	REQUIRED	The value of the specified <code>codeType</code> for the enterprise.

codeType	DEFAULT	One of DUNS or CAGE. The default is DUNS. If the DUNS <code>codeType</code> is selected then the code attribute of Enterprise is the D-U-N-S Number of the enterprise. (see the reference to D&B D-U-N-S Number at http://www.dnb.com/) If the CAGE <code>codeType</code> is used then the CAGE code of the enterprise is in the code attribute of Enterprise. (see http://www.dscc.dla.mil/offices/sourcedev/cage.html) If no CAGE or DUNS code is available use "—NONE—" as the value of the code attribute.
roleRef	REQUIRED	A role within the organization.

4.7 Persons

The `Persons` element defines a list of all `Person` elements used within the GenCAM file.



4.7.1 Person

The `Person` element provides information about a person who will be referenced within the GenCAM file. The attributes of a `Person` element are defined as follows:

Attributes	Requirement	Description
id	REQUIRED	A string that uniquely identifies the person throughout the GenCAM file. The <code>id shortName</code> must be unique within the global (top-level) namespace of the GenCAM file. (Suggest "sally", "bob"...)
name	REQUIRED	The person's full name.
enterpriseRef	REQUIRED	The <code>shortName</code> of the person's company or enterprise; if no enterprise exists, the term "SELF" should be used.
title	OPTIONAL	The job title of the person.
email	OPTIONAL	The email address of the person.
phone	OPTIONAL	The phone number of the person.
fax	OPTIONAL	The fax machine phone number of the person.

mailstop	OPTIONAL	The World Wide Web URL of the person.
publicKey	OPTIONAL	The <code>publicKey</code> attribute of a person holds the public encryption key if one exists for the person. The key is base64 encoded. (see IETF <i>RFC 1421</i> for the base64 algorithm) The person's <code>publicKey</code> is used to encrypt data so only that person can access the data.
roleRef	REQUIRED	The role of the person.

4.8 TruePositionTolerances

The `TruePositionTolerances` element defines a list of all `TruePositionTolerance` elements used within the GenCAM file.



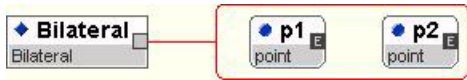
4.8.1 TruePositionTolerance

The `TruePositionTolerance` element defines the manufacturing tolerance range for positioning geometry in a product definition. An indepth explanation of product tolerancing is available in the IPC-2221 standard. The concepts are illustrated in Figure 8. The attributes of a `TruePositionTolerance` element are defined as follows:

The diagram shows the <code>TruePositionTolerance</code> element box on the left. Four red lines point from it to four attribute boxes on the right: <code>id</code> (qualifiedName), <code>Bilateral</code>, <code>Diameter</code>, and <code>MaximumMaterialConditionDiameter</code>. Each attribute box has a small 'e' icon.		
Attributes	Requirement	Description
id	REQUIRED	The <code>id</code> attribute is a <code>qualifiedName</code> that uniquely identifies the <code>TruePositionTolerance</code> within the GenCAM file. The <code>id</code> is referenced by <code>locationTolRef</code> attributes in order to associate the tolerance definition with geometries to which they apply.

4.8.2 Bilateral

The `Bilateral` element defines a square tolerance zone as the location for the centroid of any feature. This is usually expressed as a plus or minus tolerance applied to the true position location. The following describes the upper right (`posTol`) and lower left (`negTol`) corner of the tolerance zone taken from the true position of the feature.

		
p1	REQUIRED	The lower left corner of the tolerance zone
p2	REQUIRED	The upper right corner of the tolerance zone

4.8.3 Diameter

The `Diameter` element defines the tolerance zone as a diameter from the true position coordinate of the feature.

		
toleranceZone	REQUIRED	a dimension that represents the diameter of true position (DTP) tolerance zone

