GestIC® Design Guide

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Preface

NOTICE TO CUSTOMERS

All documentation becomes dated, and this manual is no exception. Microchip tools and documentation are constantly evolving to meet customer needs, so some actual dialogs and/or tool descriptions may differ from those in this document. Please refer to our web site (www.microchip.com) to obtain the latest documentation available.

Documents are identified with a "DS" number. This number is located on the bottom of each page, in front of the page number. The numbering convention for the DS number is "DSXXXXXA", where "XXXXX" is the document number and "A" is the revision level of the document.

For the most up-to-date information on development tools, see the MPLAB® IDE online help. Select the Help menu, and then Topics to open a list of available online help files.

INTRODUCTION

This chapter contains general information that will be useful to know before using the GestIC® Design Guide. Items discussed in this chapter include:

- Document Layout
- Conventions Used in this Guide
- Warranty Registration
- Recommended Reading
- The Microchip Web Site
- Development Systems Customer Change Notification Service
- Customer Support
- Document Revision History

DOCUMENT LAYOUT

This document describes the GestIC Design Guide, the MGC3030/3130 controller characteristic parameters and the design process. It enables the user to generate a good electrode design and to parameterize the full GestIC system. The document is organized as follows:

- **Chapter 1. "Introduction"**
- **Chapter 2. "Design Process Overview"**
- **Chapter 3. "Use Case Definition"**
- **Chapter 4. "Electrode Design"**
- **Chapter 5. "System Integration"**
- **Chapter 6. "GestIC Parameterization Flow"**
- **Chapter 7. "Performance Evaluation"**
- **Appendix**

CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

DOCUMENT CONVENTIONS

<table>
<tr><th>Description</th><th>Represents</th><th>Examples</th></tr>
<tr><td colspan="3">Arial font:</td></tr>
<tr><td rowspan="2">Italic characters</td><td>Referenced books</td><td>MPLAB IDE User’s Guide</td></tr>
<tr><td>Emphasized text</td><td>...is the only compiler...</td></tr>
<tr><td rowspan="3">Initial caps</td><td>A window</td><td>the Output window</td></tr>
<tr><td>A dialog</td><td>the Settings dialog</td></tr>
<tr><td>A menu selection</td><td>select Enable Programmer</td></tr>
<tr><td>Quotes</td><td>A field name in a window or dialog</td><td>“Save project before build”</td></tr>
<tr><td>Underlined, italic text with right angle bracket</td><td>A menu path</td><td><u>File>Save</u></td></tr>
<tr><td rowspan="2">Bold characters</td><td>A dialog button</td><td>Click OK</td></tr>
<tr><td>A tab</td><td>Click the Power tab</td></tr>
<tr><td>N‘Rnnnn</td><td>A number in verilog format, where N is the total number of digits, R is the radix and n is a digit.</td><td>4‘b0010, 2‘hF1</td></tr>
<tr><td>Text in angle brackets < ></td><td>A key on the keyboard</td><td>Press <Enter>, <F1></td></tr>
<tr><td colspan="3">Courier New font:</td></tr>
<tr><td rowspan="7">Plain Courier New</td><td>Sample source code</td><td><code>#define START</code></td></tr>
<tr><td>Filenames</td><td><code>autoexec.bat</code></td></tr>
<tr><td>File paths</td><td><code>c:\mcc18\h</code></td></tr>
<tr><td>Keywords</td><td><code>_asm, _endasm, static</code></td></tr>
<tr><td>Command-line options</td><td><code>-Opa+, -Opa-</code></td></tr>
<tr><td>Bit values</td><td><code>0, 1</code></td></tr>
<tr><td>Constants</td><td><code>0xFF, ‘A’</code></td></tr>
<tr><td>Italic Courier New</td><td>A variable argument</td><td><code>file.o</code>, where <code>file</code> can be any valid filename</td></tr>
<tr><td>Square brackets [ ]</td><td>Optional arguments</td><td><code>mcc18 [options] file [options]</code></td></tr>
<tr><td>Curly brackets and pipe character: { | }</td><td>Choice of mutually exclusive arguments; an OR selection</td><td><code>errorlevel {0|1}</code></td></tr>
<tr><td rowspan="2">Ellipses...</td><td>Replaces repeated text</td><td><code>var_name [, var_name...]</code></td></tr>
<tr><td>Represents code supplied by user</td><td><code>void main (void)
{ ...
}</code></td></tr>
</table>

WARRANTY REGISTRATION

Please complete the enclosed Warranty Registration Card and mail it promptly. Sending in the Warranty Registration Card entitles users to receive new product updates. Interim software releases are available at the Microchip web site.

RECOMMENDED READING

This user's guide describes how to use the GestIC Design Guide. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources.

- "*MGC3030/3130 3D Gesture Controller Data Sheet*" (DS40001667) – Consult this document for information regarding the MGC3030/3130 3D Tracking and Gesture Controller.
- "*Aurea Graphical User Interface User's Guide*" (DS40001681) – Describes how to use the MGC3030/3130 Aurea Graphical User Interface.
- "*MGC3030/3130 GestIC® Library Interface Description User Guide*" (DS40001718) – This document is the interface description of the MGC3030/3130's GestIC Library. It outlines the function of the Library's message interface, and contains the complete message reference to control and operate the MGC3030/3130 system.

> **Note:** The *"GestIC® Design Guide"* applies to the MGC3030 and MGC3130 parts. Throughout this document the term MGC3X30 will be representative for these two parts.

THE MICROCHIP WEB SITE

Microchip provides online support via our web site at www.microchip.com. This web site is used as a means to make files and information easily available to customers. Information about GestIC technology and MGC3030/3130 can be directly accessed via http://www.microchip.com/gestic.

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The Development Systems product group categories are:

- **Compilers** – The latest information on Microchip C compilers, assemblers, linkers and other language tools. These include all MPLAB® C compilers; all MPLAB assemblers (including MPASM™ assembler); all MPLAB linkers (including MPLINK™ object linker); and all MPLAB librarians (including MPLIB object librarian).
- **Emulators** – The latest information on Microchip in-circuit emulators.This includes the MPLAB REAL ICE and MPLAB ICE 2000 in-circuit emulators.
- **In-Circuit Debuggers** – The latest information on the Microchip in-circuit debuggers. This includes MPLAB ICD 3 in-circuit debuggers and PICkit™ 3 debug express.
- **MPLAB IDE** – The latest information on Microchip MPLAB IDE, the Windows Integrated Development Environment for development systems tools. This list is focused on the MPLAB IDE, MPLAB IDE Project Manager, MPLAB Editor and MPLAB SIM simulator, as well as general editing and debugging features.
- **Programmers** – The latest information on Microchip programmers. These include production programmers such as MPLAB REAL ICE in-circuit emulator, MPLAB ICD 3 in-circuit debugger and MPLAB PM3 device programmers. Also included are nonproduction development programmers such as PICSTART® Plus and PICkit 2 and 3.

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- Distributor or Representative
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- Field Application Engineer (FAE)
- Technical Support

Customers should contact their distributor, representative or field application engineer (FAE) for support. Local sales offices are also available to help customers.

Technical support is available through the web site at:

http://www.microchip.com/support.

DOCUMENT REVISION HISTORY

Revision A (August, 2013)

Initial release of the document.

Revision B (January, 2015)

Changed document title; Added note and updated titles in the Recommended Reading section; Other minor corrections.

NOTES:

Chapter 1. Introduction

1.1 GestIC® SYSTEM OVERVIEW

The MGC3030 and MGC3130 devices are products based on Microchip's GestIC technology. They are developed as a mixed-signal controller. The MGC3X30 devices have one transmit and five very sensitive receive channels that are capable of detecting distortions of the transmitted electrical field corresponding to capacitive changes in the Femtofarad (1 fF = 10^{-15}F) range. In order to transmit and receive an electrical field, electrodes have to be connected to the transmitting and receiving channels of the MGC3X30 controller. The arrangement of the electrodes allow the chip to determine the center of gravity of the electric field (E-field) distortion and, thus, tracking (e.g., a user's hand in the detection space).

The entire system solution is composed of three main building blocks (see Figure 1-1):

- MGC3X30 Controller
- Embedded GestIC Library
- External electrodes

1.1.1 MGC3030/3130 Controller

The MGC3030/3130 controller features the following main hardware building blocks:

- Low noise analog front end (AFE)
- Digital signal processing unit (SPU)
- Communication interfaces

It provides a transmit signal to generate the E-field, conditions the analog signals from the receiving electrodes and processes this data digitally on the SPU. Data exchange between the MGC3X30 and the host is conducted via the communication interfaces.

Please refer to the "*MGC3030/3130 3D Gesture Controller Data Sheet*" (DS40001667) for more details.

1.1.2 GestIC Library

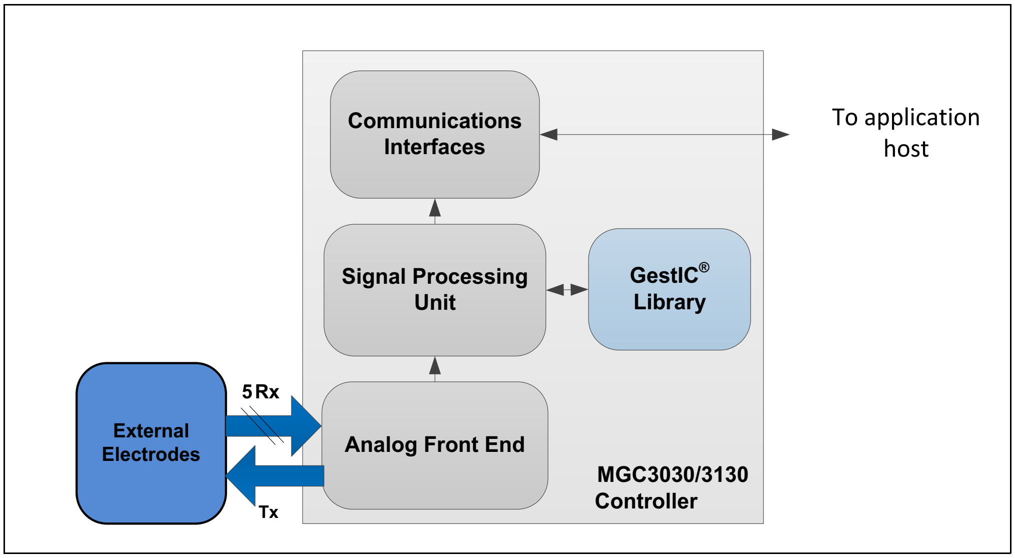
The embedded GestIC library is optimized to ensure continuous and real time free-space position tracking and gesture recognition concurrently. It is configurable and allows required parameterization for individual application and external electrodes.

Please refer to the "*MGC3030/3130 GestIC® Library Interface Description User's Guide*" (DS40001718) for more details.

1.1.3 External Electrodes

One to five external receive electrodes and one transmit electrode are connected to the MGC3X30. The electrodes need to be individually designed for optimal E-field distribution and detection of E-field variations inflicted by the user. **Chapter 4. "Electrodes Design"** focuses on how to design these electrodes.

FIGURE 1-1: MGC3X30 CONTROLLER SYSTEM ARCHITECTURE



1.2 THEORY OF OPERATION

Microchip's GestIC is a 3D sensor technology, which utilizes an electric field (E-field) for advanced proximity sensing. It allows realization of new user interface applications by detection, tracking and classification of the user's hand or finger motion in free space.

E-fields are generated by electrical charges and propagate three-dimensionally around the surface, carrying the electrical charge. Applying direct voltages (DC) to an electrode results in a constant electric field.

Applying alternating voltages (AC) makes the charges vary over time and, thus, the field. When the charge varies sinusoidal with frequency f, the resulting electromagnetic wave is characterized by wavelength $\lambda = c/f$, where c is the wave propagation velocity – in vacuum, the speed of light. In cases where the wavelength is much larger than the electrode geometry, the magnetic component is practically zero and no wave propagation takes place. The result is quasi-static electrical near-field that can be used for sensing conductive objects such as the human body.

Microchip's GestIC technology uses transmit (Tx) frequencies in the range of 100 kHz, which reflects a wavelength of about three kilometers. With electrode geometries of typically less than 14x14 centimeters, this wavelength is much larger in comparison. In case a person's hand or finger intrudes the electrical field, the field becomes distorted. The field lines are drawn to the hand due to the conductivity of the human body itself and shunted to ground. The three dimensional electric field decreases locally. Microchip's GestIC technology uses a minimum number of four receiver (Rx) electrodes to detect the E-field variations at different positions to measure the origin of the electric field distortion from the varying signals received. The information is used to calculate the position, track movements and to classify movement patterns (gestures). The simulation results in Figure 1-2 and Figure 1-3 show the influence of an earth-grounded body to the electric field. The proximity of the body causes a compression of the equipotential lines, and shifts the Rx electrode signal levels to a lower potential which can be measured.

> **Note:** The highest field strength is in the plate capacitor between Rx and Tx electrodes but a significant part of the field is also contained in the stray field. The hand is mainly effecting the E-field stray distribution, which leads to a deformation of the equipotential lines, as shown in Figure 1-2 and Figure 1-3.

FIGURE 1-2: EQUIPOTENTIAL LINES OF AN UNDISTORTED E-FIELD

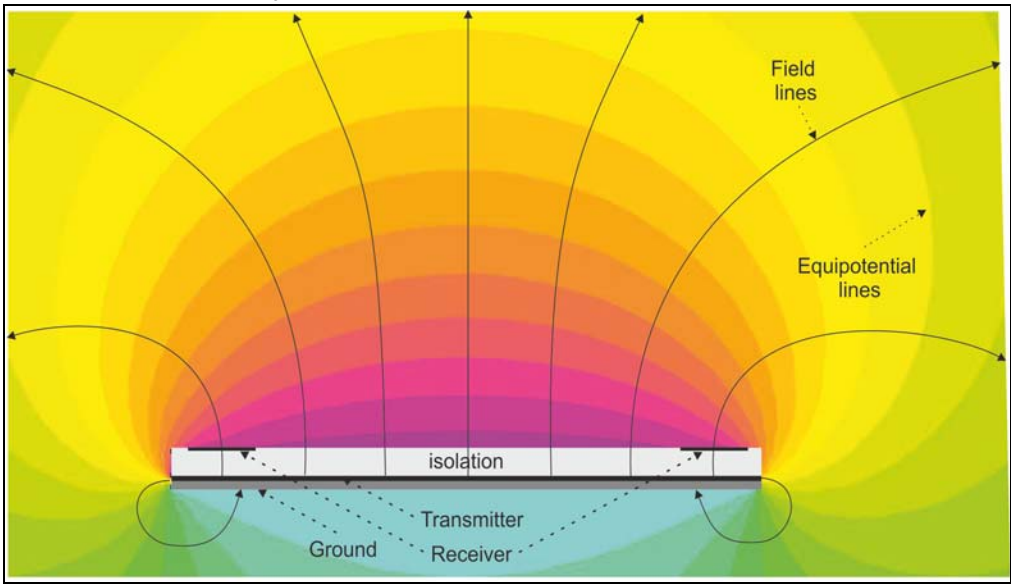
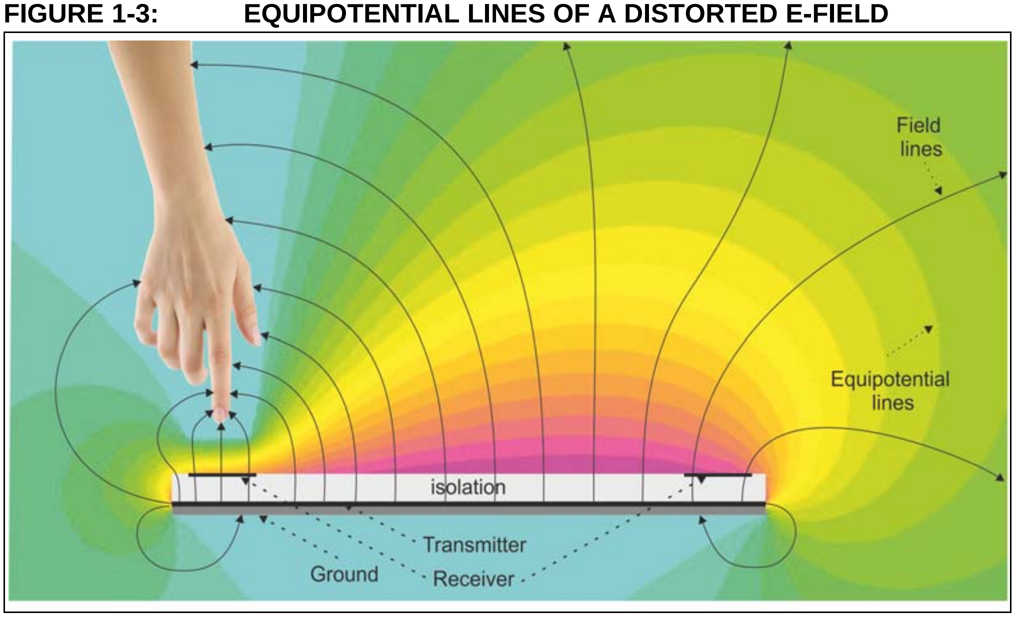


