Aurora Tool Design Guide

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IMPORTANT
Please read this entire document before attempting to design tools to use with an Aurora System

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Read Me First!

Read this section before continuing with the rest of the guide.

Warnings

Warning!

In all NDI documentation, warnings are marked by this symbol. Follow the information in the accompanying paragraph to avoid personal injury.

1. Single sensor coil and dual 5DOF tools are not capable of detecting magnetic field disturbances. The tool designer should be aware of the single sensor coil and dual 5DOF tool limitations in combination with its application, and advise the customer and/or user accordingly. Applying transformations from a system using single sensor coil and dual 5DOF tools in a disturbed magnetic field may result in injury when the application involves personal safety.
2. Do not bend or kink tool cables, or use tools with damaged tool cables. Inspect tool cables regularly for damage. Applying transformations from a system with damaged tool cables may result in injury when the application involves personal safety.
3. Do not wrap the tool cable around the Field Generator as incorrect transformations may result. Applying transformations from a system with the tool cable wrapped around the Field Generator may result in injury when the application involves personal safety.
4. Do not place the tool cable parallel to or in close proximity to the Field Generator cable as incorrect transformations may result. Applying transformations from a system with the tool cable in such a position relative to the Field Generator cable may result in injury when the application involves personal safety.
5. Do not track a tool unless you are sure that its SROM device is programmed correctly, and with the correct settings. For example, avoid using similar tools programmed with the same SROM information if they have different tool-tip offsets. Using a poorly programmed tool may produce inaccurate transformations and possible personal injury.
6. Do not use cables, transducers, or accessories other than those recommended by NDI. To do so may result in increased emissions and/or decreased immunity of the Aurora System. This may increase the possibility of personal injury.
7. Make sure that patient auxiliary leakage currents do not exceed allowable limits. Give special consideration to insulation materials and thicknesses to ensure the galvanic isolation of multiple tools connected to the Aurora System. Failure to do so may lead to personal injury. Consult IEC60601 and applicable national differences and amendments for guidance.
8. NDI is not responsible for the programming of the SROM device. Incorrect tool SROM device programming may result in incorrect transformations. Applying transformations from a system with incorrect tool SROM device programming may result in injury when the application involves personal safety.

Disclaimers

1. NDI shall make no expressed or implied warranty of any kind with regards to the information contained in the Aurora Tool Design Guide.
2. NDI is not responsible for the design of tools, and only provides the Aurora Tool Design Guide as information to assist the tool designer in the design of tools. Usage of the Aurora Tool Design Guide and the choice of materials, ergonomics, design and/or application, tool functionality and tool material biocompatibility is the sole responsibility of the tool designer.
3. NDI shall not be liable for incidental or consequential damages in connection with or arising out of the furnishing, performance or use of any information contained in the Aurora Tool Design Guide.
4. NDI supplies sensor coils specifically designed and tested for use with the Aurora System. If you use sensor coils from any other source, be aware that NDI does not guarantee the accuracy of measurements made with those sensor coils.

Questions?

If you have any questions regarding the content of this guide or the operation of this product, please contact us:

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Updates

NDI is committed to continuous improvements in the quality and versatility of its software and hardware. To obtain the best results with your NDI system, check the NDI Support Site regularly for update information:

http://support.ndigital.com

About This Guide

This guide details information concerning all aspects of the design, construction, and characterization of tools for use with the second generation NDI Aurora® System. (The second generation Aurora System incorporates the Flat Field Generator.) Before attempting to design a tool, you should have a thorough understanding of:

- the subject matter detailed in this guide, including basic wiring concepts and techniques for electronic components, and
- the NDI Aurora System, as detailed in the documentation that accompanied the system.

NDI is not responsible for the design of tools. NDI provides the *"Aurora Tool Design Guide"* only as reference to assist you in the design of tools. Decisions about materials, ergonomics, design, application, tool functionality, and tool material biocompatibility are your responsibility.

There are many aspects of tool design and development that are beyond the scope of this guide and NDI's areas of expertise. Further, this document cannot anticipate all of the relevant concerns across the broad range of tools that may be developed. For help in understanding the concepts explained in this guide, or to discuss specific design implementation, contact NDI technical support.

Warnings, Classifications, and Approvals

A complete list of the warnings, classifications, and approvals that apply to the NDI Aurora System is included in the user manual shipped with the system. Review this information before attempting to design a tool.

Organization of Content

This guide is divided up into several sections:

Basic Concepts The first three chapters in this guide explain basic concepts that you must understand before designing an Aurora System tool. These chapters are organized by subject:

- "Basic Concepts: Tool Types" describes the types of tools that can be used with an Aurora System, and how to pick which one will work best for your application.
- "Basic Concepts: Tool Design" describes the different elements of tool design that you must take into account before designing a tool.
- "Basic Concepts: Tool Measurement" describes how the Aurora System tracks tools and produces transformations. This information will help you understand how the Aurora System and the tool will interact.

Creating a Tool Design This chapter provides guidelines to help you produce an actual tool design. Refer to this chapter as you make material and design choices, to ensure the successful performance of the final product.

Constructing Tools This chapter provides guidelines to help you build and test a tool, and some important wiring instructions for each tool component. At the end of the chapter, you will find a sample tool's wiring schematics, provided for reference.

Electrical Safety Considerations This chapter provides advice about meeting electrical standards, and points you to relevant safety standard information.

1 Basic Concepts: Tool Types

1.1 Introduction

This guide provides information on how to design tools for use with the Aurora System. To ensure that the tools operate correctly and safely it is necessary that you read and understand all the information in this guide before you begin to design any tool.

You will also require a technical understanding of the Aurora System. Refer to the documentation delivered with the system. For further information contact the NDI office nearest your location. Contact details are listed on page vi.

1.2 Tool Components

All Aurora System tools consist of a combination of six basic components (some of which are optional):

Table 1-1 Basic Tool Components

Component	Description
Sensor coils	The sensor coil comprises a very fine insulated wire wound around a small metal core with a pair of lead wires. A tool can contain up to two (0, 1, or 2) sensor coils.
Serial Read Only Memory (SROM) device	The SROM device stores an individual tool’s specific information and (if necessary) characterization data. An SROM device is hardware that can be programmed only once. It is normally located inside the tool connector.
Tool connector	The uniquely keyed connector normally encloses the SROM device and is where all tool component wiring is terminated.
Tool cable	The specified eight conductor shielded cable connects the sensor coils, switches, LEDs and other input/output devices to the tool connector.
LEDs and switches (optional)	Single input/output devices indicate or initiate a tool function. Each tool can support up to three input/output devices.
Tool body	The tool body incorporates the tool’s sensor coils, LEDs, switches and other input/output devices into a tool.

Note NDI supplies sensor coils specifically designed and tested for use with the Aurora System. If you use sensor coils from any other source, be aware that NDI does not guarantee the accuracy of measurements made with those sensor coils.