4.8.4 MaximumMaterialConditionDiameter

The `MaximumMaterialConditionDiameter` element defines the diameter of true position with the allowance that if the feature positioned at that location is at a Maximum Material condition the additional difference between Maximum and Least material condition can be added to the tolerance zone.

		
mmcToleranceZone	REQUIRED	diameter of true position increased by the difference between MMC and LMC

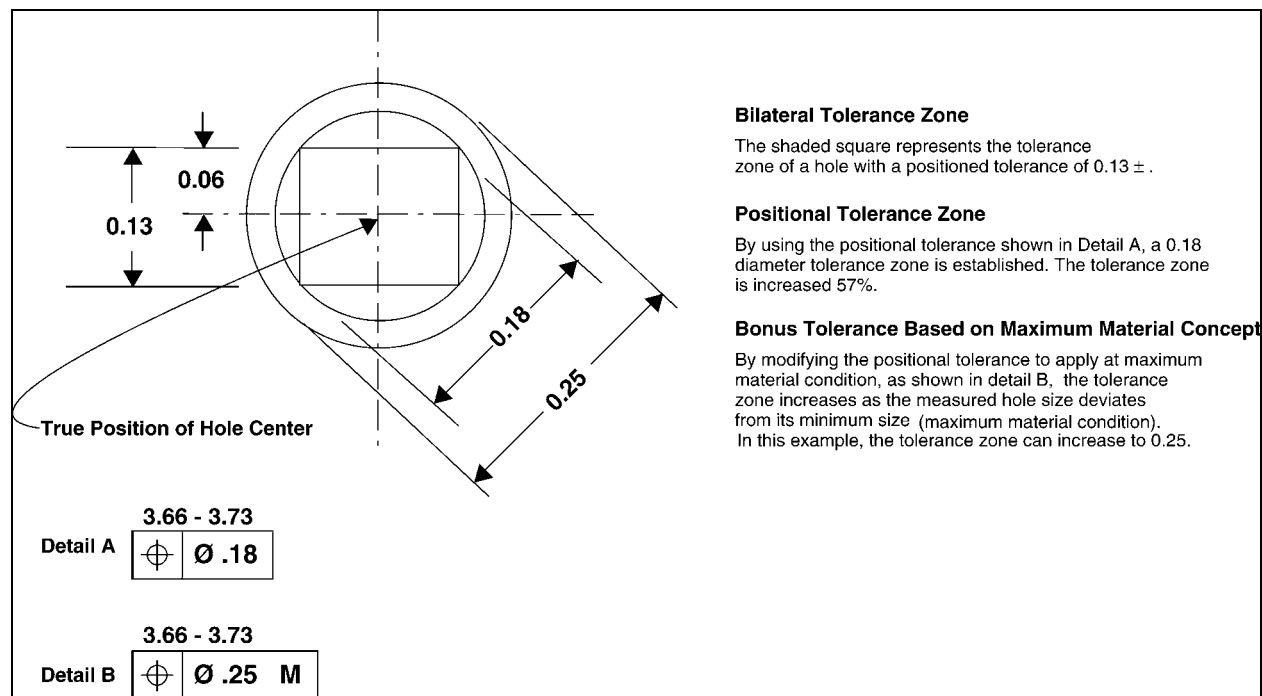
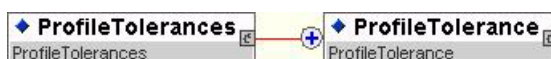


Figure 8 Advantages of positional tolerance over bilateral tolerance, mm

4.9 ProfileTolerances

The ProfileTolerances element defines a list of all ProfileTolerance elements used within the GenCAM file.