FIGURE 1-3: EQUIPOTENTIAL LINES OF A DISTORTED E-FIELD



NOTES:

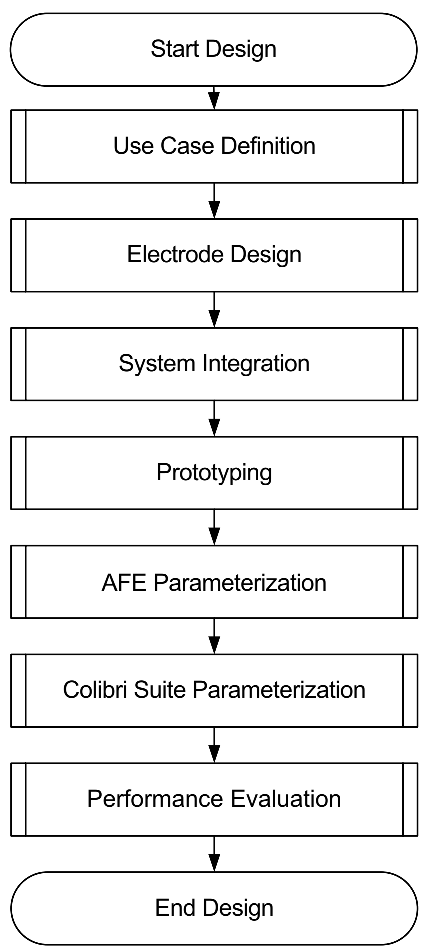
Chapter 2. Design Process Overview

The design of the GestIC system requires a deep evaluation of the use case, the required features and, in particular, the conditions on how to integrate the electrodes. The complete design can be described as a process flow and each step is detailed in the following chapters.

The design process is composed of the following steps:

- Define the use case
- Electrodes design: electrodes location, shape and sizes, ground location, stack up
- System Integration: chip placement, feeding lines, interfaces, power supply
- Prototyping: PCB Manufacturing
- Analog Front-End Parameterization: adjustment of transmit and receive signals
- Colibri Suite Parameterization: tuning of digital signal processing parameters
- Measure and verify performance

FIGURE 2-1: GestIC® DESIGN PROCESS



NOTES:

Chapter 3. Use Case Definition

The first step of the electrode design process consists of the use case definition. This step is very important, as it will have an impact on the electrodes structures and sizes. The following aspects should be checked and analyzed before starting the layout.

- **Hand or finger use**: The application defines if the target system will be optimized for hand or finger use. Hand applications (e.g., PC peripherals (3D pads)) are optimized for free-space hand movements. They are typically realized with electrodes bigger than 5". Typical finger applications (e.g., switches or trackpads) are designed with electrodes smaller than 5".
- **Hand posture**: The information on how the hand will be used in the final system is an important parameter to define the electrode design and the Colibri parameterization. To get the desired sensing space, the user has to define the hand's or finger's posture. The hand can be used in three different manners: parallel to the sensitive area (flat), perpendicular or with defined angle (see Figure 3-1, Figure 3-2 and Figure 3-3). A finger can be used as well, accordingly.

FIGURE 3-1: HAND POSTURE (1 OF 3)

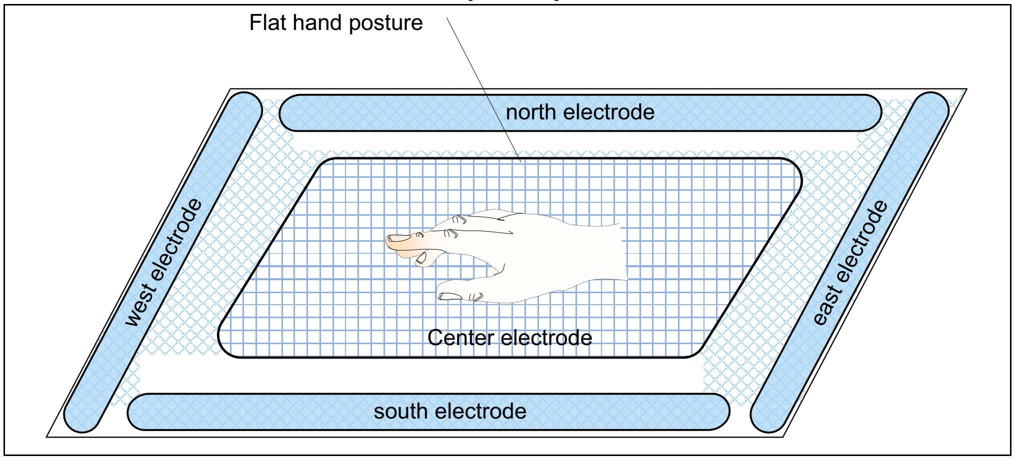


FIGURE 3-2: HAND POSTURE (2 OF 3)

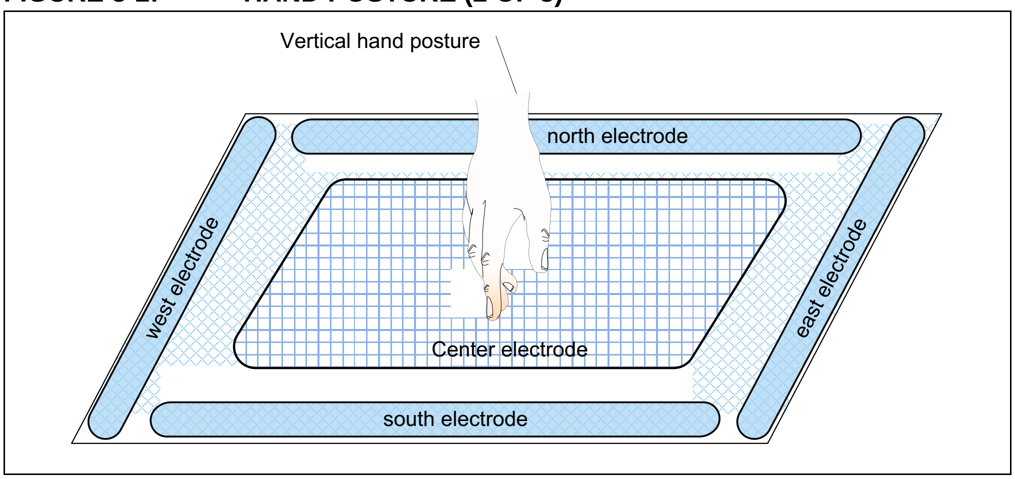
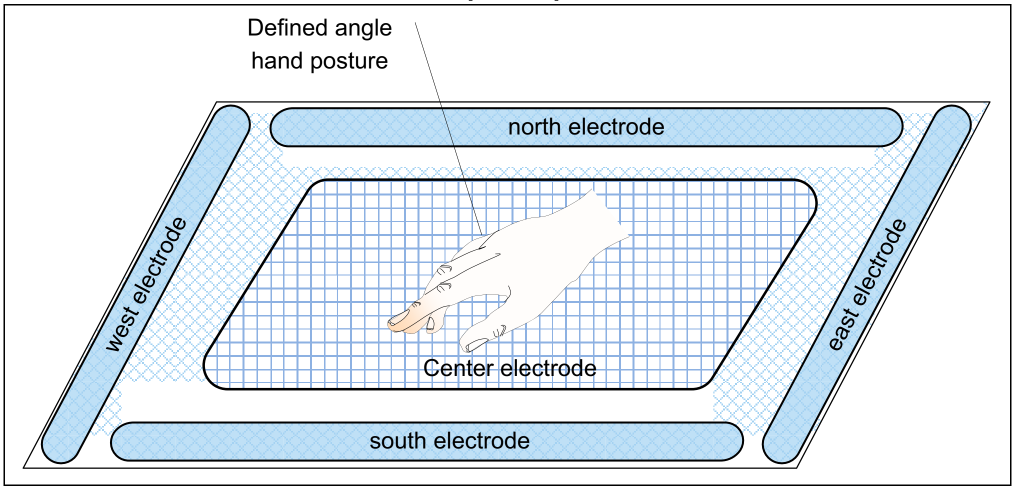


FIGURE 3-3: HAND POSTURE (3 OF 3)



- **Sensitive area**: To define the sensitive area, always use the area enclosed by the four frame electrodes. The geometric shape of the sensitive area is a primary factor, as it depends on the geometry of the final product (available area for electrodes PCB). The user has to define the frame-shape structure according to the supported diagonal range from 1.5" to 7". The recommended ratios is the range from 1:1 up to 1:2. The desired Z distance should be specified as well. Please refer to **Chapter 4. "Electrodes Design"** for more details.

  Please note that the sensitive area given by the dimensions of the electrode in most cases cannot completely be used for position tracking. The area will be reduced to achieve a linear tracking performance. Please refer to **Chapter 6. "GestIC Parameterization Flow"** for more details.

  The existence of conductive objects in the sensitive area will impact the E-field distribution and, as the system is calibrating regularly, the user has to check how long a hand, for example, will be present in the electrodes area. The user has to define as well whether the hand will touch the electrodes or not. Please refer to **Chapter 4. "Electrodes Design"** for more details.
- **Colibri Suite feature selection**: The application has to define which Colibri Suite feature will be used, and check if the target system is a tracking or a gesture system, which gestures will be used and the number of electrodes needed. Please refer to **Chapter 6. "GestIC Parameterization Flow"** for more details.
- **System Design**: This item should define the integration of the electrodes in the final system. Important points must be checked, such as the housing material, distance to ground, chip placement, expected current consumption, mainly for battery driven applications. Please refer to **Chapter 5. "System Integration"** for more details.

Chapter 4. Electrodes Design

4.1 ELECTRODES SETUP OVERVIEW

The MGC3X30 electrode system is a double-layer design with a Tx transmit electrode at the bottom layer to shield against device ground and, thus, allow good E-field stray propagation and ensure high-receive sensitivity. Up to five comparably smaller Rx electrodes are placed above the Tx layer, providing the spatial resolution of the GestIC system. Tx and Rx are separated by an isolating layer. The Rx electrodes are arranged in a frame configuration, as shown in Figure 4-1 and Figure 4-2. The frame defines the inside sensing area with maximum dimensions of 14x14 centimeters. An optional fifth electrode in the center of the frame may be used to improve the distance measurement in close proximity and add simple touch functionality.

Depending on the application, the electrodes can be designed solid or structured (cross-hatched). In addition to the thickness and the material permittivity ε_r between the Rx and Tx electrodes, the structure density also controls the capacitance C_{RxTx} and, thus, the sensitivity of the system.

Figure 4-1 and Figure 4-2 show an example of general purpose electrodes design. This standard design is suitable for hand position or finger tracking and gestures recognition and can be used for many applications.

Figure 4-3 shows more examples of possible electrode designs for different use cases such as joysticks or keyboards.