The following diagram shows an example tool incorporating each basic tool component:

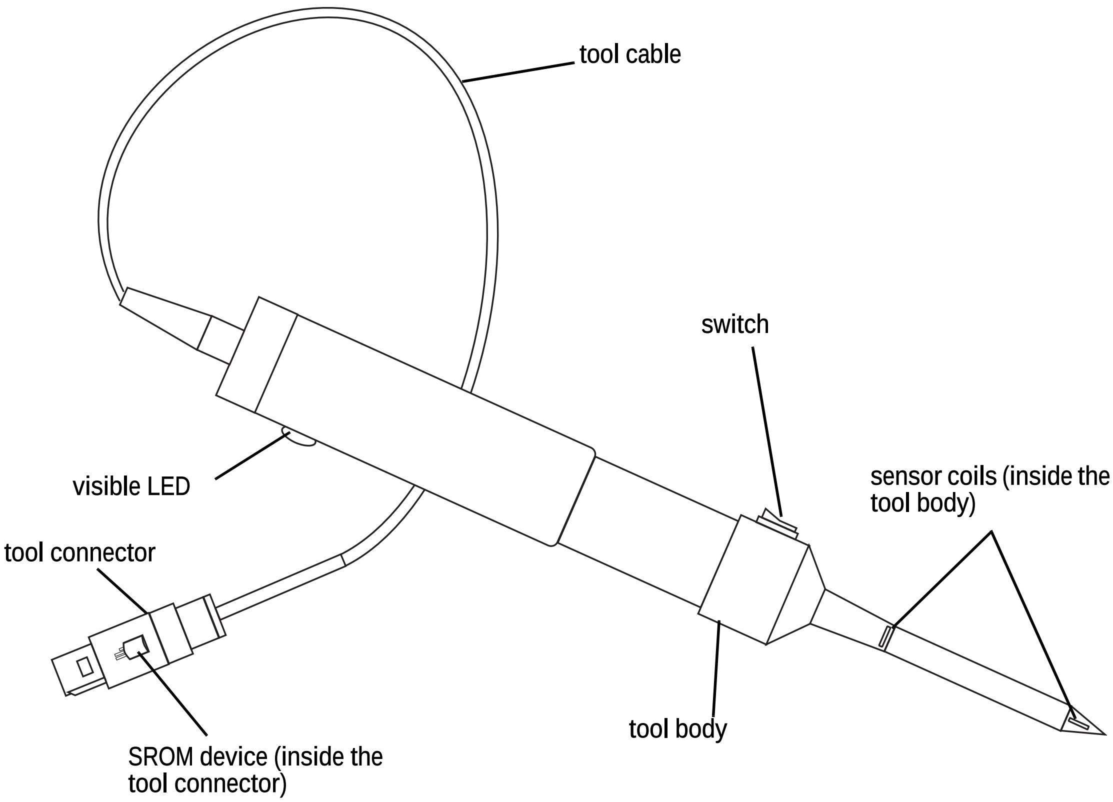

Figure 1-1 Basic Tool Components

1.3 Aurora Tool Types

A tool can be categorized as one of several basic types, depending on the number of sensor coils embedded in it:

Table 1-2 Categorizing Tool Types

# Sensor Coils	Tool Type	Sensor Coil Placement	5DOF/6DOF
0	sensorless tool	not applicable	not applicable
1	single sensor coil tool	anywhere	5DOF
2	dual 5DOF tool	not fixed relative to each other	dual 5DOF
	6DOF tool	fixed relative to each other	6DOF
	co-linear sensor coil tool	fixed relative to each other in a co-linear fashion	5DOF
	parallel sensor coil tool	fixed relative to each other in a parallel fashion	5DOF

1.4 Explaining 5DOF and 6DOF

The number of sensor coils embedded in a tool influences the kind of measurements the Aurora System can perform: 5DOF measurements or 6DOF measurements.

5DOF measurements

If a tool contains only one sensor coil, the rotation around the sensor coil's z-axis (Rz) cannot be accurately determined and is arbitrarily assigned a value by the system. As such, the position and orientation of single sensor coil tools can only be accurately determined to five degrees of freedom (5DOF): x, y, z, Rx, and Ry.

6DOF measurements

When a tool is equipped with two sensor coils *fixed relative to each other*, the system can determine all six degrees of freedom (6DOF) for the tool: x, y, z, Rx, Ry, and Rz.

1. The system determines 5DOF information for each sensor coil.
2. The system combines and compares this information, applies what it knows about the tool's design, and determines six degrees of freedom (6DOF) for the entire tool.

The accuracy of a 6DOF transformation will vary depending on the angle between the two sensor coils. Maximum accuracy is achieved when the sensor coils are orthogonal, with accuracy decreasing as the angle decreases.

Note Tools with small angles between the two sensor coils require less space, which results in smaller tools. Consider this relationship between sensor coil angle and accuracy versus tool size as you design the tool.

If the two sensor coils are fixed relative to each other in a co-linear or parallel fashion, the rotation component of the transformation about the "common" axis will not be accurate. Effectively, the tool will be a 5DOF tool. An advantage of this arrangement is that an indicator value will be produced. For information about indicator values, see "Indicator Value" on page 11.

What is Dual 5DOF?

If a tool contains two sensor coils that are *not fixed relative to each other*, the system will return a 5DOF measurement for each sensor coil. In other words, the system treats the data as if the tool is in fact two single sensor coil tools joined to a single tool connector. This type is called a "dual 5DOF tool".

Note For more information and a diagram of a sample tool, see "Dual 5DOF Tools" on page 5.

2 Basic Concepts: Tool Design

This chapter explains basic design concepts for Aurora System tools.

2.1 Understanding Local Coordinate Systems

Each tool has its own local coordinate system that is defined by an origin and three axes. Local coordinate systems are an integral part of the measurement process, and the Aurora System cannot calculate a tool's position or orientation without them.

The following sections describe possible arrangements of local coordinate systems, organized according to tool type.

2.2 Local Coordinate Systems: Single Sensor Coil Tools

The single sensor coil tool's local coordinate system is based directly on that of its sensor coil. By default, the system assigns the z-axis along the sensor coil's length, with an origin at the sensor coil's centre. The x and y axes are not fixed due to the inability to determine rotation about the z-axis.

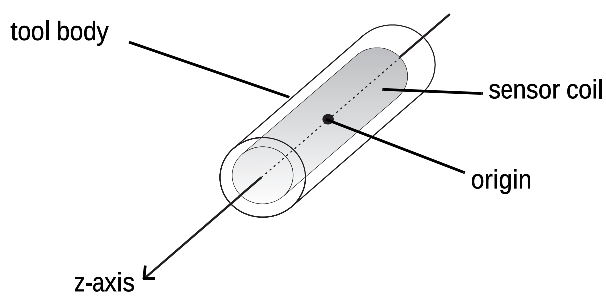

Figure 2-1 Sample Single Sensor Coil Tool

Note Single sensor coil tools do not return an indicator value. For more information about indicator values, see "Indicator Value" on page 11.

2.3 Local Coordinate Systems: Dual Sensor Coil Tools

Dual 5DOF Tools

The dual 5DOF tool is essentially two single sensor coil tools joined to the same tool connector. As such, the tool actually has two local coordinate systems, each based on one of the sensor coils incorporated into its design. These local coordinate systems are determined in the same way as that of a single sensor coil tool.

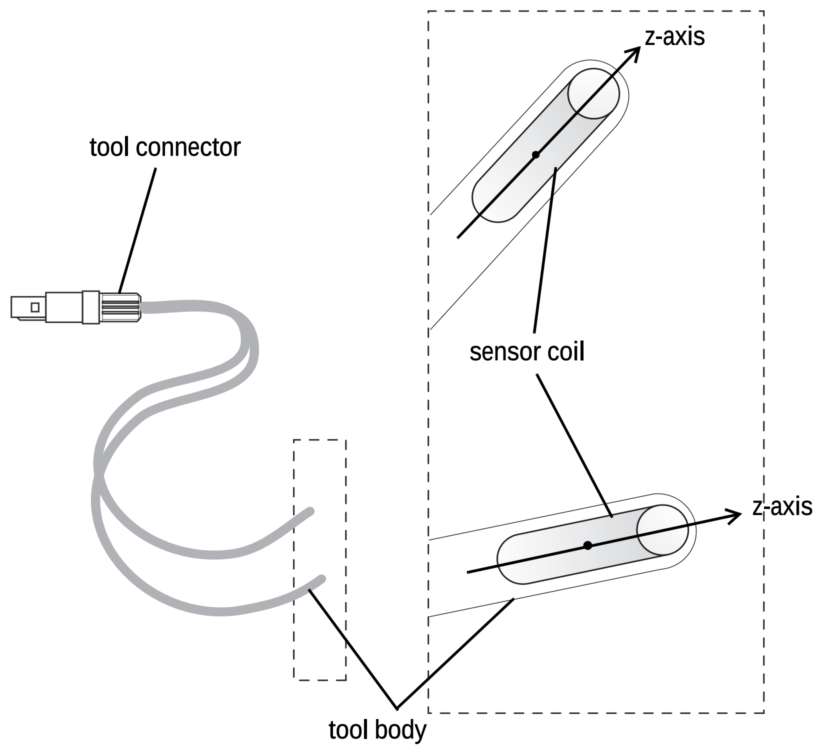

Figure 2-2 Sample Dual 5DOF Tool

6DOF Tools

A tool with two sensor coils fixed relative to each other is assigned its *own* coordinate system, independent of its sensor coils. The description of this local coordinate system is contained in the tool definition file and programmed onto the tool's SROM device.