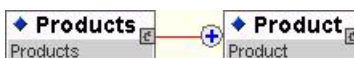
4.9.1 ProfileTolerance

The ProfileTolerance element defines the rectangular manufacturing tolerance range for positioning geometry in a product definition. An indepth explanation of product tolerancing is available in the IPC-2615 standard. The attributes of a ProfileTolerance element are defined as follows:

Attributes	Requirement	Description
id	REQUIRED	The id attribute is a qualifiedName that uniquely identifies the ProfileTolerance within the GenCAM file. The id is referenced by profileTo1Ref attributes in order to associate the tolerance definition with geometries to which they apply.
finishedLMC	REQUIRED	The permitted variation from nominal to the least material condition (LMC) of a feature of the product.
finishedMMC	REQUIRED	The permitted variation from nominal to the maximum material condition (MMC) of a feature of the product.
startLMC	OPTIONAL	The permitted variation from nominal to the least material condition (LMC) of a feature or the product prior to plating, coating or additional material removal.
startMMC	OPTIONAL	The permitted variation from nominal to the maximum material condition (MMC) of a feature or the product prior to plating, coating or additional material removal.

4.10 Products

The `Products` element defines a list of all `Product` elements used within the GenCAM file.



4.10.1 Product

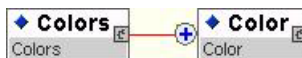
The `Product` element identifies a product that is described in the GenCAM file. The attributes of a `Product` element are defined as follows:

Attributes	Requirement	Description
id	REQUIRED	The <code>id</code> attribute is a <code>shortName</code> that uniquely identifies the Product within the GenCAM file. The <code>id</code> is referenced by attributes of with types <code>boardRefType</code> , <code>assemblyRefType</code> , <code>panelRefType</code> , and <code>fixtureRefType</code> in order to associate the product administrative definition with product configuration definition.
name	REQUIRED	A descriptive name or title for the product.
number	REQUIRED	The part number of the panel or subpanel.
revision	OPTIONAL	The revision level of the panel or subpanel.
type	REQUIRED	The type of the product. One of BOARD PANEL ASSEMBLY FIXTURE.
type	REQUIRED	The type of transaction. A transaction may be a purchase order (PO), a request for quote (RFQ), a request for proposal or information (RFP), a request for audit (RFA), or a change order (CO).
number	REQUIRED	An externally generated identifier for the transaction. GenCAM does not interpret this identifier. The value of this attribute can be used to link the GenCAM transaction with an external system, such as a factory ERP or MES information system.

date	REQUIRED	The date on which the transaction was initiated.
		
quantity	REQUIRED	The quantity of the item to be delivered on the deliverableDate date.
deliverableDate	REQUIRED	The date by which the item is to be received.
		
enterpriseRef	REQUIRED	The enterpriseRef attribute references the Enterprise/@id to define the preferred vendor(s) for the product.
personRef	OPTIONAL	The personRef attribute references the Person/@id to identify the contact point at the preferred vendor.

4.11 Colors

The `Colors` element defines a list of all `Color` elements used within the GenCAM file.



4.11.1 Color

The `Color` element defines a color that is referenced throughout the GenCAM file. The color is defined by three values that represent the red, green and blue components of the composite color. If `r`, `g`, and `b` are all set to 0 the color is black. If all values are 255 then the color is white. The attributes of a `Color` element are defined as follows:

Attributes	Requirement	Description
id	REQUIRED	The <code>id</code> attribute is a <code>qualifiedName</code> that uniquely identifies the <code>Color</code> within the GenCAM file. The <code>id</code> is referenced by <code>colorRef</code> attributes in order to associate the color definition with geometries to which it applies.
r	REQUIRED	Defines the red color intensity as a value between 0 and 255.
g	REQUIRED	Defines the green color intensity as a value between 0 and 255.
b	REQUIRED	Defines the blue color intensity as a value between 0 and 255.