FIGURE 4-1: FRAME-SHAPE ELECTRODES

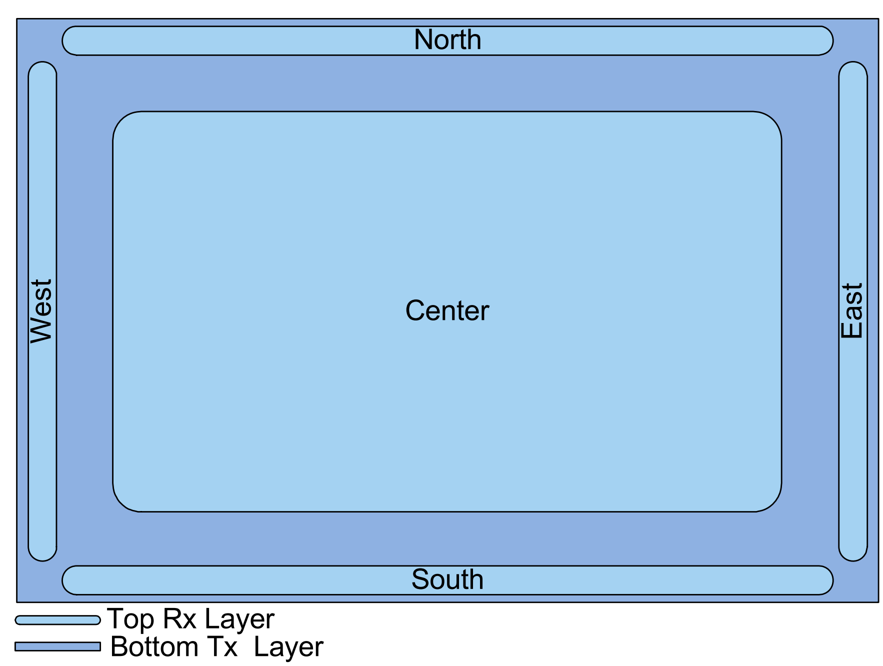


FIGURE 4-2: FRAME-SHAPE ELECTRODES: CROSS-SECTION VIEW

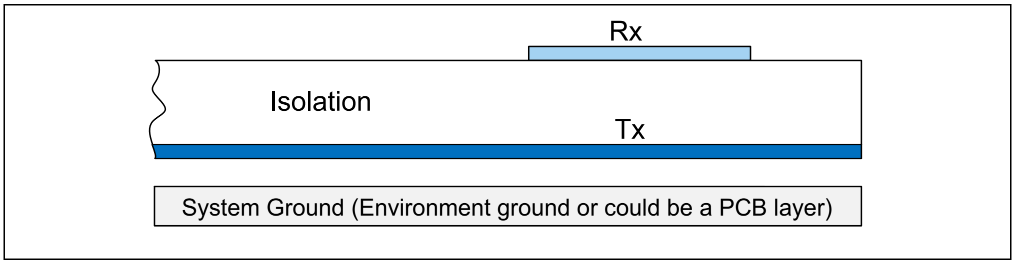
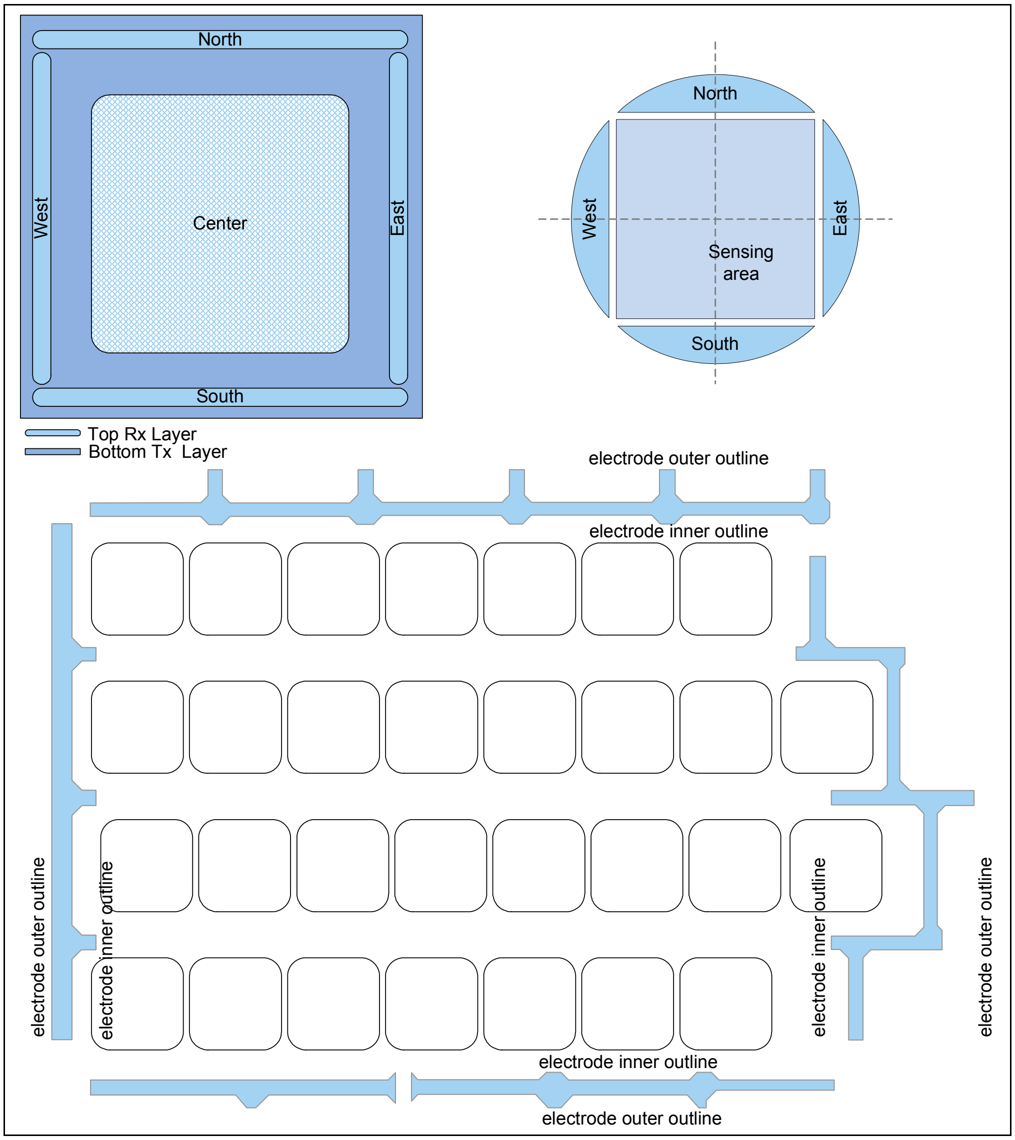


FIGURE 4-3: FRAME-SHAPE ELECTRODES EXAMPLES



4.2 GestIC EQUIVALENT CIRCUIT

A simplified model of the electrodes setup is provided for easier design guidelines. This capacitive model is combining plate (C_p) and E-field stray (C_{stray}) capacitances.

In addition, this model helps the user to easily understand the functional principle of the GestIC system.

4.2.1 Standard Electrode Equivalent Circuit

The simplified equivalent circuit model of a generic GestIC electrode system is illustrated in Figure 4-4 and Figure 4-5. This model provides the capability to estimate the system characteristics and gives main dependencies between electrodes, chip and the hand. The system sensitivity can be also deducted.

FIGURE 4-4: GestIC® ELECTRODES SYSTEM WITH CHARACTERISTIC CAPACITANCES

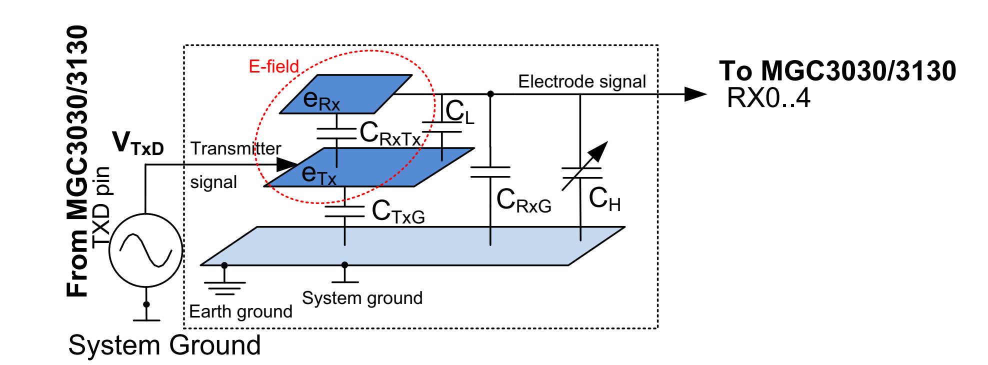
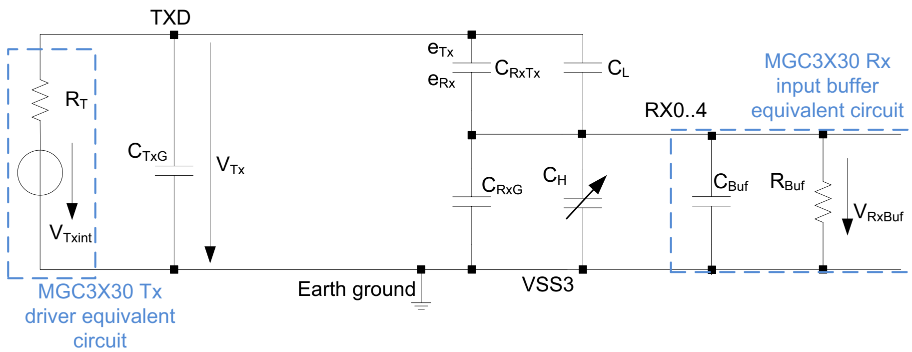


FIGURE 4-5: STANDARD ELECTRODE EQUIVALENT CIRCUIT



Where:

$\mathbf{V_{Txint}}$	Internal MGC3X30 Tx output signal
$\mathbf{V_{Tx}}$	Tx output signal on MGC3X30 TxD pin
$\mathbf{V_{RxBuf}}$	Rx input signal on MGC3X30 Rx0..4 pins
$\mathbf{e_{Tx}}$	Transmit Tx electrode of the system
$\mathbf{e_{Rx}}$	Receive Rx electrode of the system
$\mathbf{C_{TxG}}$	Capacitance from TxD pin to ground
$\mathbf{C_{RxTx}}$	Capacitance between Rx and Tx electrode
$\mathbf{C_L}$	Rx feeding line capacitance to TxD pin
$\mathbf{C_{RxG}}$	Capacitance from Rx electrode to ground
$\mathbf{C_H}$	Capacitance between hand and Rx
$\mathbf{C_{Buf}}$	Input capacitance of MGC3X30 Rx input buffer
$\mathbf{R_T}$	MGC3X30 Tx driver source resistance
$\mathbf{R_{Buf}}$	Input resistor of MGC3X30 Rx input buffer. For easier system understanding, this resistor is connected in the equivalent circuit to ground instead of VDDA/2.
Vss3	Ground pin of MGC3X30

The MGC3X30 has a low-impedance output of $R_T = 800\Omega$ and is designed to drive load capacitances C_{TxG} up to 1 nF. For further considerations in this chapter, it is assumed that $V_{Txint} = V_{TxD}$.

4.2.2 Typical System Capacitances

The Rx and Tx electrodes in a GestIC electrode system build a capacitance voltage divider with the capacitances ($C_{RxTx} + C_L$) and ($C_{RxG} + C_{Buf}$), which are determined by the electrode design. The hand capacitance, C_{Hand}, is by order of magnitudes smaller than all other system capacitances.

The voltage divider ratio should be around 1 to achieve the best sensitivity and allow high-noise superposition without clipping (see Equation 4-1).

EQUATION 4-1: OPTIMUM ELECTRODE CAPACITIVE VOLTAGE DIVIDER RATIO CONDITION

$$C_{RxTx} + C_L \approx C_{RxG} + C_{Buf}$$

The Rx electrode measures the potential of the generated E-field. If a conductive object (e.g. a hand) approaches the Rx electrode, C_H changes its capacitance. This minuscule change in the femtofarad range is detected by the MGC3X30 receiver.

Typical values of the electrodes capacitances are summarized in Table 4-1.

TABLE 4-1: ELECTRODES CAPACITANCES TYPICAL VALUES

Capacity	Typical Value
C_{RxTx}	10...30 pF
C_{TxG}	10...1000 pF
C_{RxG}	10...30 pF
C_H	1 fF...1 pF
C_L	<< C_{RxTx}

Note: For rough estimations of the C_{TxG}, C_{RxTx} and C_{RxG} capacitances, it is useful to calculate the plate capacitances. Please take into account that especially C_{RxTx} can be significantly higher than the calculated value via the plate capacitors formula ($C = (\varepsilon_0\ \varepsilon_r\ A)/d$), because the stray E-field is neglected. In typical designs, the real capacitance is roughly twice the plate capacitance.

4.2.3 System Parameters

4.2.3.1 RECEIVER INPUT SIGNAL

The receiver input is the signal received by the MGC3X30 chip at its Rx input channels. This signal is a function of the hand capacitance, Tx transmit signal and electrodes capacitances.

EQUATION 4-2: RECEIVER INPUT SIGNAL

$$V_{RxBuf} = \frac{V_{Tx}}{1 + \frac{C_{RxG} + C_{Buf} + C_H}{C_{RxTx} + C_L}}$$

The recommended condition of the voltage divider ratio should be around 1 to achieve the best sensitivity and allow high-noise superposition without clipping (Equation 4-3):

EQUATION 4-3: OPTIMUM RECEIVER INPUT SIGNAL

$$V_{RxBuf} = \frac{V_{Tx}}{2}$$

V_{RxBuf} cannot be measured directly since the applied load, even from an active voltage probe, would be too high. V_{RxBuf} can be calculated according to the formula in Equation 4-4 below.

EQUATION 4-4: V_{RXBUF} vs. SIGNAL MATCHING VALUE

$$V_{RxBuf} = \frac{RXDIFF[7:0]}{255} \times V_{Tx}$$

Where: RxDIFF[7:0] is the signal matching value.

Chapter 6. "GestIC Parameterization Flow" provides a method to determine the V_{RxBuf} voltage directly with MGC3X30. Please refer to **Section 6.2 "Analog Front End (AFE) Parameterization"** for more details.

4.2.3.2 RECEIVER SIGNAL SENSITIVITY

The receiver signal sensitivity regarding the hand influence is defined as the signal delta with and without the hand capacitance at noise-free conditions (see Equation 4-5).

EQUATION 4-5: RECEIVER SIGNAL SENSITIVITY

$$\Delta S = V_{RxBuf}\big|_{C_H = 0} - V_{RxBuf}\big|_{C_H = C_{Hand}}$$

Assuming that C_{Hand} is small compared to the Tx-Rx electrode capacitance.

$$\Delta S \approx V_{Tx} \bullet \left[\frac{C_{Hand}}{C_{RxTx} + C_L + 2(C_{RxG} + C_{Buf}) + (C_{RxG} + C_{Buf})^2 / (C_{RxTx} + C_L)}\right]$$

where ΔS is approximately a linear function of the hand capacitance, C_{Hand}.

The signal sensitivity is an important parameter of the signal deviation (SD) that is calculated from the MGC3X30 digital signal processing unit, and can be displayed with the Aurea Control Software.

4.2.3.3 SIGNAL DEVIATION

In the MGC3X30 GestIC-based system, the signal deviation, S_D, is defined as the receiver signal sensitivity amplified by the MGC3X30 receiver gain (g_{PGA} = 10), and referenced to the analog voltage range of the chip of VDDA = 3.0V (see Equation 4-6).

EQUATION 4-6: SIGNAL DEVIATION

$$S_D = 10 \bullet \frac{2^{15}}{3V} \Delta S$$

S_D is given in digits of a 16-bit integer value.

4.2.4 Equivalent Circuit Rules Summary

From the formulas in the last section, some rules for good electrode design can be derived. The main target is to maximize the receiver signal sensitivity and signal deviation.

Equation 4-5 shown in the previous section confirms that the signal deviation is better when the following conditions are met:

- Low Rx ground capacitance, C_{RxG}: most relevant parameter in the formula. Decreasing this value will highly improve the electrodes sensitivity when keeping the hand capacitance constant (C_{Hand})
- Low Rx-Tx capacitance (C_{RxTx})
- High hand capacitance (C_H)
- Low feeding line capacitance (C_L)
- The condition of $C_{RxTx} + C_L \approx C_{RxG} + C_{Buf}$

The following sections will detail how to use these rules to build high-sensitive electrodes and to explain how to apply them in an application electrodes design.

4.3 Rx ELECTRODES DESIGN

4.3.1 Rx Electrodes Shape and Size

The most important constraint when designing GestIC Rx electrodes is to achieve high sensitivity and detection range. The GestIC Rx electrodes shape and size should satisfy many requirements such as area, distance to Tx electrode and Rx to ground capacitance.

If a greater Rx electrode area is exposed to the hand, capacity C_H increases and leads to a higher signal deviation. On the other hand, a big Rx electrode will cause higher capacitance between Rx and Tx electrodes and higher Rx to ground capacitance. The consequence of that is a loss of signal sensitivity (refer to Equation 4-5).

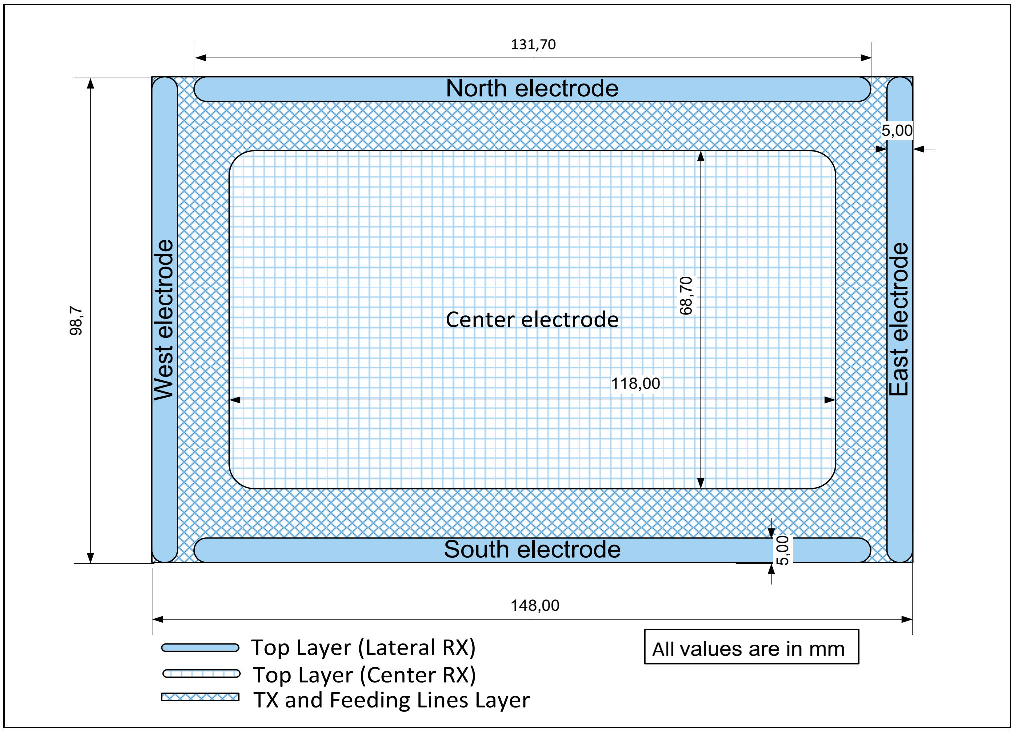
Thus, the Rx electrode area and shape are a settlement between being sensitive to hand gestures and being less coupling to Tx electrode and ground.