The following diagram illustrates a 6DOF tool with a local coordinate system independent of its sensor coils. When the Aurora System calculates this tool's position and orientation, it will return only one transformation.

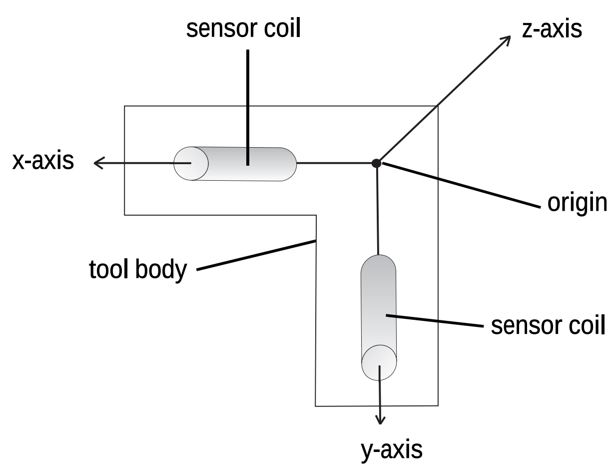

Figure 2-3 Sample 6DOF Tool

Co-linear Sensor Coil Tools

When two sensor coils are fixed in a co-linear fashion, the system will calculate 6DOF, but the rotation about the common axis will not be accurate. This is because the two coils are co-linear rather than orthogonal. As such, this tool is considered a 5DOF tool.

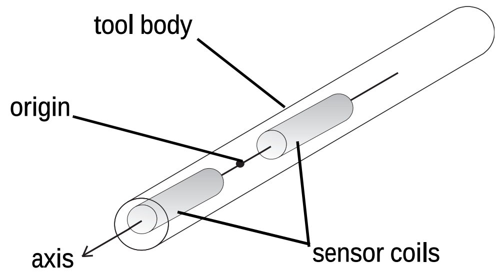

Figure 2-4 Sample Co-linear Sensor Coil Tool

One advantage of a co-linear sensor coil tool is that, unlike single sensor coil tools, you can define the axis running the length of the two sensor coils as something other than the z-axis. You can also assign the tool's point of origin, as long as it falls upon this axis. Another advantage is that it provides indicator values. For further information on indicator values see "Indicator Value" on page 11.

Parallel Sensor Coil Tools

When two sensor coils are fixed parallel to each other, the system will calculate 6DOF, but the rotation about the common axis will not be accurate. This is because the two coils are parallel rather than orthogonal. As such, this tool is considered a 5DOF tool.

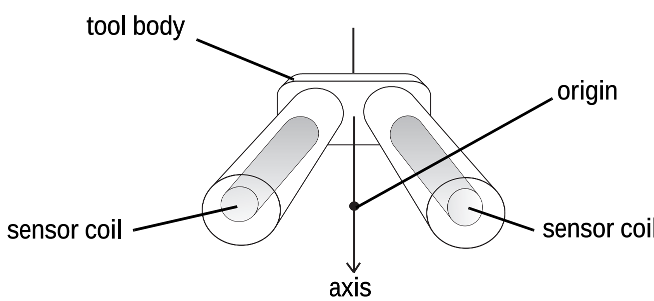

Figure 2-5 Sample Parallel Sensor Coil Tool

As shown in the figure above, you can assign the axis running lengthwise between the two sensor coils. You can also assign the tool's origin, as long as it falls upon this axis. The axis must be parallel to the two sensor coils and exactly half way between them.

2.4 Points of Interest

Points of interest may be defined as points on or near a tool where accuracy is most important and is determined by the tool’s intended use.

As you design a tool, it is important to understand and consider the relationship between points of interest, the origin of the tool’s local coordinate system, and the resulting transformations that will be returned by the system. Your aim is to design a tool that produces the greatest accuracy at the point(s) of interest.

Points of interest need to be considered when placing sensor coils in the tool. The closer the sensor coil(s) are placed to the point(s) of interest, the greater the accuracy at the point(s) of interest.

Ideally the origin of the local coordinate system, sensor coil(s) and point of interest would all be the same. In practice this is not always possible, and in some cases not even advisable.

Consider a simple probe. It is not possible to place the sensor coils at the probe’s tip because of physical restrictions. However, placing the sensor coils as close to the tip as possible will minimize the offset vector required and improve accuracy. Offset vectors are discussed below.

Consider the tip of the probe: it is delicate and may be easily bent or damaged if the probe is dropped. In theory, placing the tool’s origin at the point of interest (the tool’s tip) is best practice; however, since that tip is likely to change location, it is better practice to place the origin in another location on the tool, and apply a changeable offset vector to transformations that the tool produces.

2.5 Axes of Interest

Similar to a point of interest, an axis of interest represents an imaginary vector in (or projected from) a tool where measurement accuracy is most important. For example, if the tool is a probe that needs its trajectory to be in a particular direction before being used, the axis of interest is an imaginary line travelling along that trajectory.

The same criteria discussed for points of interest also apply to axes of interest.

Axes of interest need to be considered when placing sensor coils and defining the tool’s local coordinate system. The closer that one of the sensor coils is aligned with an axis of interest, the greater the accuracy of that axis of interest.

2.6 Offset Vectors

Although you may be able to place sensor coils such that their origins fall on either the point of interest or axis of interest, there are situations in which this may be physically impossible. For example, you may not be able to embed a sensor coil inside a probe’s tip because the tip is too small, or because it is likely to bend or break.

In such situations, you will need to apply an offset vector to describe the location of the point of interest with respect to the tool's origin. This value can be permanently stored in the user portion of the SROM device and applied using your application software. It can also be calculated as part of the tool's application, producing an independent and constant value that is applied to collected data in real-time.

Note To determine an offset vector for a tool with a tip (otherwise known as the tip offset), you can perform a pivot. For more information, see "Pivoting" on page 28.

3 Basic Concepts: Tool Measurement

It is important when designing tools to have a general understanding of the Aurora System and the concepts that drive its measurement functionality. This chapter explains the more important concepts in greater detail.

3.1 Understanding the Global Coordinate System

Just as each tool has its own local coordinate system, the Aurora System has its own global coordinate system. These coordinates are based on the Field Generator's characterized measurement volume, and uses the Field Generator as their point of origin. The global coordinate system is also integral to the measurement of a tool's position and orientation.