Examples of Colors

```
<Colors>
  <Color id = "IPCstd:white" r = "255" g = "255" b = "255"/>
  <Color id = "IPCstd:black" r = "0" g = "0" b = "0"/>
  <Color id = "IPCstd:red" r = "255" g = "0" b = "0"/>
  <Color id = "IPCstd:green" r = "0" g = "255" b = "0"/>
  <Color id = "IPCstd:blue" r = "0" g = "0" b = "255"/>
</Colors>
```

4.12 LineDescs

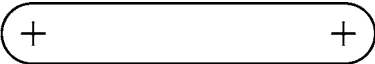
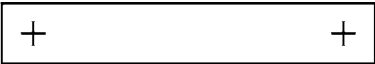
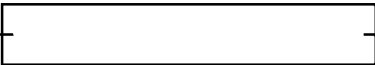
The LineDescs element defines a list of all LineDesc elements used within the GenCAM file.

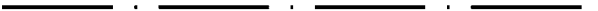
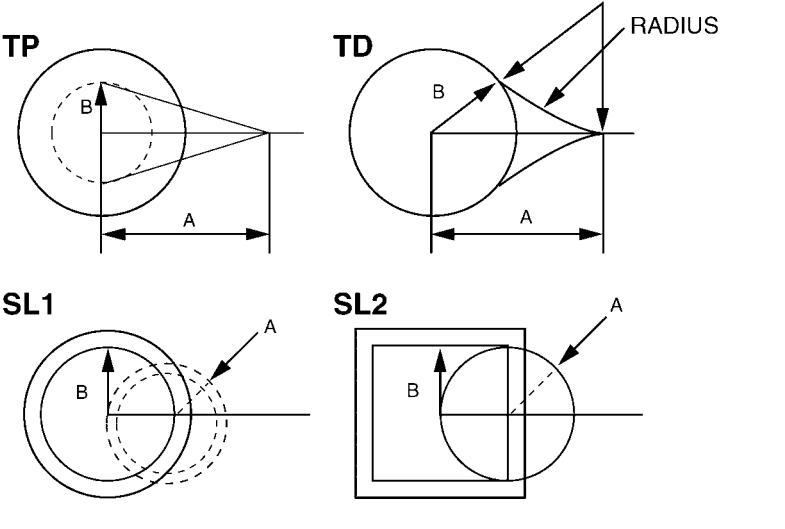


4.12.1 LineDesc

The LineDesc element defines the characteristics of a line. When a LineDesc/@id is referenced by an enclosing element contains a lineDescRef attribute the characteristics of the LineDesc are applied to all the enclosed line segments. The line characteristics includes the line width, the line type, the end characteristics, end modifications, and color. The rules of precedence for LineDesc are defined in Figure 10. The attributes of a LineDesc element are defined as follows:

Attributes	Requirement	Description
id	REQUIRED	The id attribute is a qualifiedName that uniquely identifies the LineDesc within the GenCAM file. The id is referenced by lineDescRef attributes in order to associate the LineDesc definition with geometries to which it applies.
width	REQUIRED	The line width in length dimension units.
lineEnd	DEFAULT	The line end is one of SQUARE, ROUND or NONE. The default is ROUND.
colorRef	OPTIONAL	A reference to a Color/@id attribute. The default color is black.
type	DEFAULT	The line type is one of SOLID, DOTTED, DASHED, CENTER, PHANTOM or (solid) ERASE. The default is SOLID.
space	OPTIONAL	The spacing between dots and dashes. The meaning by LineDesc/@type is: DOTTED – the spacing between the dot centers. DASHED – the spacing between the end of one dash and the start of the next dash. CENTER – the spacing between the center of the dot and the line ends of the line segments. PHANTOM – the spacing between the center of the dots and the line ends of the line segments.