To achieve high sensitivity in the GestIC system, the Rx electrode area should be in the same order of magnitude of the human hand or finger size. Only frame electrodes are supported by MGC3X30. Typically, longer electrodes increase the coupling between the Rx electrodes and the hand for better sensitivity.

Rx electrode dimensions determine the sensitive area. These electrodes should be at the edges of this area to ensure a good resolution x, y, z.

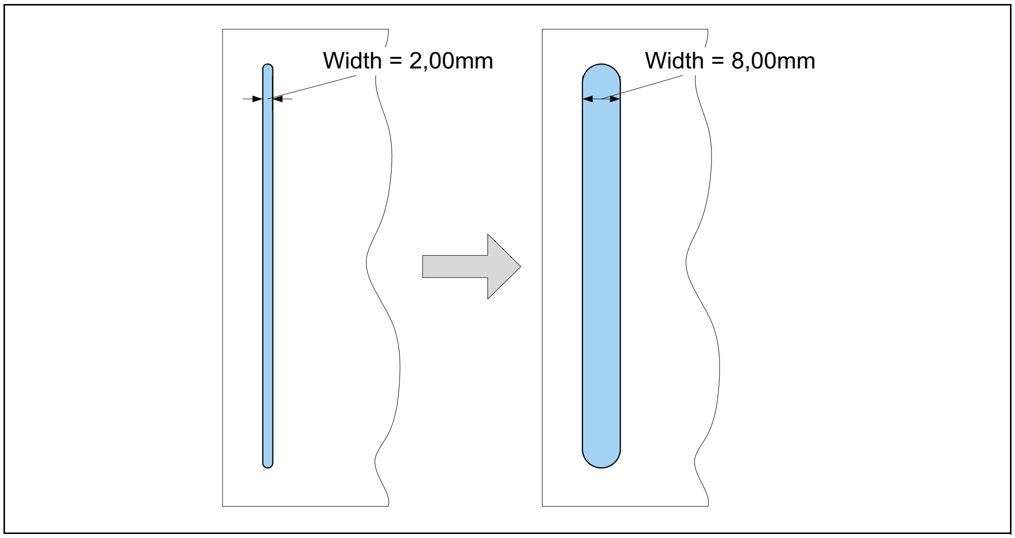
From a capacitances point of view, a good design should provide maximum C_{Hand} and minimum C_{RxG}/C_{RxTx}. Figure 4-6 illustrates an example of 7" Rx electrodes shape and size. This example conforms to the frame-shape electrode defined previously, which is defined by a central sensitive area with four symmetric Rx electrodes. The MGC3X30 supports design forms from 1:1 up to 1:2 ratios with a maximum diagonal of 7".

FIGURE 4-6: Rx ELECTRODES SHAPE AND SIZE 7" EXAMPLE



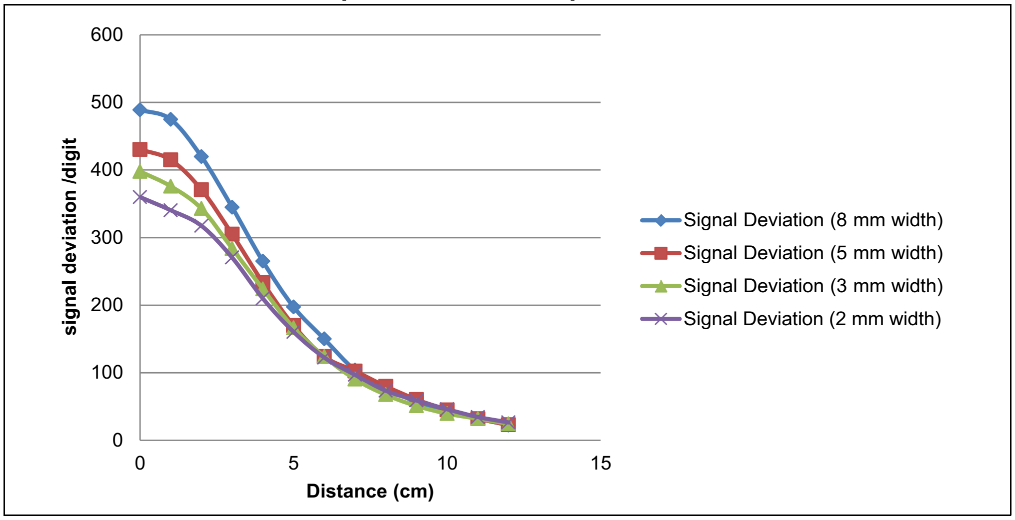
The Rx electrodes width depends on how much sensitivity is targeted when the hand is very close to the electrode. The greater the width, the higher the sensitivity (see Figure 4-7).

FIGURE 4-7: INFLUENCE OF Rx WIDTH



However, the width of the Rx electrode has very low impact when the hand is at some distance, as shown in Figure 4-8.

FIGURE 4-8: SIGNAL DEVIATION WITH DIFFERENT Rx ELECTRODE WIDTH (LENGTH = 90 mm)

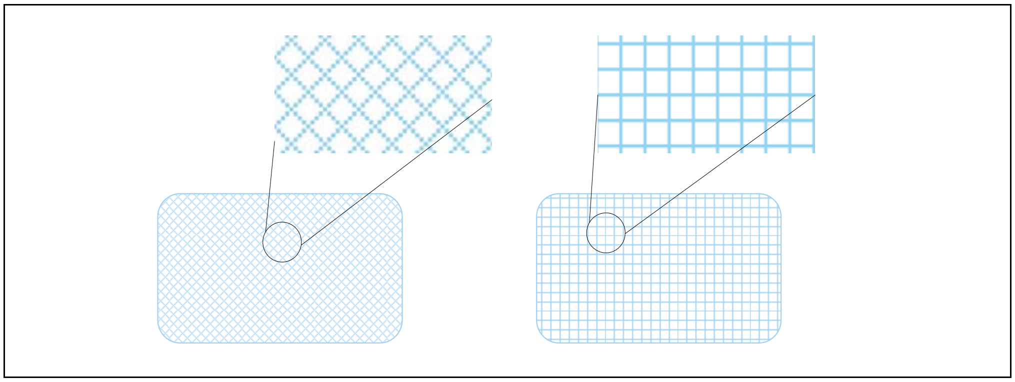


Due to its large surface, Rx center electrode should be cross-hatched to obtain similar sensitivity compared to the frame electrodes. Hatching reduces the effective electrode area and the coupling to the Tx electrode.

5% to 20% hatching is a good value for the Rx center electrode, providing there is a high sensitivity with a minimal C_{RxTx} capacitance. An example of hatch structures is provided in Figure 4-9.

Note:	5% hatching means that 5% of the area is covered with copper.

FIGURE 4-9: Rx CENTER ELECTRODE HATCH STRUCTURES



4.3.2 Rx Electrode and System Ground Design

Due to the fact that the GestIC sensing method is influenced by the parasitic capacitance of a sensor electrode to ground, placing ground very close to the sensor will reduce sensitivity by increasing C_{RxG}. Furthermore, the Tx E-field stray propagation is compromised and, thus, the sensitivity of the Rx electrodes reduces further.

Generally, it is required to keep the system ground away from sensors and feeding lines leading to the sensors.

Equation 4-5 shows that the sensitivity to the hand increases when the denominator is minimized. In GestIC applications, the following parameters are influencing factors:

- Rx feeding line capacitance (C_L)
- Rx electrode ground capacitance (C_{RxG})
- Capacitance between the Rx and the Tx electrode (C_{RxTx})

To reduce the C_{RxG} capacitance, the distance between the Rx-Tx electrode stack-up and ground can be increased. A good value is between 1.0 mm and 2.5 mm.

Since ground parts typically cover large areas in a GestIC system, E-field stray effects dominate typically C_{RxG}, and it often does not make sense to increase the height of the stack-up and, thus, to increase the Rx electrode distance-to-ground to more than 2 mm. Additionally, the distance-to-ground in the neighborhood of Rx has to be maximized as illustrated in Figure 4-10 and Figure 4-11. The ground housing should be kept away from the Rx electrodes at least 5 mm (d1 in Figure 4-10), and the Rx electrode should be away from the sensitive area corner of at least 3 mm (d2 in Figure 4-11).

FIGURE 4-10: BAD DESIGN OF Rx TO GROUND CONSTRUCTION

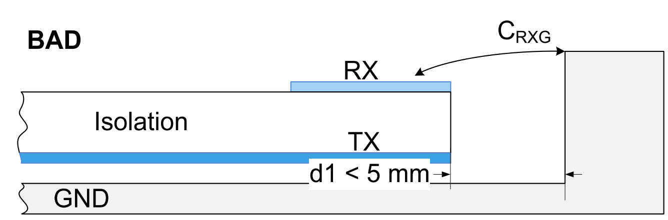


FIGURE 4-11: GOOD DESIGN OF Rx TO GROUND CONSTRUCTION

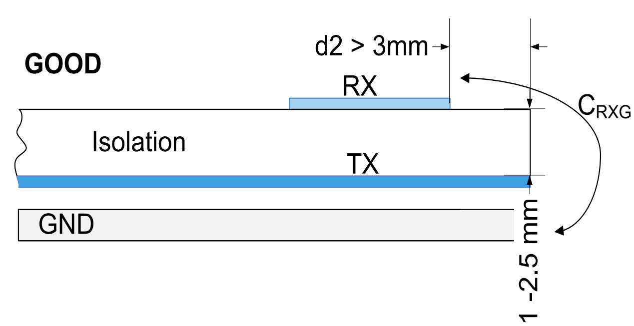


Figure 4-12 and Figure 4-13 provide a simulation result showing that, with a close ground to the sensing electrodes, the E-field stray distribution (equipotential lines) becomes significantly lower at the Rx electrodes. The complete sensing area is also reduced and, thus, the overall signal sensitivity is reduced.

FIGURE 4-12: EQUIPOTENTIAL LINES OF AN UNDISTORTED E-FIELD WITHOUT GROUND

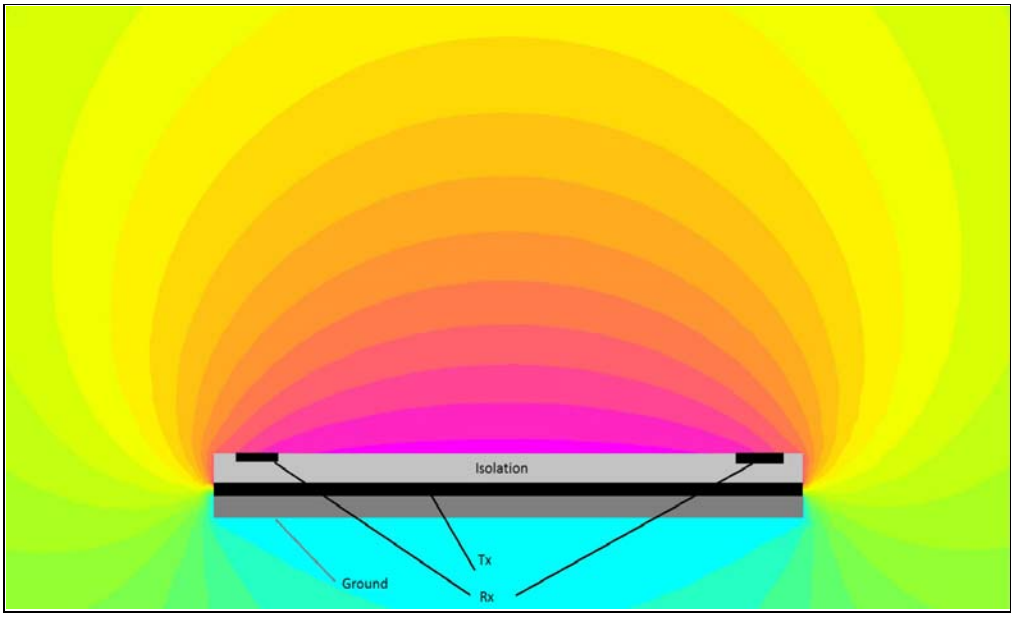


FIGURE 4-13: EQUIPOTENTIAL LINES OF AN UNDISTORTED E-FIELD WITH CLOSE GROUND TO ELECTRODES

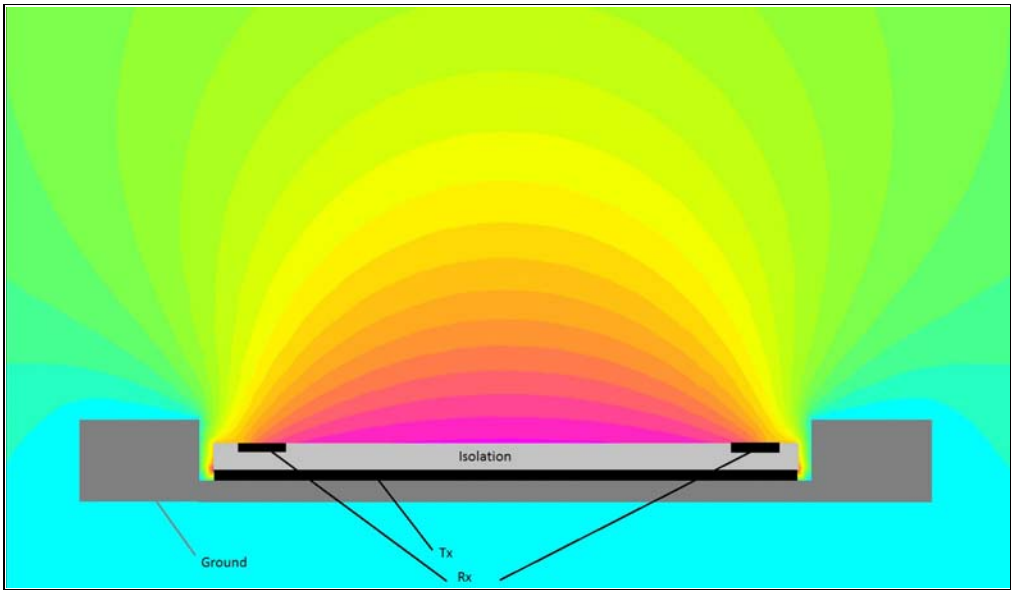
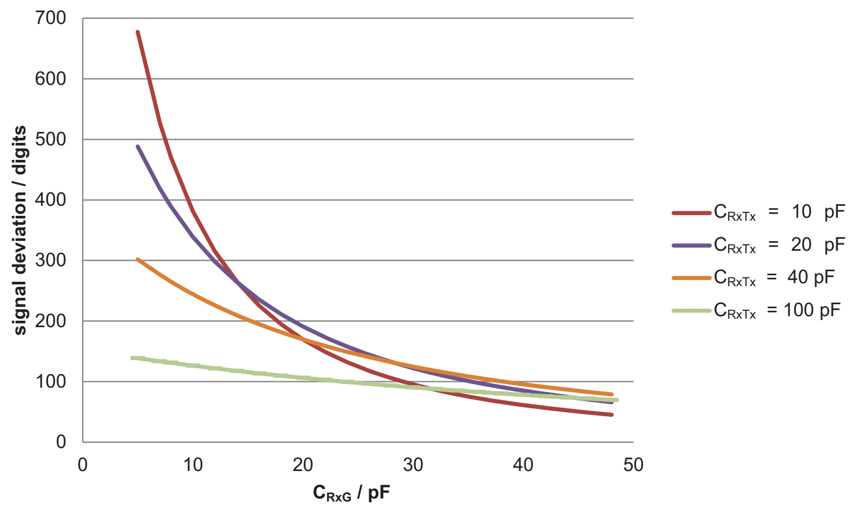


Figure 4-14 provides an example of changing the Rx to GND coupling for different Rx to Tx capacitance. This calculation confirms the design rules stated in **Section 4.2.4 "Equivalent Circuit Rules Summary"**. The best sensitivity can be achieved when C_{RxTx} and C_{RxG} are in the same range and they are both kept small.