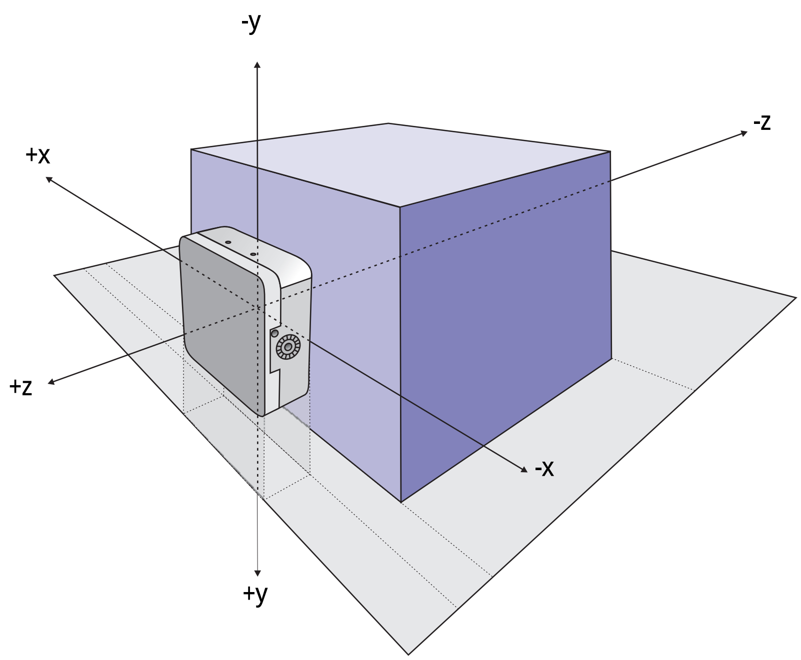

Figure 3-1 The Aurora System's Global Coordinate System

3.2 Explaining Transformations

Once the Aurora System has calculated the position and orientation of a tool, it returns a *transformation* representing the results. Transformations are returned in the following format:

q0 qx qy qz Tx Ty Tz indicator_value

Where:

1. **q0 qx qy qz** represents the tool's orientation (in quaternion format),
2. **Tx Ty Tz** represents the tool's position in the measurement volume, and
3. **indicator_value** represents the transformation's indicator value.

Note — The Aurora System calculates a tool's rotation in quaternion format (q0 qx qy qz), but Aurora documentation explains a tool's rotation in Euler format (Rx, Ry and Rz), as it is easier to visualize. NDI application software can display tool rotation using either format.

Indicator Value

With each transformation calculated, the Aurora System returns an *indicator value*. The indicator value is an estimate of how well the system calculated that particular transformation. The indicator value is formatted as a number (without unit) between 0 and 9.9 (where 0 is the absence of error and 9.9 is the highest indication of error).

For 6DOF tools, the indicator value compares sensor coil measurements to the tool's design (as described by the information in the SROM device). The greater the difference between the measured sensor coil positions and orientations and the known positions and orientations of the sensor coils within the tool, the higher the indicator value. Such discrepancies are often an indication that magnetic field disturbances are affecting the collected data.

For 5DOF transformations, the indicator value is always zero. (This does not indicate an absence of error, but the inability to determine the error.)

Indicator values less than 1.0 are typically considered acceptable. You should set your own indicator value thresholds, depending on the nature of your application needs.

Note — The indicator value is not an absolute indication of overall error, but simply an indication that the measurement may be compromised, or that there may be a mismatched tool definition file.

For more information about the indicator value and how to use it with applications, see the *"NDI Polaris and Aurora Combined Application Programmers' Interface Guide"*.

3.3 Producing Transformations

The following procedure describes how the Aurora System produces transformations:

1. When a tool is placed in the measurement volume, magnetic fields, produced by the Field Generator, cause the sensor coils(s) in the tool to produce signals.
2. The system receives the sensor coil signals via the Sensor Interface Unit (SIU).
3. The system processes the signals using a specific mathematical model. The end result is a 5DOF transformation for each sensor coil (that is producing signals).
4. The next step the system performs depends on the type of tool, as follows:

Single Sensor Coil Tool The system does not need to perform any additional steps. The 5DOF transformation produced in step 3 is the final transformation for the entire tool. No indicator value is produced. Tool offset is possible (along the z-axis), but the offset must be applied using the customer software.

6DOF Tool The system takes the two 5DOF transformations produced in step 3 and processes them using a mathematical model and the information in the SROM device. The result is a single 6DOF transformation that reflects the position and orientation of the entire tool. Part of this 6DOF transformation is an indicator value.

Co-linear Sensor Coil Tool/Parallel Sensor Coil Tool The system takes the two 5DOF transformations produced in step 3 and processes them using a mathematical model and the information in the SROM device. The result is a single 6DOF transformation that reflects the position and orientation of the entire tool. However, the roll component of the transformation cannot be considered accurate because the sensor coils are not orthogonal in these tool types. Therefore these tools must be considered 5DOF tools. In addition, the indicator value produced is not as representative as those produced with 6DOF tools, and may not be useful for application's purposes.

3.4 What Are Reference Tools?

Issue

Measuring a tool's position and orientation, throughout the measurement volume, is a simple procedure as long as the following are true:

1. The Field Generator does not accidentally and unknowingly shift. If it does shift, the global coordinate system also shifts. This change affects the perceived location of a tool within the global coordinate system, producing misleading measurement data.
2. The object of interest does not accidentally shift. If you are using the Aurora System to place a tool at a specific point on the object of interest, it is very important that the object does not move with respect to the Field Generator, while you are trying to place the tool. There is no way for the system to perceive such movement, and you may end up placing the tool in the wrong location.

In many application environments, shifting objects and bumped Field Generators are not uncommon occurrences. As such, the two above requirements are often difficult to meet.

Solution

A *reference tool* is designed to be affixed to an object of interest (or a Field Generator). Once affixed, when the object shifts, the reference tool will shift as well. Other tools can be measured relative to the reference tool, that is in the reference tool's local coordinate system.

The Aurora System measures the reference tool's movement as well as the tracking tool's movement, producing two sets of measurements. You can design your application to interpret these measurements in the following way:

1. Calculate the reference tool's movements to capture any shifting.
2. Calculate the transformation from the tracking tool's local coordinate system to the reference tool's local coordinate system. This reports the tracking tool in the frame of reference of the reference tool (as opposed to the global coordinate system).

4 Creating a Tool Design

This chapter describes the design considerations required to construct Aurora System tools. It is your responsibility to ensure that each tool complies with the appropriate standards specific to its intended application.

4.1 Complete the Design To-Do List

The following list explains the decisions you will need to make as you create a tool design:

1. **Determine the type of measurement required for your application.** Does your application require that you know the tool's full orientation as well as its position? If so, you will need to design a 6DOF tool.
2. **Determine the number of sensor coils required.** If the tool must produce 6DOF data, you will need to create a design that includes two sensor coils; 5DOF tools may contain one or, in the case of co-linear or parallel coil tools, two sensor coils. In addition, if you wish to create a tool that simply acts as an input/output device, you do not need to use any sensor coils.
3. **Determine the requirement for an indicator value.** If the tool must produce an indicator value, then you must design a 6DOF tool. See "Indicator Value" on page 11.
4. **Determine the tool's shape and points/axes of interest.** Taking into account the number of sensor coils that need to be incorporated into its body, consider a shape that best suits the application needs. Once you know the shape, determine if it has any points or axes of interest. This will help you decide where to best place the sensor coils.
5. **Determine sensor coil placement.** Taking into account the locations of the tool's points of interest and/or axes of interest, begin to plan the placement of the sensor coils. For more information about this very important step, see "About Sensor Coil Placement" on page 13.
6. **Determine the tool's local coordinate system and origin.** Although you cannot assign a local coordinate system to the tool until you characterize it, you can at least determine where it will be located as part of the design efforts. Remember that if you have a point of interest or an axis of interest, the position and orientation of the local coordinate system (and origin) can be closely associated with them.

4.2 About Sensor Coil Placement

Planning sensor coil placement is one of the most important tool design tasks. This section will help you understand the different options available, so that you can plan the best possible placement in a particular tool.

Single Sensor Coil (5DOF) Tools and Dual 5DOF Tools

Remember that the local coordinate system for a single sensor coil tool is automatically defined based on the sensor coil; it cannot be assigned by the user. As such, how you place the sensor coil directly affects the tool's local coordinate system.

Note You should consider that single sensor coil tools are not capable of producing an indicator value.

Consider the following guidelines:

Rule #1 The ideal location for the sensor coil's origin is at the tool's point of interest.