length	OPTIONAL	The length of dashes. The meaning by LineDesc/@type is: DASHED – the length of the dashes. CENTER – the length of the line segments between the dots. PHANTOM – the length of the line segments between the dots.
lineMod	DEFAULT	The line end modification is one of tear-drop (TD), tapered (TP), or one of two sub-land patterns (SL1, SL2). See the following table. The default is NONE.
modEnd	DEFAULT	The ends of the line that are to have LineDesc/@lineMod applied. The value is one of START FINISH BOTH. The default is BOTH. BOTH – modify both start and finish of line ends START – modify the start point of a line FINISH – modify the last point of a line
dimA	OPTIONAL	The meaning is dependent on the LineDesc/@lineMod attribute. The meaning by LineDesc/@lineMod is: TP – length of the taper fillet as measured from the center of the pad along the x-axis. TD – length of the tear-drop as measured from the center of the pad along the x-axis. SL1 – radius of the sub-land circle. SL2 – radius of the sub-land circle.
dimB	OPTIONAL	The meaning is dependent on the LineDesc/@lineMod attribute. The meaning by LineDesc/@lineMod is: TP – z-axis dimension of the taper fillet as measured at the center of the pad. TD – the radius of the pad. SL1 – distance measured along the x-axis from the center of the pad to the center of the sub-land. SL2 – distance measured along the x-axis from the center of the pad to the center of the sub-land.
dimC	OPTIONAL	The LineDesc/@lineMod attribute. The meaning by LineDesc/@lineMod is: TD – radius joining curvature of land to the x-axis.
This diagram illustrates the LineDesc/@lineEnd attribute		ROUND  SQUARE  NONE 

This diagram illustrates the LineDesc/@type attribute. Line type attributes, other than SOLID and ERASE, also require attributes to define spacing characteristics for the line segments, dashes and dots of the lines.	SOLID  DOTTED  DASHED  CENTER  PHANTOM  ERASE 
This diagram illustrates the LineDesc/@lineMod, LineDesc/@dimA, LineDesc/@dimB, and LineDesc/@dimC attributes taper (fillet) TP,.... tear-drop TD,.... Sub-lands SL1,.... Sub-lands SL2,....	 The diagrams illustrate the following attributes: TP (taper/fillet): Shows a circular feature with a tapered fillet. Dimensions A and B are indicated. TD (tear-drop): Shows a circular feature with a tear-drop fillet. Dimensions A and B are indicated. A radius is also shown. SL1 (sub-land): Shows a circular feature with a sub-land. Dimensions A and B are indicated. SL2 (sub-land): Shows a circular feature with a sub-land. Dimensions A and B are indicated.

The following table defines the rules of interaction between lineMode types and the additional line dimensioning attributes.

Table 2 Line Modification Rules

lineMod	dimA	dimB	DimC
TP	required	required	Prohibited
TD	required	required	Required
SL1	required	required	Prohibited
SL2	required	required	Prohibited
--NONE--	prohibited	prohibited	Prohibited

LineDesc Examples:

```
<LineDesc id = "IPCstd:courtyard1" width = "1.0" type = "DOTTED"
length = "2.5"/>
```

The lines to which it is applied will be a black dotted line, 1.0 mm diameter for the dot, 2.5 mm for the space between dot centers.

```
LINEDESC: "line3", 1.0, , , CENTER , 1.5, 2.8;
```

The lines to which it is applied will be a repeating black dash, dot, dash line, 1.0 mm wide (this is also the diameter of the dots), 1.5 mm space between dot center and start or ending of dash, and 2.8 mm for length of dash.

```
LINEDESC: "Line9", 1.0, SQUARE , , CENTER, 8.0, 40.0,
TP, BOTH, 2.5, 1.3;
```

The lines to which it is applied will be a CENTER line, black by default, 1.0 wide, where the length of the dash is 40.0 and the clearance between the center of the dot and the beginning and end of the dash is 8.0. Since the line ends are SQUARE, the dot is also square - 1.0 x 1.0). Both ends of the line segment are tapered.

```
<LineDesc id = "IPCstd:phantom" width = "1.0" type = "PHANTOM"
colorRef = "IPCstd:red" lineEnd = "ROUND" space = "8.0"
length = "25.0" modEnd = "START" lineMod = "TD" dimA = "2.0"
dimB = "1.7" dimC = ".5"/>
```

The lines to which it is applied will be a red PHANTOM line, 1.0 wide, where the dashes are 8.0 long, and the distance from beginning and end of the dash to the center of the dots, or the distance between dot centers is 8.0. The starting end of the line is a teardrop, while the opposite end is round by default.