FIGURE 4-14: Rx TO GROUND INFLUENCE FOR DIFFERENT Rx-Tx CAPACITANCE



4.4 Tx ELECTRODES DESIGN

4.4.1 Tx Electrodes Shape and Size

The Tx electrode is used to generate the E-field from the MGC3X30 bandwidth-limited square wave signal (44-115 kHz). It should cover the whole frame of the sensitive area. Tx electrode design should respect two main criteria:

- Low direct coupling (plate capacitance) between Rx and Tx electrodes
- Low Tx coupling to ground

Using a hatched Tx layer will reduce these coupling and results in lower C_{RxTx} and C_{TxG} capacitances.

Figure 4-15 illustrates the impact of having a hatched Tx layer. Nevertheless, it is a compromise between E-field stray distribution and capacitances optimization. 20% to 50% hatching is a good value.

FIGURE 4-15: Tx STRUCTURES INFLUENCE

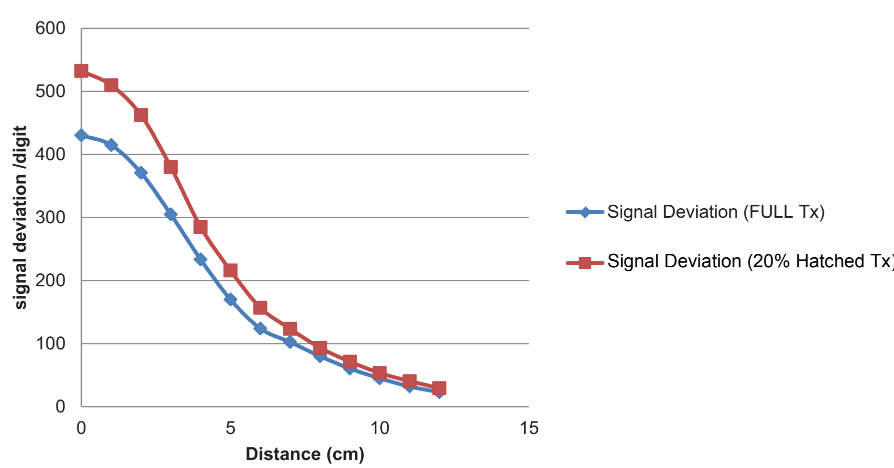


Figure 4-16 provides an example of a cross-hatched Tx electrode and ground layer. This structure was used in the Sabrewing V1.0 evaluation board. This double-hatched layer is designed to have:

1. Lower Rx-Tx plate capacitance due to 20% hatched Tx structure
2. Lower Rx ground capacitance due to the shielding effect of 20% Tx hatching under Rx
3. Good E-field stray distribution due to 50% Tx hatching in the center of the sensitive area
4. Lower Tx ground capacitance and, thus, better Tx drive capability.

Good design should balance between both parameters described in 1 and 2.

FIGURE 4-16: HATCHED Tx EXAMPLE (SABREWING V1.0)

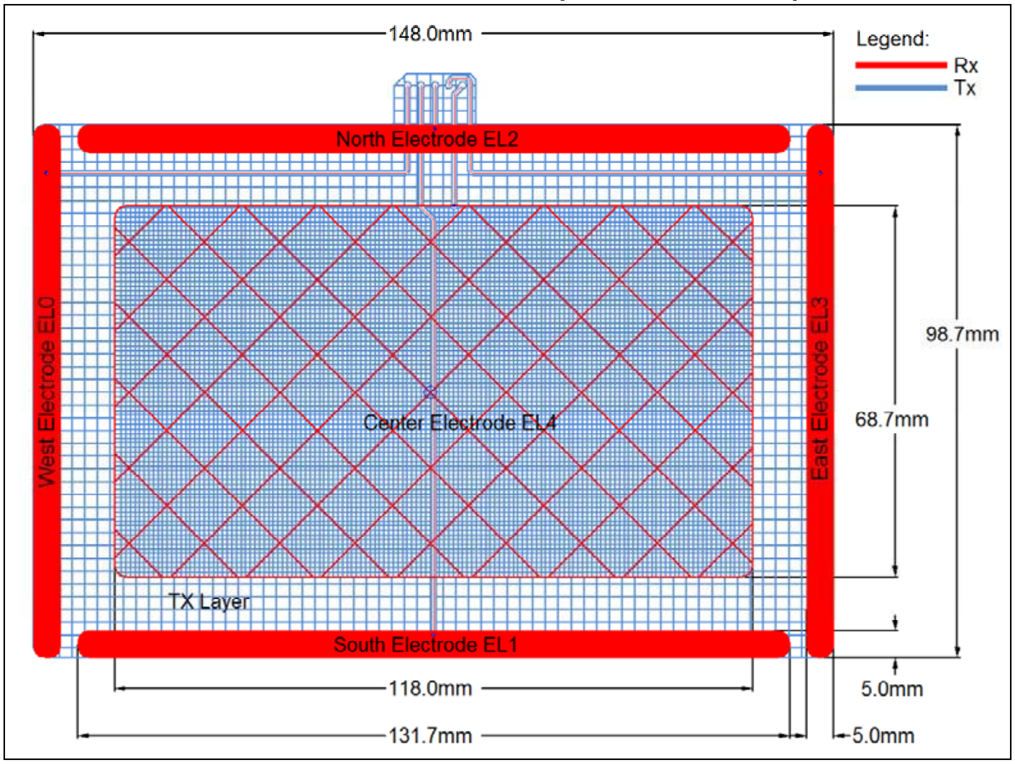


TABLE 4-2: ELECTRODE DIMENSIONS AND HATCHING SABREWING V1.0

	Length	Width	Cover Style
Horizontal Electrodes (Rx) North, South	131.7 mm	5 mm	solid
Vertical Electrodes (Rx) West, East	98.7 mm	5 mm	solid
Center Electrode (Rx)	118 mm	68.7 mm	5% structured
Tx Electrode (see Figure 4-16) Part I (under Center Electrode) Part II (Outside Part I)	148 mm 118 mm 148 mm	98.7 mm 68.7 mm 98.7 mm	 50% structured 20% structured
Sensing Area	< 130 mm	< 90 mm	
Ground Area	180 mm	126.6 mm	40% structured

4.4.2 Tx Electrodes and Ground

In many applications, the Tx electrode is relatively large, with up to 200 cm^2. In the case where Tx is comparably close to the system ground, like keyboards, it is important to consider Tx to ground capacitance and MGC3X30 Tx pin drive capability. The MGC3X30 can drive up to 1 nF capacitance with an output impedance of 800Ω. For capacitance higher than 1 nF, it is recommended to use an external boost amplifier (see **Appendix**).

4.5 FEEDING LINES (ROUTING, DISTANCE TO Tx/GND/NOISE SOURCES)

The Rx electrode feeding lines connect Rx electrodes with the receive pins of MGC3X30. Thus, they are sensitive in the same way the Rx electrodes are.

In addition, they add capacitance between the Rx and Tx electrodes, as well as between Rx and system ground. That will reduce the intended system sensitivity and the need to be compensated by the right layout.

Having that in mind, the following rules for the Rx feeding line layout should be considered (highest priority first):

- Keep Rx feeding lines thin and short
- Do not expose the Rx feeding lines to the hand. Route them in an inner PCB layer
- Keep Rx feeding lines away from other analog and digital sources within the system
- Keep Rx feeding lines away from ground
- Keep area underneath the Rx electrodes clear of feeding line traces
- Keep Rx feeding lines away from Tx

In addition, it is recommended to achieve a symmetrical layout of the Rx feeding lines to allow DSP algorithms to overcome possible inconsistencies.

In case the design does not allow a feeding line layout according to these rules, it is possible to shield them with a Tx layer. That decreases the electrodes sensitivity but will result in a stable and homogeneous sensitive area. There are two effective ways to shield: place an additional Tx layer over the feeding line or embed the feeding lines into the Tx electrode. In both cases, the distance between the feeding line and Tx should be 0.1-0.25 mm. If the application targets a very close hand position (less than 1 cm), then it is better to decrease the distance to Tx to avoid undesired hand influences on the feeding line.

The placement of the MGC3X30 controller on the PCB is very important in reducing all Rx feeding lines length and for optimum symmetry.

The MGC3X30 should be placed in the center and in a way to avoid having long feeding lines and adjacent traces to reduce cross talk between Rx channels.

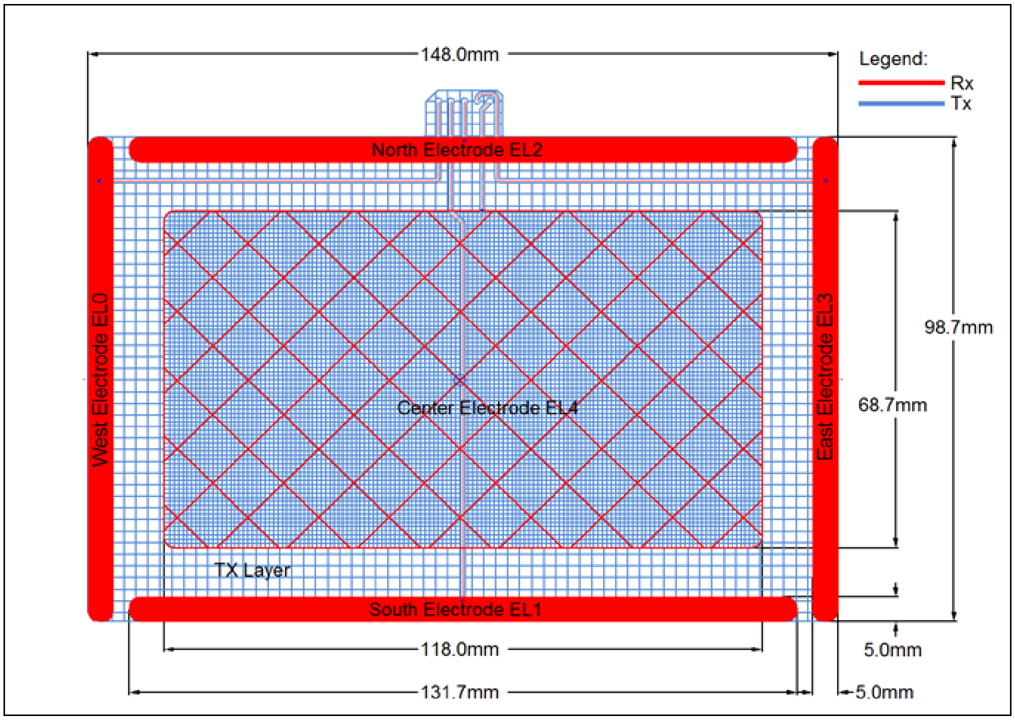
Two different designs can lead to a good system performance:

- Place MGC3X30 outside the electrode area as far as possible from the expected region, where the hand will be used.
- Place the MGC3X30 at the backside of the electrodes area (e.g., in a layer that ensures the shortest feeding lines and best symmetry).

Examples:

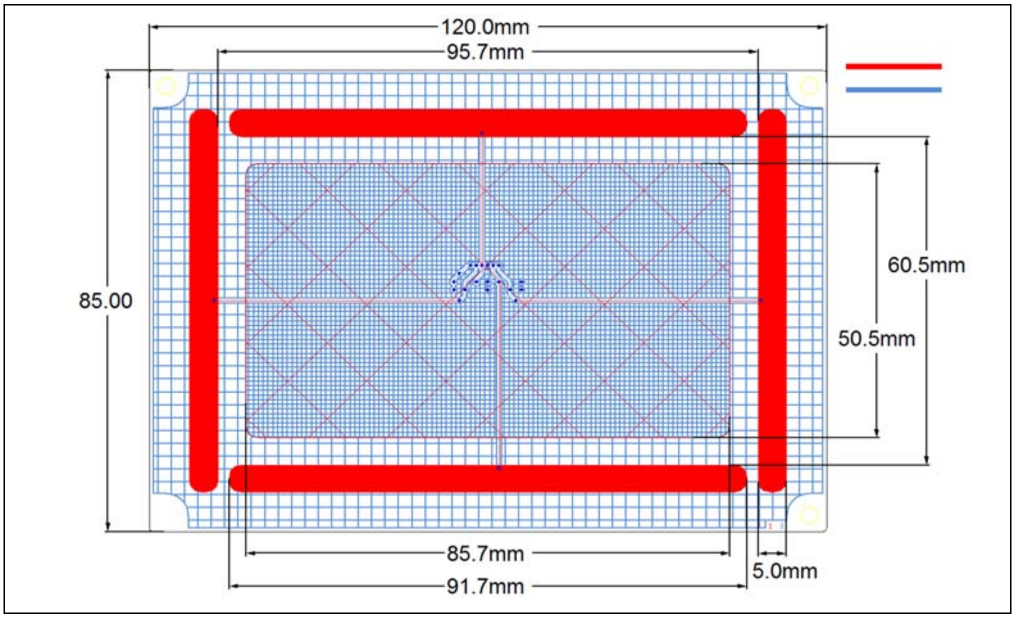
- Sabrewing evaluation board layout:
  - MGC3X30 is placed in the north (away from typical hand approach direction)
  - MGC3X30 is placed on the horizontal symmetry axis of the electrode
  - Feeding lines connect the electrodes at the shortest possible distance by directly crossing the electrodes area
  - Feeding lines are routed in the second layer as 0.1 mm tracks
  - Feeding lines are embedded in Tx layer having a distance to Tx of 0.25 mm
  - Strict separation between electrode area and digital circuitry

FIGURE 4-17: LAYOUT REFERENCE: SABREWING 140x90 mm ELECTRODE



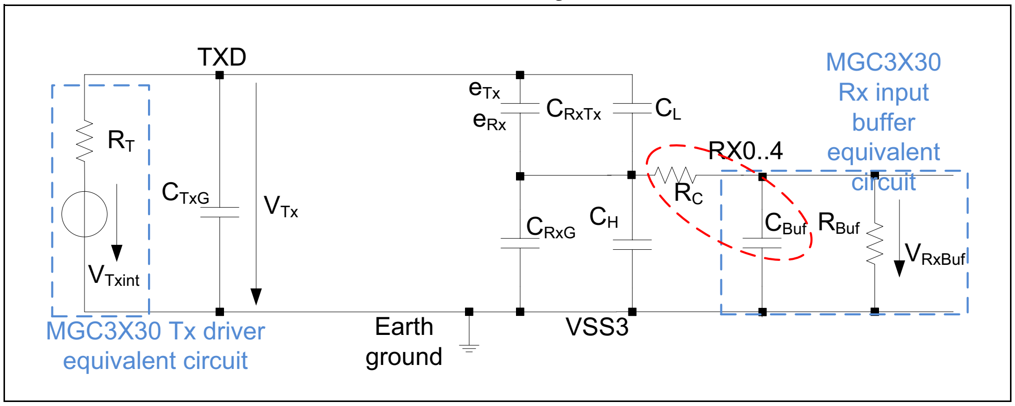
- 95x60 mm sensor module layout:
  - MGC3X30 is placed in the center of the electrode’s back
  - Feeding lines connect the electrodes at the shortest possible distance, starting from the center of the PCB
  - Feeding lines are routed in the second layer as 0.1 mm tracks
  - Feeding lines are embedded in Tx layer, having a distance to Tx of 0.25 mm
  - Tx as shielding layer between electrode area and digital circuitry

FIGURE 4-18: LAYOUT REFERENCE: 95x60 mm SENSOR MODULE



> **Note:** In order to suppress irradiated high-frequency signals, the five Rx channels of the chip are connected to the electrodes via serial 10 kΩ resistors as close as possible to MGC3X30 (see Figure 4-19). As an example, R_C (10 kΩ) and C_{Buf} (5 pF) are building a low-pass filter with a corner frequency of 3 MHz.