Rule #2 The ideal orientation of the sensor coil is such that its z-axis falls on the tool's axis of interest.

Rule #3 The tool will require an offset vector if you cannot place the sensor coil so that its origin is on the tool's point of interest. This offset vector must align along the sensor coil's long axis (z).

Rule #4 Keep the distance between the sensor coil and the tool cable as small as possible, in order to reduce noise.

Note Performing a pivot is one method of determining an tool's offset value. See "Pivoting" on page 28 for more information.

6DOF Tools

Unlike the single sensor coil tool, you can assign a local coordinate system for a 6DOF tool independent of its sensor coils' individual coordinate systems.

Consider the following guidelines:

Rule #1 The sensor coils should be placed as close to each other as is practical within the design constraints, but no closer than 2 mm. If two sensor coils are placed closer than 2 mm, they may interfere with each other.

Rule #2 The sensor coils must be firmly affixed inside the tool body, so that they cannot move from their assigned position.

Rule #3 Sensor coils should be placed such that their long axes (z) are arranged orthogonal to each other.

Rule #4 At least one of the sensor coils should be placed as close as physically possible to the point of interest.

Rule #5 The sensor coils should be placed symmetrically about and as close as physically possible to the axis of interest.

Rule #6 To optimize the measurement repeatability, locate the tool's origin at the translational average of the tool's two sensor coils.

Rule #7 Keep the distance between the sensor coils and the tool cable as small as possible, in order to reduce noise.

Co-linear Sensor Coil Tools

The co-linear sensor coil tool can only return 5DOF data, but differs from the single sensor coil tool in the following ways:

- Although it also returns 5DOF data, on average the co-linear sensor coil tool is more accurate than a single sensor coil tool, and will provide an indicator value.

- Unlike the single sensor coil tool, you can define the axis running the length of both sensor coils as other than the z-axis.
- Unlike the single sensor coil tool, you can assign the tool's origin anywhere along the axis running the length of both sensor coils.

The following list provides more specific guidelines for sensor coil placement within a co-linear sensor coil tool body.

Rule #1 The sensor coils should be placed as close to each other as is practical within the design constraints, but no closer than 2 mm. If two sensor coils are placed closer than 2 mm, they may interfere with each other.

Rule #2 At least one of the sensor coils should be placed as close as physically possible to the point of interest.

Rule #3 If possible, the sensor coils should be placed so that the axis running the length of both sensor coils aligns with the tool's axis of interest.

Rule #4 Keep the distance between the sensor coils and the tool cable as small as possible, in order to reduce noise.

Parallel Sensor Coil Tools

The parallel sensor coil tool can only return 5DOF data, but differs from the single sensor coil tool in the following ways:

- Although it also returns 5DOF data, on average the parallel sensor coil tool is more accurate than a single sensor coil tool, and will provide an indicator value.
- Unlike the single sensor coil tool, you can define the axis running parallel to and between both sensor coils as other than the z-axis.
- Unlike the single sensor coil tool, you can assign the tool's origin anywhere along the axis running parallel to and between both sensor coils.

The following list provides more specific guidelines for sensor coil placement within a parallel sensor coil tool body.

Rule #1 The sensor coils should be placed as close to each other as is practical within the design constraints, but no closer than 2 mm. If two sensor coils are placed closer than 2 mm, they may interfere with each other.

Rule #2 The sensor coils should be placed so that the axis running parallel to and between both sensor coils aligns with the tool's axis of interest.

Rule #3 The sensor coils should be placed so that the tool's origin will fall along the axis running parallel to and between both sensor coils.

Rule #4 Keep the distance between the sensor coils and the tool cable a small as possible, in order to reduce noise.

5 Constructing Tools

This chapter provides the following information on how to assemble an Aurora System tool correctly:

- Constructing the Tool Body
- Using Tool Connectors
- Using Tool Cables
- Wiring Sensor Coils
- Installing SROM Devices
- Adding LEDs and Switches
- Managing Metallic Components
- What is the Tool Definition File?
- Verifying Tools

Included at the end of this chapter is a sample tool wiring schematic diagram, for reference.

Note You should consider the tool's verification process when designing the tool. This is to ensure that the tool will meet the requirements of its intended application.

5.1 Constructing the Tool Body

Consider the following rules when you select tool body materials:

Rule #1 The tool body should be constructed of low conductivity materials (such as plastics), rather than high conductivity materials (such as metals and carbon). Limiting the use of high conductivity materials will reduce the possibility of shorting the sensor coils and other internal components. This practice will also reduce the distortion of the electromagnetic field produced by the Field Generator.

Note Metal tube configurations, such as needles, are acceptable.

Rule #2 The tool body should be sealed to reduce the possibility of moisture coming into contact with the internal components of the tool. Moisture coming into contact with the internal components of the tool may result in tool damage.

Rule #3 Electrical isolation should be considered for all internal tool components as well as other objects with which the tool may come into contact (depending on the required application).

Rule #4 The tool body material strength should be considered when designing a rigid type tool. Using a rigid type tool that has been bent may result in inaccurate measurements.

Rule #5 For tools used in a steam sterilization (autoclave) process, consider tool body materials that have low thermal expansion. This may reduce measurement errors caused by sensor coils moving relative to each other or within the tool body. It will also reduce the possibility of damage to the sensor coils.

Rule #6 For tools that may come into contact with a patient, it is the responsibility of the tool designer to analyze tool body materials to ensure only biocompatible materials are used.

Warning!

The exchange of non-biocompatible materials between the tool and the patient may result in injury. It is the responsibility of the tool designer to determine the biocompatibility of tool body materials.

5.2 Using Tool Connectors

Disassemble the tool connector by unscrewing the two halves of the outer tool connector body. This will expose the inner terminals that connect to the SROM device and the cable wiring:

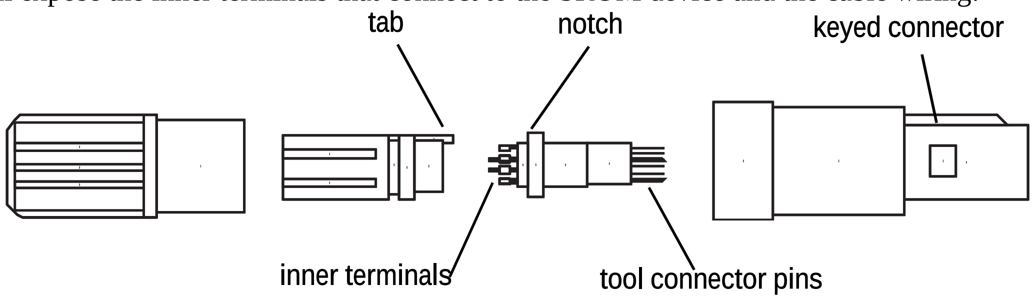

Figure 5-1 Disassembled Tool Connector

All tool components (apart from the body) connect to the tool connector. Refer to the following table and diagram when determining these wiring connections:

Table 5-1 Tool Connector Pin Functions

Pin #	Pin Function	Pin #	Pin Function
1	#1 Sensor Coil + (jumpered to pin 2 if not used)	6	Tool-in-port present (jumpered to pin 8)
2	#1 Sensor Coil - (jumpered to pin 1 if not used)	7	GPIO 1 (typically switch or LED) max. 10 mA
3	#2 Sensor Coil + (jumpered to pin 4 if not used)	8	SIU circuit ground
4	#2 Sensor Coil - (jumpered to pin 3 if not used)	9	GPIO 2 (typically switch or LED) max. 10 mA
5	SROM device wire interface	10	GPIO 3 (typically switch or LED) max. 10 mA

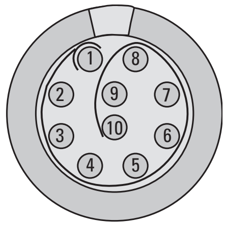

Figure 5-2 Tool Connector Pin Orientation - Viewed from Rear

5.3 Using Tool Cables

Consider the following guidelines if you plan to use a tool cable to connect the tool to the tool connector. For further information refer to the *Aurora Tool Component Guide*:

Rule #1 Each sensor coil must be connected to one of the tool cable’s dedicated twisted pairs. (The twisted pairs consist of very thin red and green wires.)