4.13 PaintDescs

The PaintDesc element defines the fill characteristics that can be applied to a closed shape. The paint description definitions are referenced throughout the GenCAM file using a paintDescRef attribute. GenCAM supports the paint types of HOLLOW, FILL, MESH, HATCH and VOID (see Figure 9). The following table defines all the attribute options for PaintDesc.



4.13.1 PaintDesc

Attributes	Requirement	Description
id	REQUIRED	The id attribute is a qualifiedName that uniquely identifies the PaintDesc within the GenCAM file. The id is referenced by PaintDescRef attributes in order to associate the PaintDesc definition with geometries to which it applies.
type	DEFAULT	The texture of the fill is one of HOLLOW, HATCH, MESH, FILL or VOID. The default is HOLLOW.
colorRef	OPTIONAL	A reference to a Color/@id attribute. The default color is black.
lineWidth	OPTIONAL	The width of the lines used in a HATCH or MESH. (This attribute only applies to the paint types HATCH and MESH.)
pitch1	OPTIONAL	The distance between the first set of lines in a HATCH or MESH. The default pitch between the hatch lines is 4 times the lineWidth. (This attribute only applies to the paint types HATCH and MESH.)
pitch2	OPTIONAL	The distance between the second set of lines in a MESH. The default pitch between the hatch lines is 4 times the lineWidth. (This attribute only applies to the paint type MESH.)
angle1	OPTIONAL	The angle of a set of lines in a HATCH or a MESH. The angle is measured relative to the x-axis of the local coordinate system. The range of values is limited to between 0 and 90 degrees. The default is 45 degrees. (This attribute only applies to the paint types HATCH and MESH.)
angle2	OPTIONAL	The angle of the second set of lines in a MESH. The angle is measured relative to the x-axis of the local coordinate system. The angle must be between 90 and 180 degrees. The default is 135 degrees. (This attribute only applies to the paint type MESH.)

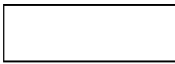
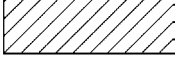
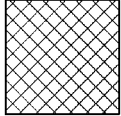
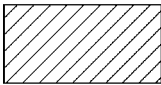
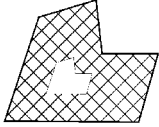
This diagram illustrates the <code>PaintDesc/@type</code> attribute. The <code>LineDesc/@type</code> is set to <code>SOLID</code> in the examples to provide an outline around the shapes that are painted with <code>MESH</code>, <code>HATCH</code>, or <code>VOID</code>.	HOLLOW FILL MESH HATCH VOID
This diagram illustrates the <code>PaintDesc/@type</code> attribute with several different shapes. <code>VOID</code> removes the immediately previous, positive instance. A <code>VOID</code> overlapping a <code>VOID</code> only extends the <code>VOID</code> and does not remove the second positive instance.	circle – FILL rectangle – MESH rectangle – HATCH polygon with VOID

Figure 9 `PaintDesc` fill definitions

Example:

```
<PaintDesc id="IPCstdFills:compfill" type="HATCH" colorRef="IPCcolors:BLACK"
  lineWidth="0.20" pitch1="0.20" angle1="45" />
```

The closed shape to which it is applied will be a hatched black fill with a line width of 0.20 mm and a pitch between lines of 0.20 mm and an angle of 45 degrees.