FIGURE 4-19: IRRADIATED HIGH-FREQUENCY SUPPRESSION



4.6 LAYER STACK-UP (RX/TX ELECTRODES COUPLING)

Equation 4-5 shows that decreasing the coupling between Rx and Tx electrodes will lead to higher signal sensitivity. This can be achieved by:

- Increasing the distance between the Rx and the Tx electrode
- Using different dielectric material (lower ε_r)
- Structuring of Tx layer (hatching)

4.6.1 Increasing the Distance Between the Rx and the Tx Electrodes

Figure 4-20 and Figure 4-21 show examples of short and long distances between the Rx and the Tx electrodes. This distance should be in the range of 0.5-2.5 mm. In a good GestIC electrode design, C_{RxTx} dominates the other capacitances. Thus, it should be optimized to the smallest possible values.

FIGURE 4-20: SHORT Rx TO Tx DISTANCE

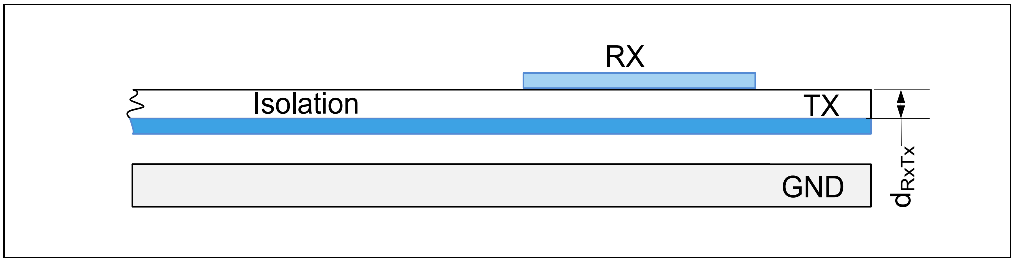
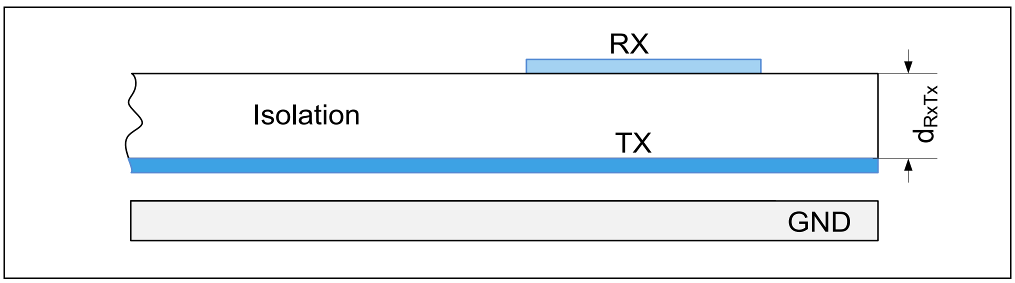
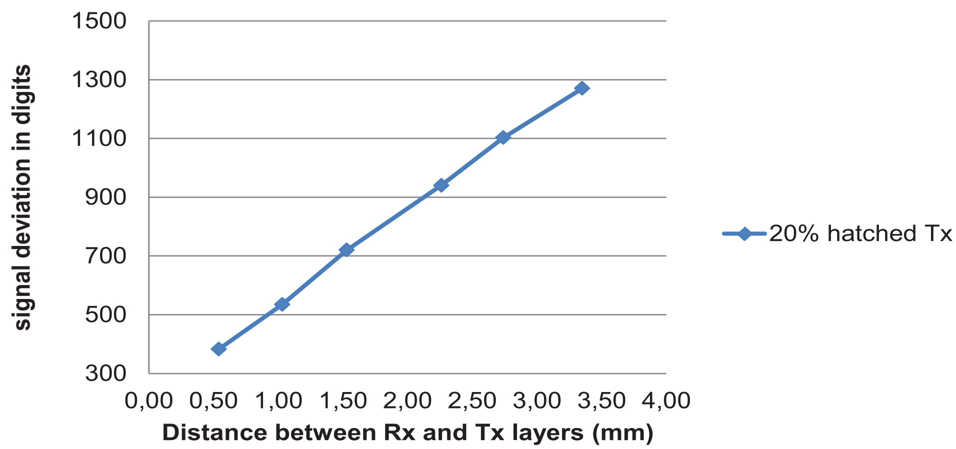


FIGURE 4-21: LONG Rx TO Tx DISTANCE



An example of changing the Rx to Tx distance is provided in Figure 4-22, using a 5 mm x 90 mm Rx electrode and FR4 as isolation between Rx and Tx. It shows that the Rx to Tx distance affects the Signal deviation linearly in a defined range. This result is also confirmed by Equation 4-5 – decreasing the distance will lead to a higher C_{RxTx} capacitance and, thus, to less system sensitivity.

FIGURE 4-22: Rx TO Tx DISTANCE VARIATION



4.6.2 Using Different Dielectric Material (Lower ε_r)

According to plate Capacitance formula ($C = (\varepsilon_r \varepsilon_r A)/d$), there are a number of variables that could affect the capacitance between the Rx and Tx GestIC electrodes. One is the relative dielectric constant ε_r, which is proportional to the capacitance. ε_r is a characteristic parameter of the isolation material between Rx and Tx, and should be chosen to be as small as possible. Examples of different materials are given in Table 4-3.

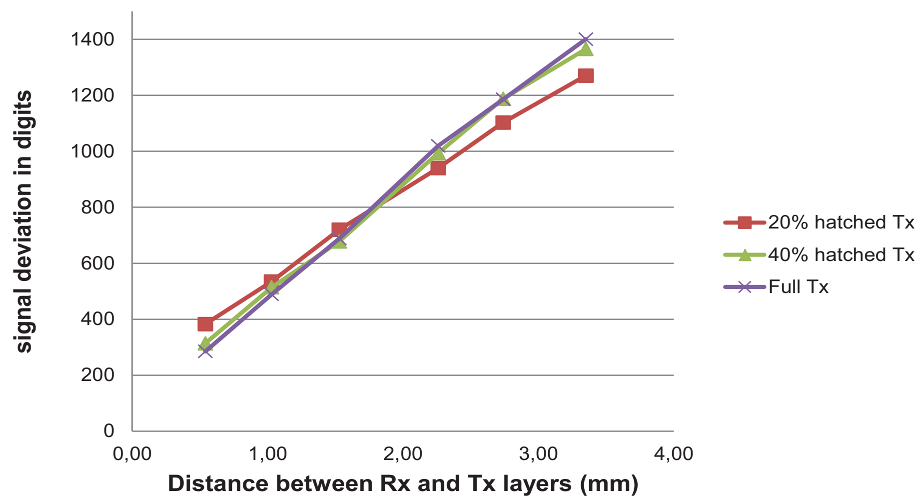
TABLE 4-3: RELATIVE PERMITTIVITY FOR DIFFERENT MATERIALS

Material	Relative Permittivity (ε_r)
Air	1.00059
Foamed Polystyrene (Styrofoam)	1.03
PTFE (Teflon)	2.0-2.6
Polyethylene terephthalate (PET)	3.0
Polycarbonate	2.0-3.5
PCB FR4	4.7-5.0
Glass	6-9

4.6.3 Cross-Hatching of Tx Layer

Other measures are to structure (hatch) the Tx electrode to lower its plate capacitance to Rx. Structuring the Tx electrode means designing the Tx electrode as a grid pattern instead of a completely filled conductive surface (see Figure 4-23). Nevertheless, this solution impacts the shielding of the GestIC system against noise and increases the electrode ground capacitance (C_{RxG}).

FIGURE 4-23: Rx TO Tx DISTANCE AND Tx STRUCTURES INFLUENCES



Decreasing the area of the Rx electrode is another possibility. This has to be done carefully since the hand capacitance, C_{Hand}, is also built between the Rx receive-electrode and the hand, and is a function of the Rx electrode design.

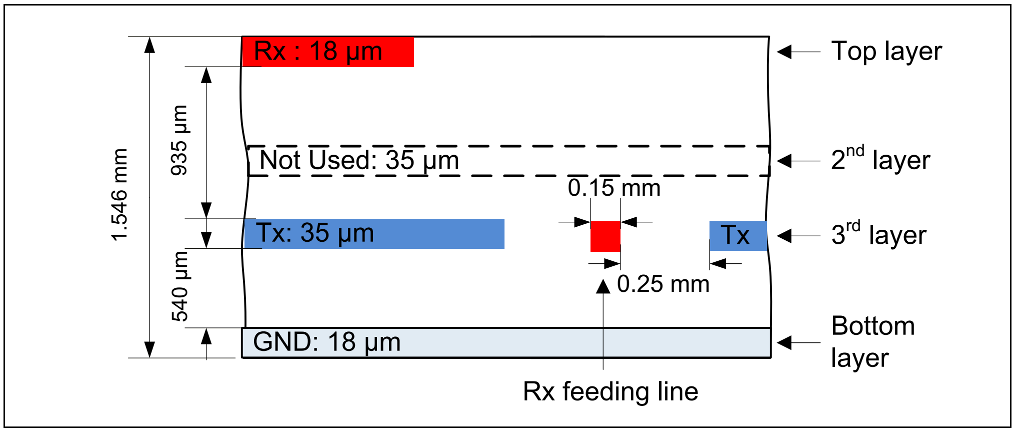
4.6.4 Multi-Layer Electrode Stack-Up

In case the target device does not provide a ground layer underneath the electrodes system, and it is required to improve shielding from the backside (to be insensitive from a backside approach), it is advantageous to include a dedicated ground layer into the electrode design. Some advantages and disadvantages of adding ground layer are listed below. The electrode layout example in Figure 4-24 shows the four-layer PCB of Microchip's Sabrewing Evaluation board.

Three functional layers of a four-layer PCB are used:

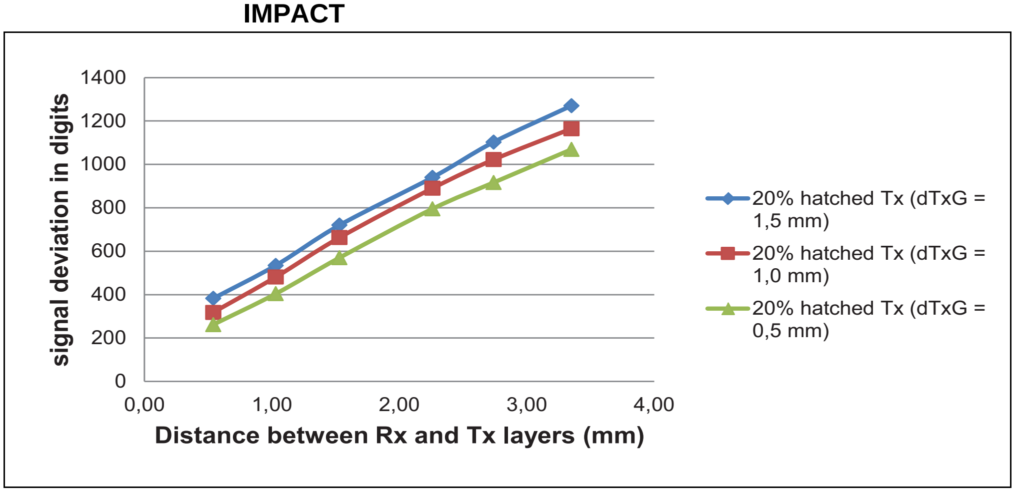
- Layer 1 (Top): Rx electrodes
- Layer 2 is not used
- Layer 3: Tx electrode and Rx feeding lines
- Layer 4 (Bottom): Ground

FIGURE 4-24: FOUR-LAYER PCB DESIGN



> **Note:** The integration of GestIC® technology into a target device does not necessarily require the GND layer. If no shielding is needed, or if the device already contains grounded planes, a 2-layer design is preferable. Placing a close ground layer to Tx will lead to system-sensitivity loss (see Figure 4-25).

FIGURE 4-25: Rx-Tx DISTANCE VARIATION AND Tx GROUND DISTANCE IMPACT

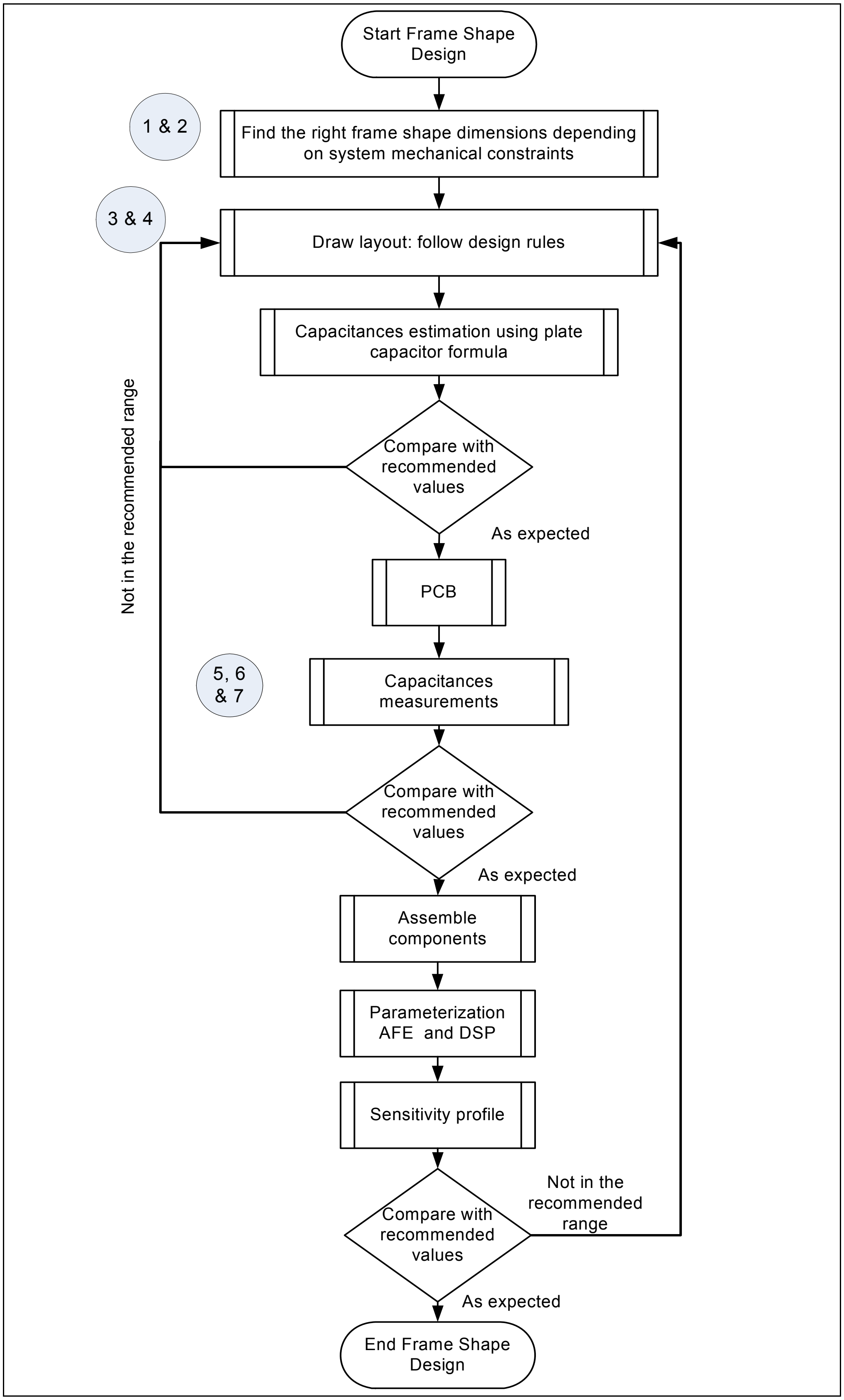


4.7 DESIGN RULES SUMMARY

- Sensing electrodes:
  - Sensing electrodes geometry defines the sensitive space
  - Use frame-shape electrodes: one pair vertical and one pair horizontal
  - Optional 5th electrode (center) to improve low-distance resolution for less than 2 cm and to support touch capability
  - Keep C_{RxG} as low as possible: the electrodes stack up (Rx on top of Tx), provides a good design to get high backside shielding and smallest C_{RxG} capacitance, which lead to high sensitivity
  - Keep C_{RxTx} low (only for plate capacitance)
  - Optimum: $(C_{RxG} + C_{Buf}) = (C_{RxTx} + C_L)$
  - Tx should cover complete area below the Rx electrodes
  - Keep $C_{TxG} < 1$ nF
- Feeding Lines:
  - Keep Rx feeding lines thin (0.1 mm) and short
  - Do not expose the Rx feeding lines to the hand. Route them (e.g., in an inner PCB layer)
  - Keep Rx feeding lines away from other analog and digital sources within the system
  - Keep Rx feeding lines away from ground
  - Keep area underneath the Rx electrodes clear of feeding line traces
  - Use Tx for shielding (keep 0.25 mm distance between Rx feeding line and Tx)
  - Avoid crosstalk: use a minimum distance of 0.25 mm between Rx feeding lines