Rule #2 The shield of the cable must be connected to the SIU circuit ground (pin 8).

Rule #3 Cable length should be kept as short as possible to reduce interference. The maximum suggested overall length of the tool cable (from the sensor coil(s) to the tool connector) is 2.5 m. That said, keep the distance between the sensor coil and the tool connector as small as possible.

Rule #4 All unused wires within the tool cable should be connected to the tool connector’s pin 8 (SIU circuit ground). Not grounding unused wires may result in increased sensor coil measurement noise.

Warning!

Do not bend or kink tool cables or use tools with damaged tool cables. Inspect tool cables regularly for damage. Applying transformations from a system with damaged tool cables may result in injury when the application involves personal safety.

5.4 Wiring Sensor Coils

This section will help you correctly wire the sensor coils to the tool connector. For further information refer to the *Aurora Tool Component Guide*:

Sensor Coil Warnings

Warning!

Before connecting any wiring to the sensor coils, read these warnings:

1. **Care should be taken to avoid damage to the sensor coil lead wires during handling and mounting of the sensor coils (in particular, the wires close to the sensor coil). The soldering point on the sensor coil (where the lead wires attach) is extremely delicate.**
2. **Sensor coils should be mounted securely within the tool body. Should a sensor coil move out of position, this will affect the accuracy of the tool.**
3. **Sensor coils should be electrically isolated from all metallic or conductive materials.**

4. **The tool body should be designed such that the sensor coils do not come into contact with moisture. Should a sensor coil come into contact with moisture, accuracy of the tool may be affected.**

Wiring Instructions

1. Before you connect a sensor coil to the tool connector (either directly or via a tool cable), take note that how you wire a sensor coil's leads will determine which direction its long axis points:

Table 5-2 Wiring Sensor Coils

Axis Direction	Sensor Coil Wiring
Positve z-axis pointing away from the sensor coil lead wires.	Connect the copper wire to sensor coil + (pin 1 or 3) Connect the green wire to sensor coil - (pin 2 or 4)
Positive z-axis pointing towards the sensor coil lead wires.	Connect the green wire to sensor coil + (pin 1 or 3) Connect the copper wire to sensor coil - (pin 2 or 4)

2. Connect sensor coil #1 to the tool connector using pins 1 and 2.
3. Connect sensor coil #2 to the tool connector using pins 3 and 4.

Note: If only one sensor coil is used, jumper pins 3 and 4. The sensor coil of a single sensor coil tool must be wired to pins 1 and 2.

To keep the tool's local coordinate system in the expected orientation, ensure consistent wiring of the sensor coils when assembling multiple tools of the same design.

5.5 Installing SROM Devices

The following instructions will help you install an SROM device in the tool connector:

Note: All wiring and SROM device connections should be performed by a qualified technician.

1. Before wiring the SROM device to the tool connector, trim all SROM pins to approximately 6 mm in length. This will allow the SROM device to fit inside the connector.

2. Refer to Figure 5-3 and cut the pin identified in the figure flush to the body of the SROM device.

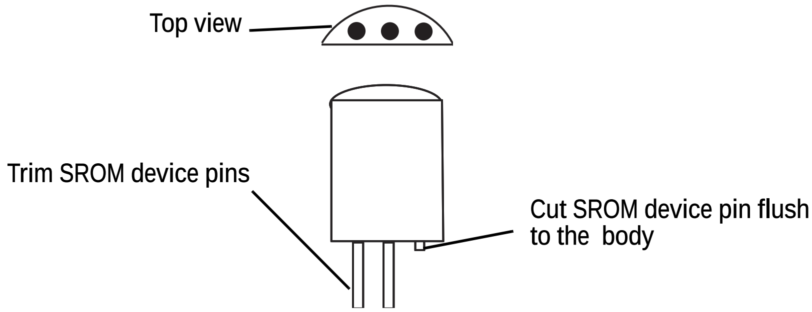

Figure 5-3 SROM Device

3. Connect the SROM device centre pin to the tool connector pin 5 (SROM device wire interface).
4. Connect the SROM device remaining pin to the tool connector pin 6 (Tool-in-port present).
5. Jumper the tool connector pin 6 to pin 8 (SIU circuit ground).

Note If pin 6 is not jumpered to pin 8, the Aurora System will not detect when the tool is connected to the system, making it unusable.

5.6 Adding LEDs and Switches

Although other devices can interface with the Aurora System (through the tool connector), LEDs and switches are the ones most commonly used. Consider the following guidelines when adding LEDs, switches or other inputs/outputs to the tool:

Rule #1 The Aurora System can support a combination of up to three LEDs and switches per tool port. The maximum current draw for each of these devices is 10 mA.

Rule #2 A limited autoclave study has been conducted on LEDs. It is the responsibility of the tool designer to determine if their biocompatibility standards are met. For further information on this study contact NDI.

Rule #3 LED and switch wiring should be accessible for connection to the tool cable wiring (inside the tool body).

Rule #4 If you are going to add a Tracking LED, be aware that this functionality is only supported when the Tracking LED anode is connected to the tool connector’s pin 7 (GPIO 1).

Wiring Instructions

1. Inside the tool body, connect the LEDs and/or switches to the tool cable wiring. Do not use the sensor coil wires to connect LEDs and/or switches. The sensor coil wires consist of two sets of red and green twisted wires.
2. Connect one side of each switch (or the anode side of each LED) to tool connector pin 7, 9 or 10.

3. Connect the other side of each switch (or the cathode side of each LED) to tool connector pin 8 (SIU circuit ground). Use an appropriately sized series resistor to limit the current through the LED.

5.7 Managing Metallic Components

The possibility of distortion to the electromagnetic field should be considered when the tool's design includes the use of metallic components.

Rule #1 Metallic component considerations include:

- the concentration of metal
- isolation from other components
- the proximity of metal relative to the sensor coils and/or the system's electromagnetic field

Rule #2 When metallic components must be incorporated into the tool design, stainless steel and titanium may offer better results.

Rule #3 Some tools may include sensor coils that are enclosed within a metallic tool component (e.g. needle, endoscope, etc.). For additional information regarding sensor coils enclosed within a metallic tool component, contact NDI.

5.8 What is the Tool Definition File?

Characterization is the process of creating a file that describes a tool. This file, known as the tool definition file, includes information such as the sensor coil placement and the placement of the tool's local coordinate system. Without this information the Aurora system cannot accurately interpret the data it has collected from the tool.

The tool definition file is stored in the tool's SROM device. When the tool is connected to the Aurora System, the tool definition file is automatically read as soon as the tool is initialized.

Note After characterization, be sure to validate the tool to confirm it is operating as expected and that it is returning correct transformations.

NDI 6D Architect is an NDI software tool designed to help you characterize tools, produce tool definition files and program SROM devices. This is included in the Aurora Tool Developer Kit.

Warning! NDI is not responsible for the programming of the SROM device. Incorrect SROM device programming may result in incorrect transformations. Applying transformations from a system with incorrect SROM device programming may result in injury when the application involves personal safety.

5.9 Verifying Tools

You must perform testing to ensure that the tool will meet the performance requirements in an environment typical of the tool's application.