4.13.2 Rules of Precedence

Both the `LineDesc` and `PaintDesc` elements have an optional `colorRef` attribute. The addition of an optional `colorRef` attribute, directly on the element instance has the possibility of causing a conflict with the `colorRef` on a definition element. Should this happen, the `colorRef` specified for the more local enhancement element (`LineDesc`, `PaintDesc`) overrides a previously defined value or the default value. The `colorRef` example in figure 10 shows the rules of precedence and indicates how usage textures override referenced textures included in the definition of an artwork or pattern. The `colorRef` attribute is used as an example.

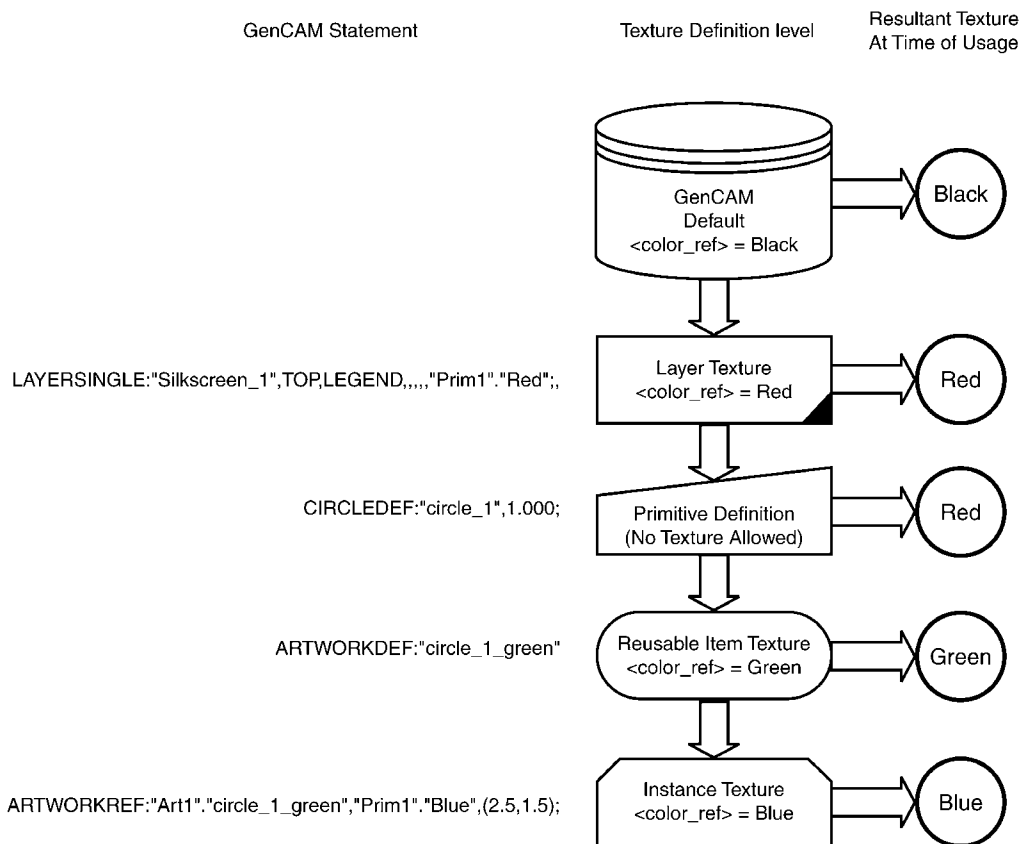


Figure 10 Rules of precedence

4.14 PrimitiveShapes

The physical characteristics of an electronic interconnection product allow the product geometry definition to be represented using a small set of primitive 2-D shapes. It would be possible to represent everything using just polygon and polyline primitives, however, a more concise and descriptive product representation is possible if the base set of primitives also includes the most commonly used closed shapes, such as rectangles, thermals, and circles. The description of the product geometry can more accurately and concisely reflect the product design if standard sized graphical elements, such as pads in a land pattern, can also be defined once and referenced when used. The graphical elements that are defined in *PrimitiveShapes* element enable this reuse. Figure 11 shows the list of primitive shapes that can be defined. These definitions are referenced to create instances of the shapes.