4.8 STEP-BY-STEP ELECTRODE DESIGN FLOW

FIGURE 4-26: ELECTRODE DESIGN FLOWCHART



1. Define general sensor area by application
2. Define electrode stack-up:
   a) Define non-conductive carrier material:
      - Low ε_r is better: PC-ABS, PET, FR4 and glass.
   b) Define how the electrode can be applied to selected carrier material:
      - Ensure that conductive Tx and Rx electrode areas can be tightly tied to the carrier material (constant over temperature, aging)
      - Recommendation: Galvanize, sputter, paint, deposit, etc. In general, adhesive bonding is not a good idea.
3. Define frame-electrode design:
   a) Tx electrode covers the complete bottom side of the sensor
   b) Rx electrode on top side of the sensor
   c) Rx frame-electrode length and width (use case and application-driven). Length should be <14 cm, width should be about 3.5% - 7% of length
   d) Rx frame electrodes should always be solid
4. Define size and structuring of Rx center electrode (only if the center electrode is required by the application. See **Chapter 6. "GestIC Parameterization Flow"**):
   a) Center electrodes should be hatched. Apply hatching structure that gives the center electrode about the same signal deviation as the frame electrodes. Good starting point is about 5-10% hatching
5. Define general Tx ground environment:
   a) Define distance of Tx Layer to ground – the larger, the better
   b) Measure Tx to ground capacitance (C_{TxG})
      - If C_{TxG} < 500 pF → ok next step
      - If 500 pF < C_{TxG} < 1 nF → consider hatching of Tx electrode (no less than 35% average) and consider hatching of the ground area (when possible)
      - If C_{TxG} > 1 nF → increase ground distance and/or use lower ε_r material
6. Measure Rx-Tx capacitance (C_{RxTx}) of frame electrodes:
   a) If C_{RxTx} < 10 pF → very good
   b) If 10 pF < C_{RxTx} < 20 pF → ok
   c) If C_{RxTx} > 20 pF → consider higher thickness of carrier material or material with lower ε_r and check cross-coupling to other electrodes (increase distances between feeding lines)
7. Measure Rx-ground capacitance (C_{RxG}) of the frame electrodes:
   a) If C_{RxG} < 10 pF → very good
   b) If 10 pF < C_{RxG} < 20 pF and smaller than Rx-Tx capacitance (C_{RxTx}) → ok
   c) If Rx-Tx capacitance (C_{RxTx}) < Rx-ground capacitance (C_{RxG}) → improve Tx shielding of Rx electrodes and feeding lines
   d) If C_{RxG} > 20 pF → it might be required to increase distance to surrounding ground (depending on the desired tracking distance)
      - Draw Rx frame electrodes further into the Tx area
      - Assure distance to (conductive) metal housing

NOTES:

Chapter 5. System Integration

5.1 CHIP PLACEMENT AND LAYOUT RECOMMENDATIONS

This section provides a brief description of layout hints for a proper system design.

The PCB layout requirements for MGC3X30 follow the general rules for a mixed-signal design.

The chip should be placed as close as possible to the electrodes to keep their feeding lines as short as possible. The feeding lines should be also routed symmetrically to the electrodes axis (see Figure 5-1).

The frame electrodes are named according to their cardinal directions – north, east, south and west, and can be mapped flexibly in any order to MGC3X30 Rx0..4 pins to optimize feeding lines routing.

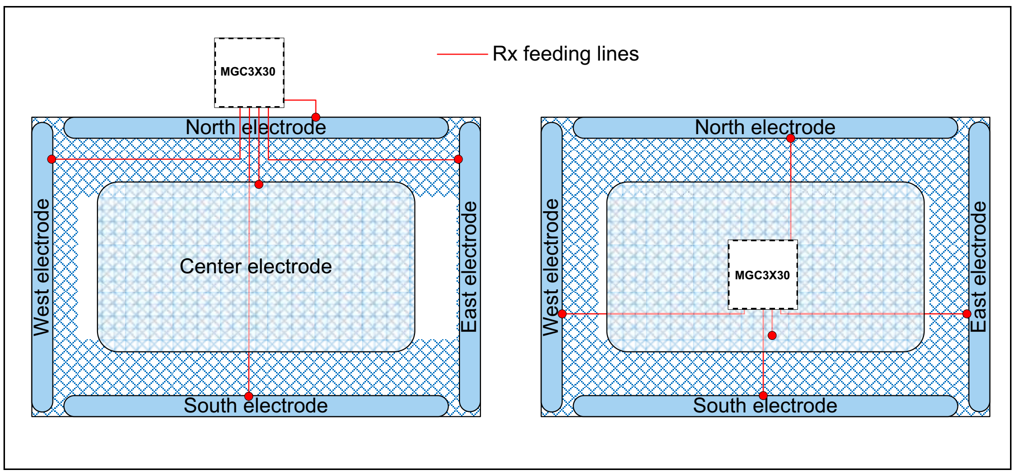
Furthermore, it is recommended to keep MGC3X30 away from electrical and thermal sources within the system.

Analog and digital signals should be separated from each other during PCB layout in order to minimize crosstalk.

VDD lines should be routed as wide as possible. For designs using the STEP-UP circuitry, the additional components required should be placed as close as possible to the MGC3X30.

MGC3X30 requires a proper ground connection on all VSS pins, including the exposed pad (pin 29).

FIGURE 5-1: CHIP PLACEMENT



5.2 MECHANICAL STABILITY

The whole system's mechanical stability is crucial to ensure deterministic system sensitivity. The mechanical stability can be disturbed by many factors and below are some recommendations for system mechanical integration.

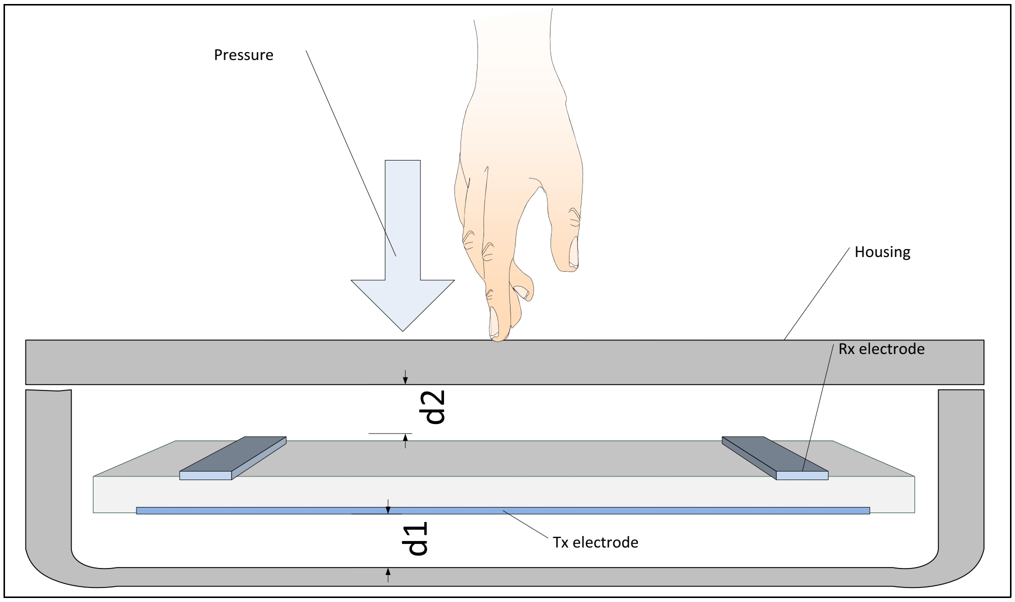
5.2.1 Electrodes and Feeding Lines Environment

The electrodes stack-up should be maintained stable and away from potentially moving parts. The distances Rx-GND and Tx-GND should be very constant and stable (d1 and d2 in Figure 5-2). High mechanical stability is required in the GestIC sensing area.

The electrodes and feeding lines should be placed in a mechanically stable area where the deformation of housing is minimal. It is not a good practice to have feeding lines and electrodes close to hand holding or hand resting areas (see Figure 5-2).

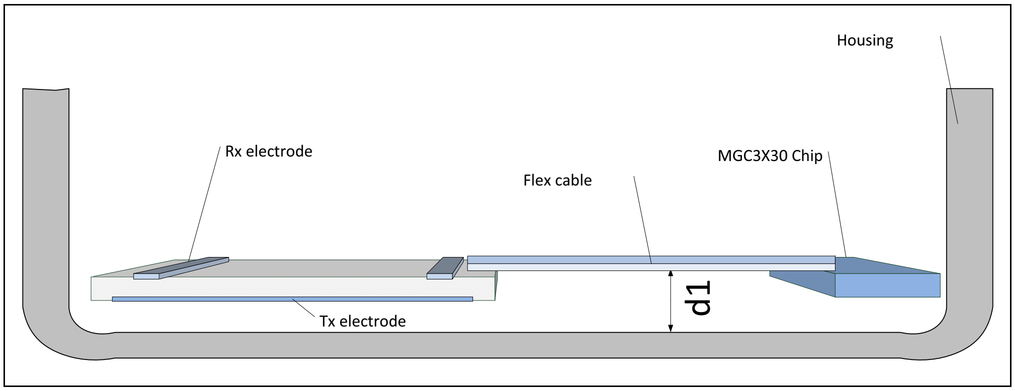
It is also highly recommended to avoid using metal housing close to the electrodes, and it is better to use non-conductive material (e.g., plastic).

FIGURE 5-2: ELECTRODES STACK-UP AND HOUSING



The electrode feeding lines should also always be kept at a constant distance from the ground and from other conductive items. Whenever possible, the feeding lines should not be placed close to moving parts. Mechanical deformation of the housing can influence the electrode signals. In general, a flexible feeding line cable should be fixed (d1 in Figure 5-3).

FIGURE 5-3: FLEX CABLE DISTANCE TO GROUND



5.2.2 Conductive Items

Conductive items within the housing influence the electric field and lead to reduced system sensitivity. In order to achieve a high sensitivity, it is recommended to keep as much distance as possible between the electrodes and other conductive parts inside the target device. In the case of conductive parts being behind the electrode, the distance to the electrode should be steady over the whole electrode area. This ensures constant sensitivity over the entire electrode.

When using foils on top of the Rx electrodes (e.g., decoration foils), they should be hard glued (avoid air bubbles); otherwise, the signal sensitivity can be influenced. It is also recommended not to use metal springs to contact electrodes. Furthermore, metal springs, being considered as movable parts, should not be close to Rx electrodes and feeding lines.

It is also recommended to avoid using conductive plastic parts in the detection area (e.g., black plastic material is often dyed by conductive carbon).

5.2.3 Housing Thickness and Dielectric Constant

The housing between the electrode and the user has an effect on the sensing performance of GestIC. The housing reduces the detection range of GestIC by its thickness and its relative dielectric constant, ε_r. Thus, the distance between the housing and all electrodes should be in the same order to assure a homogenous sensitivity.

5.3 NOISE CONSIDERATIONS

MGC3X30 self-noise can create instability in GestIC systems. Since the MGC3X30 self-noise is a flicker noise, which is related to the level of DC, this noise increases when the V_{RxBuf} input voltage increases. The tolerated self-noise level is 3 LSB ±10%. If the noise is higher than this level, the application should find a way to reduce this noise and a re-design may be required.

5.4 PARAMETERIZATION CIRCUIT

Figure 5-4, Figure 5-5 and Figure 5-6 show a typical hardware circuit for MGC3X30 debugging and parameterization. Aurea Control Software uses an I^2C™ to USB Bridge to control and parameterize MGC3X30. As the I^2C to USB Bridge acts as an I^2C master, the application processor I^2C should be:

- Switched off (I^2C lines configured as high Z)
- Switched to Slave or Listen mode
- Disconnected (through an external switch)