Consider the following suggestions when performing tool verification:

- Establish a baseline for the tool's performance. This may include testing in an environment with minimal magnetic field disturbances.
- Introduce each object (that might disturb the magnetic field) and objects that would be typical of the environment used in the required application.
- Establish an indicator value threshold reflective of the required application. (Applicable only if the tool produces an indicator value.)
- Placement of the Field Generator may affect the tool's performance. Change the placement of the Field Generator within the environment in order to simulate the required application.
- Ensure that the tool cable is not wrapped around the Field Generator or is in close proximity to the Field Generator cable.
- Verify the tool in an environment that will simulate the required application environment.
- Refer to the Warnings section at the beginning of this guide to ensure that all possible hazards have been taken into account during the design and construction of the tool.

5.10 Sample Tool Wiring Schematic Diagram

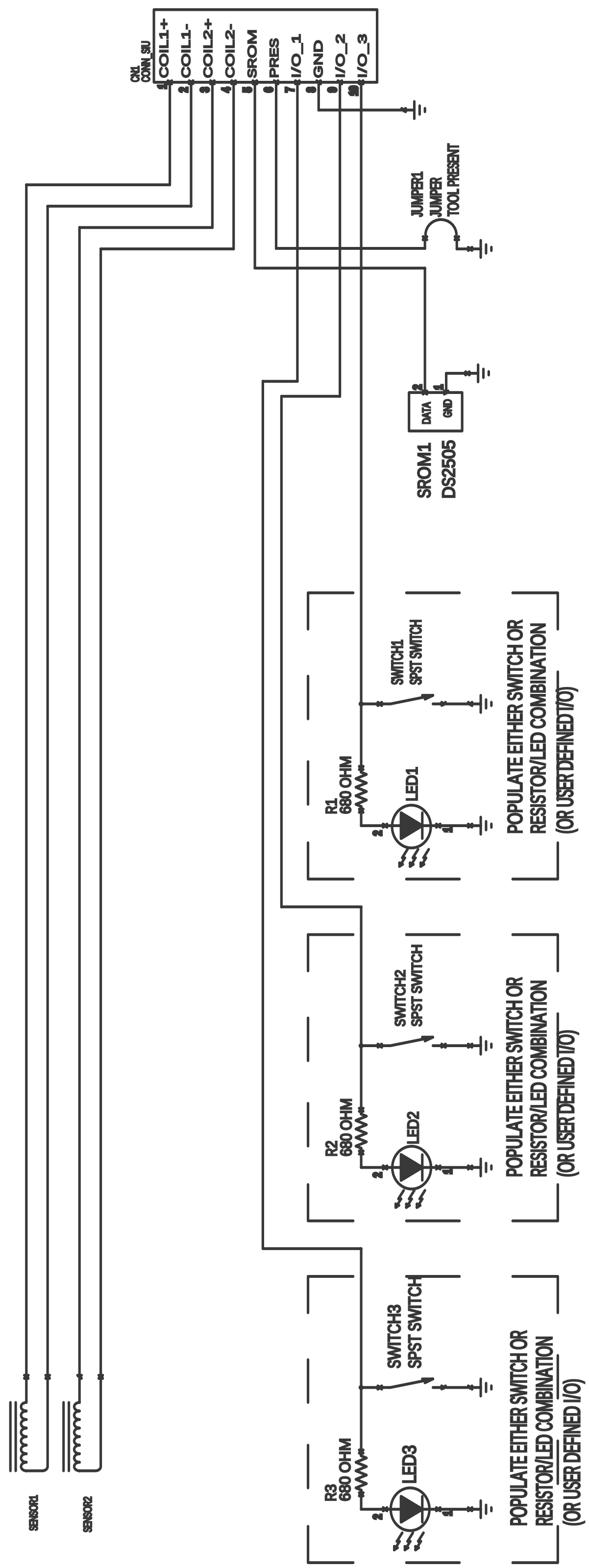

Figure 5-4 Wiring Schematic of a Sample Tool

6 Electrical Safety Considerations

It is beyond the scope of this guide to describe all electrical safety issues associated with tool design. Furthermore, the Aurora System is only one component in the overall system — safety considerations must also be applied to the workstation, computer peripherals, isolation transformer, the suite of tools, and all other components of the application. It is the responsibility of the OEM manufacturer to test and certify that the entire system complies with the necessary safety standards.

To ensure that the tool design complies with all relevant electrical safety standards, remember the following:

1. Work with an approval agency qualified in testing medical standards. You must consult with the necessary safety approval agencies to obtain advice specific to a particular design.
2. Consult and comply with the following standards:
   - ❒ **IEC60601-1** Medical electrical equipment - Part 1: General requirements for safety
   - ❒ **IEC60601-1-1** Medical electrical equipment - Part 1-1: General requirements for safety - Collateral standard: Safety requirements for medical electrical systems
   - ❒ **IEC60601-1-2** Medical electrical equipment - Part 1-2: General requirements for safety - Collateral standard: Electromagnetic compatibility - Requirements and tests
3. Consult and comply with additional applicable national standards and amendments.
4. The Aurora System is designed for Type BF applied parts only.
5. Take into consideration tool port isolation. See below for more information.

Note It is not straightforward to interpret the IEC60601 standard as it applies to tools incorporating sensor coils, especially when these tools are, in turn, connected to other electro-medical devices such as a surgical microscope or bipolar coagulating forceps. NDI recommends that the OEM manufacturer involve experts from the necessary safety approval agencies at the onset of the development project. This early involvement will potentially avoid an expensive re-design of the tool in order to comply with requirements of the medical standards.

6.1 About Tool Port Isolation

The System Control Unit (SCU) has four Sensor Interface Unit (SIU) ports suitable for connection to Type BF (body floating) tools. These four ports are not, however, isolated from one another. You must take into account this lack of inter-port isolation when considering limits on patient auxiliary leakage currents (i.e. leakage current between tools in contact with a patient).

Warning! Make sure that patient auxiliary leakage currents do not exceed allowable limits. Give special consideration to insulation materials and thicknesses to ensure the galvanic isolation of multiple tools connected to the Aurora System. Failure to do so may lead to personal injury. Consult IEC60601 and applicable national differences and amendments for guidance.

The lack of isolation between SIU ports also requires that when you are designing a tool intended to be attached to other pieces of equipment (e.g. surgical microscope), you must consider isolation of the tool from that equipment. For example, that the isolation between a patient (connected to another tool port via a Type BF tool) and earth-ground and/or mains is preserved. If any one tool port's isolation is violated then the isolations of all four tool ports is violated.

7 Troubleshooting

When I plug the tool in and attempt to track it, one or both sensor coils are not being tracked.

There are several possibilities for the tool not tracking properly:

- Even if a tool has been perfectly designed and constructed, the Aurora System still will not be able to understand its tracked data without an accompanying file that describes the tool’s features and sensor coil locations. You must create a tool definition file and program it to the tool’s SROM device before you can actually track it in the measurement volume.
- The sensor coils may not be wired correctly, or their leads may have been accidentally damaged during construction.

When I plug the tool in and attempt to track it, the tracking LEDs and switches do not work properly.

- Check the tool’s GPIO wiring to make sure they are soldered correctly and to the right connections.
- Check to make sure that the tool definition file includes GPIO information so that the Aurora System knows the LEDs and switches actually exist.

Although the tool is stationary, the Aurora System returns wavering transformations, implying that the tool is moving.

There are several possibilities for the stationary tool to be returning “moving” data:

- You may have accidentally damaged a sensor coil lead wire when installing it in the tool.
- You may have not soldered the sensor coil lead wires correctly and to the right connections.
- You may have accidentally soldered the sensor coil lead wires together during construction.

8 Abbreviations and Acronyms

Abbreviation or Acronym	Meaning
5DOF	Five Degrees of Freedom
6DOF	Six Degrees of Freedom
GPIO	General Purpose Input/Output
LED	Light Emitting Diode
SCU	System Control Unit
SIU	Sensor Interface Unit
SROM	Serial Read Only Memory

Appendix A Pivoting

Pivoting is the procedure used for tools with tips, to determine the distance between the tool origin and its tip (otherwise known as the tip offset vector). There are many applications in which the position of the tool tip needs to be reported. For example, a needle where the sensor coils cannot physically be located at the tip.

Pivot Block Design

A pivot block should be used to ensure that the pivoting procedure is accurate and repeatable. The following points should be considered when you design a pivot block:

1. It should be designed to have a substantial mass, to reduce the possibility of movement during use.
2. It should be manufactured in a material that is not conductive and has no ferromagnetic properties.
3. It should be possible to securely clamp the pivot block.
4. The divot should match the tip:
   - The tool tip should fit the divot such that the tip does not move during pivoting. For example, the divot should not be so wide that the tool tip moves within the divot, nor should it be so small that the tool tip tends to leave the divot.
   - Shallow divots (dents) work well for pivoting tools with sharp points.
5. An appropriately-sized convex arrangement (ball) should be provided to accommodate tools with concave tips.

How to perform a pivoting procedure

A pivot wizard is provided with both the NDI 6D Architect and the NDI Toolviewer software tools. Application specific instructions are detailed in the appropriate documentation.

You can use the pivot wizard to calculate the location of a tool’s end-tip. You can use this information to do the following:

- For 6DOF tool, use the vector to transform a local coordinate system so that its origin is located at the end-tip.
- Permanently program the vector as a user-specified tag in a tool’s SROM device.
- Use the vector to test a tool definition file.

Note NDI does not recommend permanently transforming a tool’s local coordinate system to its end-tip if the tool design is such that the location of the end-tip can be altered as a result of damage (such as a probe bending as a result of being dropped). It is better to perform a pivot procedure and re-align a local coordinate system as a part of your application procedure, every time you are about to track the tool. Contact NDI for more information about incorporating a pivot procedure into your application.

The physical pivoting procedure is the same in both applications and is as follows:

1. Make sure that the tool and pivot block are within the characterized measurement volume.
2. Position the tool tip in the appropriately sized divot. (The size and shape of the divot must match the tool tip to ensure that the tip does not move.)
3. As the measurement system collects the data, continuously pivot the tool back and forth and side to side, with its tool-tip remaining stationary at the fixed point. Ideally, the angles of your pivot movements should fall between 30 and 60 degrees:

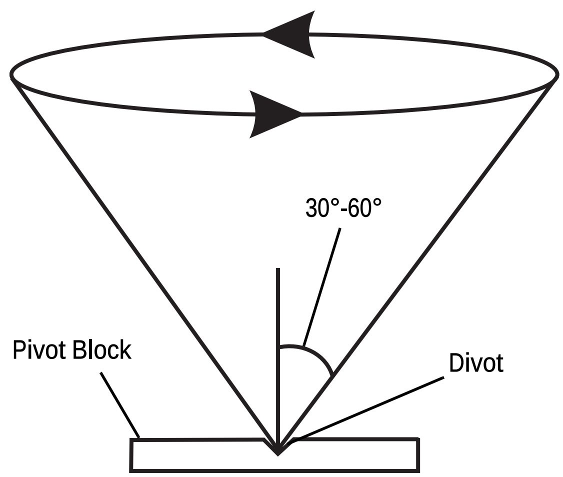

Figure A-1 Pivoting Technique

Note It is very important that the tool-tip remains stationary while the tool is being pivoted. The design of the pivot block should take into account the shape of the tool's end-tip.

Appendix B Component Manufacturer Information

When constructing a tool for the Aurora System, NDI suggests the following components:

Table B-1 Component Manufacturer Information

Component	Manufacturer Information
Sensor Coils	There are a variety of sensor coils available. Contact NDI for specific information to determine the best sensor coil for the required application.
Connector	Not supplied by NDI. Redel P/N PAA.M1.0GL.AC39G (standard) or P/N PAA.M1.0TL.AC39N (for autoclave considerations). For specific information contact www.lemo.com.
Cable	NDI P/N 2600591. For specific information, contact NDI.
SROM Device	Not supplied by NDI. Dallas Semiconductor P/N DS2505. For specific information contact www.dalsemi.com.
LEDs	NDI P/N 3000018. For specific information, contact NDI. Other output devices (not supplied by NDI) can be interfaced (max. 10 mA).
Switches	Not supplied by NDI and is the responsibility of the tool designer.
Tool Body	Not supplied by NDI and is the responsibility of the tool designer.

Glossary

5DOF

Five of the six degrees of freedom. Three translation values on the x, y and z axes and any two of the three rotation values – roll, pitch and yaw.

6DOF

Six degrees of freedom. The three translation values on the x, y, and z-axes; and the three rotation values roll, pitch and yaw.

axis of interest

An axis of interest represents an imaginary vector that is projected through a tool and represents an area where measurement values are required. For example, if the tool is a probe, an axis of interest might be an imaginary line travelling along the body of the probe and out its tip.

characterization (tool)

Characterizing a tool is the process of creating its tool definition file (.rom) which determines the actual positions of its sensor coils.

characterized measurement volume

The characterized measurement volume is the volume within the detection region where accuracy is within specified limits. NDI cannot guarantee measurement accuracy outside this region.

dual sensor coil tool

A dual sensor coil tool contains two sensor coils. If the sensor coils are affixed relative to each other inside this tool, the system is able to measure the transformations of the tool in 6DOF.

Field Generator

The Field Generator is the component of the Aurora System that generates the electromagnetic field.

global coordinate system

The global coordinate system is an NDI measurement system's coordinate system. The global coordinate system is used by the measurement system as a frame of reference against which tool transformations are reported. By default, the global coordinate system’s origin is set at the Field Generator.

indicator value

The indicator value is a unitless estimate of how well the system calculated a particular transformation.

local coordinate system

A local coordinate system is a coordinate system assigned to a specific tool.

measurement volume

See *characterized measurement volume*.

offset vectors

An offset vector describes the location of the point of interest with respect to the tool origin.

pivoting

Pivoting is a procedure (of rotating a tool about its tip) used to determine the tool tip offset.

point of interest

The point of interest is a point on or near the tool that represents a specific point where measurement values are required. For example, if the tool is a probe, the tip of the probe is most likely its point of interest.

quaternion rotation

Quaternion rotation is a mathematical method of describing rotations in three-dimensional space, using four-dimensional objects that are represented as ordered quadruples [q0, qx, qy, qz].

q0, qx, qy, qz

The terms q0, qx, qy, qz represent the four elements of a single quaternion rotation.

reference tool

A reference tool is a tool whose local coordinate system is used as a frame of reference in which other tools are reported/measured.

Rx, Ry, Rz

The terms Rx, Ry, and Rz refer to angles of rotation around the x, y and z-axes respectively.

sensor coil

A sensor coil is a coil of wire with two lead wires whose position can be determined in 5DOF by the Aurora System.

Sensor Interface Unit (SIU)

The SIU is the component of the Aurora System that connects tools to the System Control Unit (SCU).

sensorless tools

Tools that have no sensor coils, and cannot have their position determined. For example, a foot switch.

single sensor coil tool

A single sensor coil tool contains one sensor coil. This tool provides 5DOF position and orientation information.

SROM device

An SROM device is a memory device located inside a wired tool. A tool definition file can be programmed into the SROM device so that the tool can carry its own information for automatic retrieval by an NDI measurement system.

System Control Unit (SCU)

The System Control Unit (SCU) controls the Aurora System. The SCU powers and directs the Field Generator’s output, collects measurement data from tools, and calculates transformations.

tool definition file

A tool definition file stores information about a tool. This includes information such as the placement of the tool's sensor coils, the location of its origin, and its manufacturing data. The tool definition file is formatted as .rom.

tool origin

The tool origin is the origin of the tool’s local coordinate system.

tool tip offset

The tool tip offset is the distance between the tip of the tool and the tool origin.

transformation

A transformation is a combination of translation and rotation values that describe the location of the tool in position and orientation.

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