FIGURE 5-4: MGC3X30 PARAMETERIZATION CIRCUIT WITH INTERNAL SWITCH

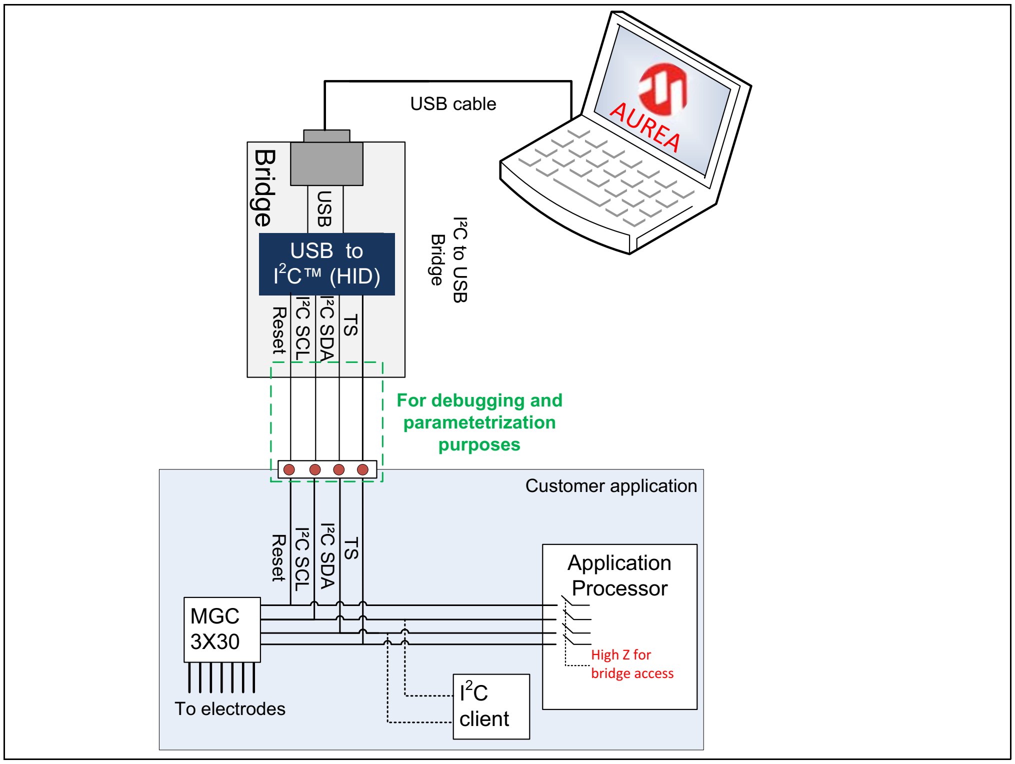


FIGURE 5-5: MGC3X30 PARAMETERIZATION CIRCUIT WITH EXTERNAL SWITCH

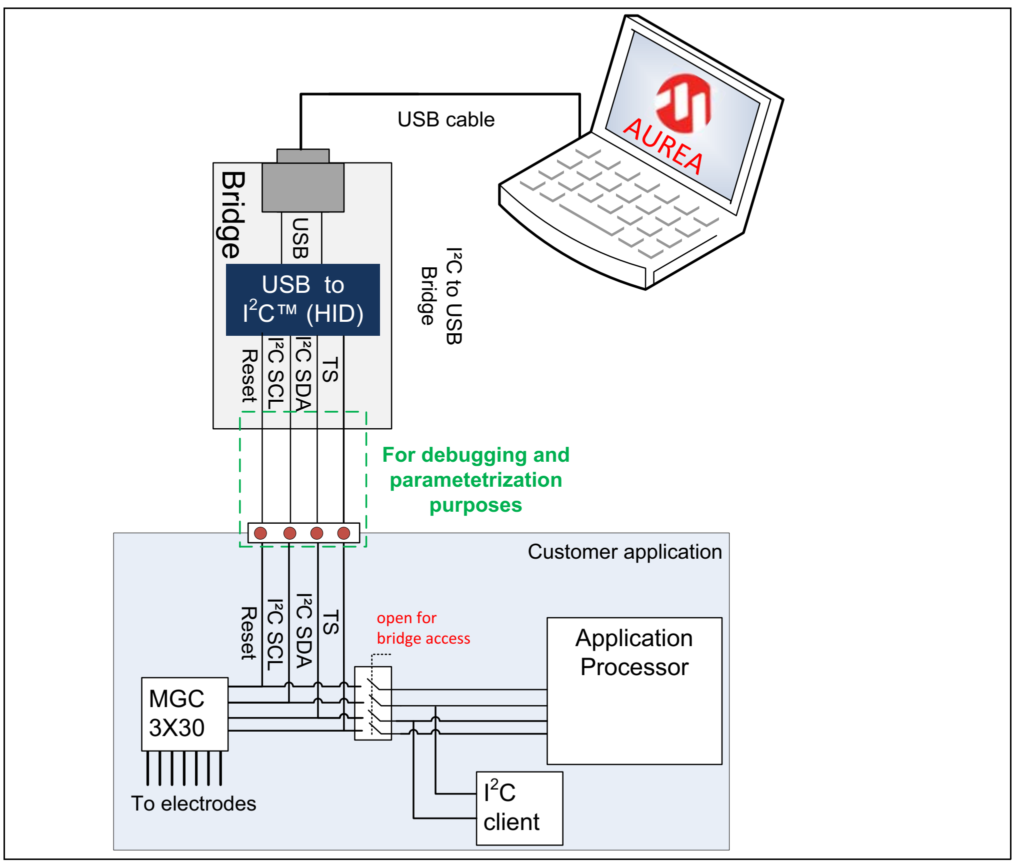


FIGURE 5-6: MGC3X30 PARAMETERIZATION CIRCUIT FOR USB-BASED APPLICATIONS

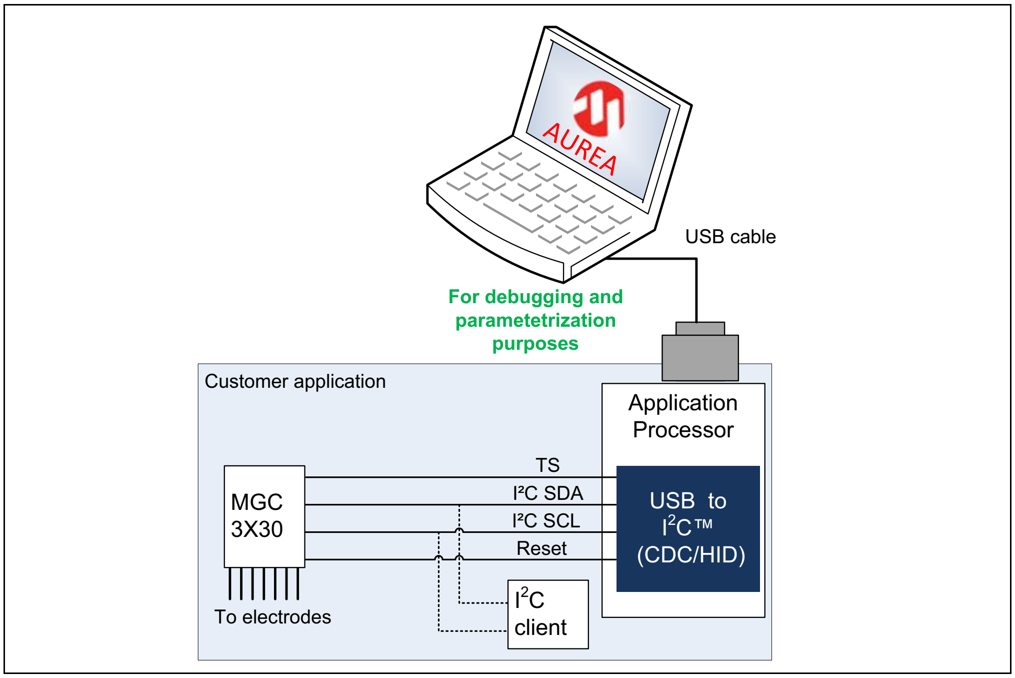


TABLE 5-1: PARAMETERIZATION CIRCUITS COMPARISON

Parameterization Circuit	Advantages	Drawbacks
With Internal Switch	Easy approach	Processor pins need to be switchable to high Z
	Low-hardware efforts	No other clients can be controlled during Aurea access
With External Switch	Communication to other I²C™ clients is not interrupted	Additional hardware switch
USB-Based Applications	No hardware efforts	Additional software efforts
	Works if other I²C™ clients are connected to the bus	

NOTES:

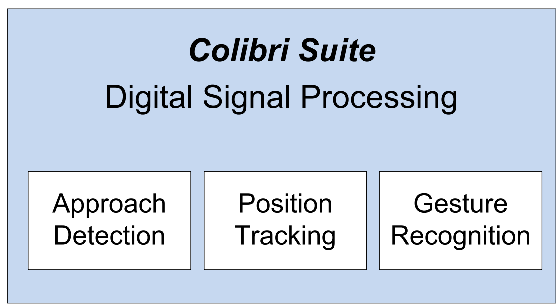
Chapter 6. GestIC Parameterization Flow

MGC3X30 devices are provided with a GestIC Library, stored on the chip's Flash memory.

The library includes:

- **Colibri Suite**: It combines data acquisition, digital signal processing (DSP), provides positioning data and recognized gestures. The Colibri Suite core features are illustrated in Figure 6-1.
- **System Control**: MGC3X30 hardware control features, such as Analog Front-End (AFE) access, interface control and parameters storage.
- **Library Loader**: GestIC Library update through the application host's interface.

FIGURE 6-1: COLIBRI SUITE CORE ELEMENTS

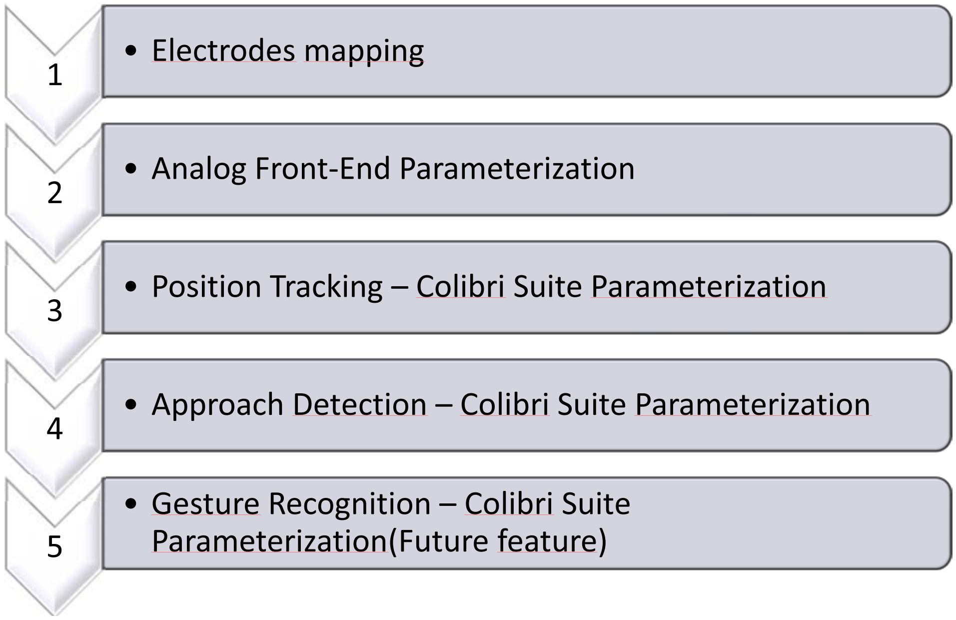


Please refer to "*MGC3030/3130 3D Gesture Controller Data Sheet*" (DS40001667) for more Colibri Suite details.

In order to obtain optimal functionality, the GestIC system has to be parameterized. Therefore, several rules have to be respected to match the AFE settings with electrode characteristics and match the Colibri Suite parameters with the sensitive area geometry. This chapter provides step-by-step instructions for proper GestIC parameter settings. The parameterization steps are grouped into separate sections independent from each other and displayed in Figure 6-2.

Note:	The parameterization can only be done via Aurea PC Software. A customer design should take this into account. For this reason, we recommend preparing the parameterization circuit as described in **Section 5.4 "Parameterization Circuit"**.

FIGURE 6-2: GestIC® PARAMETERIZATION FLOW



1.	Electrodes mapping	Assign cardinal directions to Rx electrode pins
2.	Analog Front-End Parameterization	Adjustment of transmit and receive signals
3.	Position-tracking Colibri Suite Parameterization	Tuning of Position Tracking Colibri Suite parameters
4.	Approach Detection Colibri Suite Parameterization	Adjusting of Approach Detection parameters
5.	Gesture Recognition Colibri Suite Parameterization (Future feature)	Tuning of HMM Recognizer thresholds and gestures set of definitions

6.1 ELECTRODES MAPPING

The design of Rx electrodes includes four frame electrodes and one optional center electrode, as shown in Figure 4-1. The frame electrodes are named according to their cardinal directions – north, east, south and west. The first parameterization step assigns the electrodes with their cardinal directions to the Rx pins of MGC3X30. The electrodes mapping can be updated by the user using GestIC Library messages or Aurea PC Software. For more details, please refer to "*Aurea Graphical User Interface User's Guide*" (DS40001681).

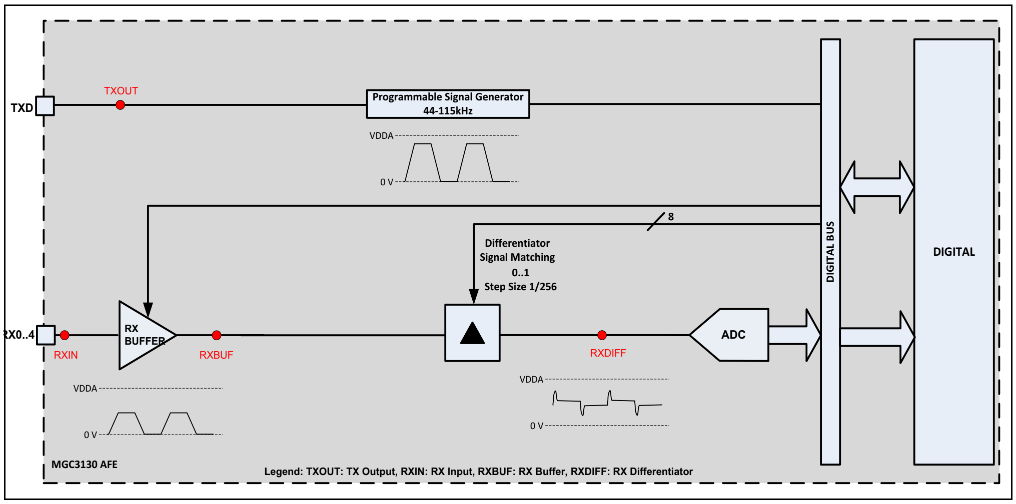
6.2 ANALOG FRONT END (AFE) PARAMETERIZATION

The MGC3X30 controller provides a high flexibility to be adjusted according to the application electrodes design. Some MGC3X30 internal parameters can be partially adjusted by the user through firmware messaging, while others are automatically fine-tuned by the GestIC Library to save application development time. The AFE parameters are listed in Table 6-1.

TABLE 6-1: AFE PARAMETERS

Parameter Name	Description	Action
TxGEN [44, 67, 88, 103, 115]	The frequency of transmit electrode, Tx. The Tx frequency has a tolerance of ±10%. GestIC® Library is dynamically controlling this frequency.	Automatic selection of the best frequency out of a list of five. The user can enable and disable each of them.
RxDIFF [0, 1, … 255]	Rx Differentiator: Signal matching control to allow maximum dynamic range.	Automatic adjustment with Aurea tool.

FIGURE 6-3: MGC3X30 CONTROLLER EXTENDED BLOCK DIAGRAM



6.2.1 Tx Frequency (TxGEN)

The MGC3X30 Tx signal generation block provides the rectangular signal for the transmit electrode. The MGC3X30 adjusts automatically the Tx carrier frequency in the range of 44-115 kHz, depending on the external noise conditions. The Tx frequency is controlled by the GestIC library through frequency hopping, which adjusts continuously the Tx frequency, according to the noise power measurement. The user can enable or disable, through GestIC Library messages or Aurea PC Software, each of the following frequencies: 44 kHz, 67 kHz, 88 kHz, 103 kHz or 115 kHz. For more details, please refer to "*Aurea Graphical User Interface User's Guide*"(DS40001681).

6.2.2 Signal Matching (RxDIFF)

The parameterization of the Signal Matching block is performed to enable maximum dynamic range. Therefore, the electrical field should not be disturbed by any external object during the Signal Matching parameterization process.

The Signal Matching parameter is intended to get a flat signal of approximately VDDA/2 (corresponding to 32,768 digits) at the sampling point (3,7 µs) (see Figure 6-4).

FIGURE 6-4: GestIC® RxDIFF ANALOG SIGNAL

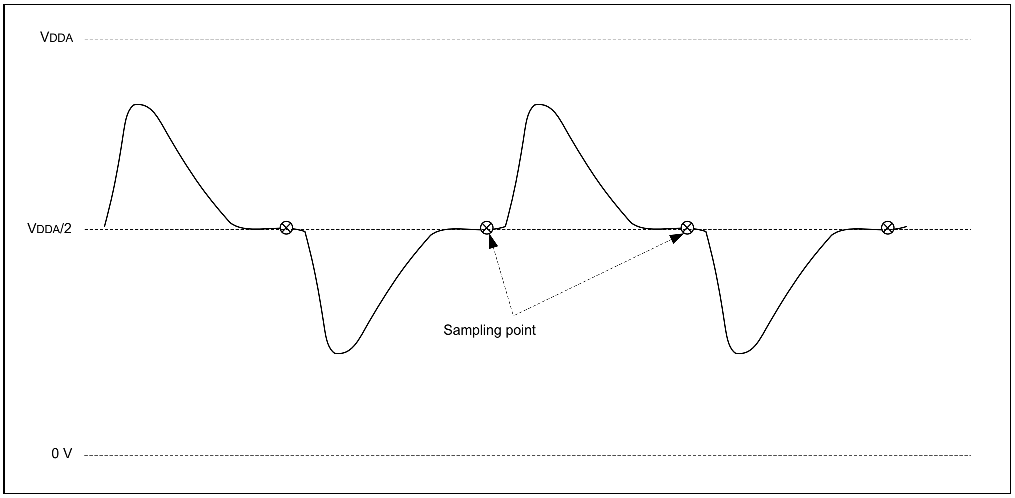


Figure 6-5 shows a bad-signal matching example illustrating signals clipping and non-centered signals at VDDA/2 when sampling. Figure 6-6 and Figure 6-7 provide a good-signal matching parameterization. The over-swing and under-swing depend on Tx to ground capacitance (C_{TxG}). High C_{TxG} (500 pF-1000 pF) will lead to low-pass behavior at the Rx input and results to over-swing signal. The low pass is formed by the Tx output impedance (R_T = 800Ω) and the C_{TxG} capacitance. In contrast, low C_{TxG} (< 50 pF) results in a high pass behavior and an under-swing signal. The high pass is formed by the Rx input impedance (R_{Buf} = 10 MΩ) and the C_{RxTx} capacitance.

FIGURE 6-5: BAD-SIGNAL MATCHING

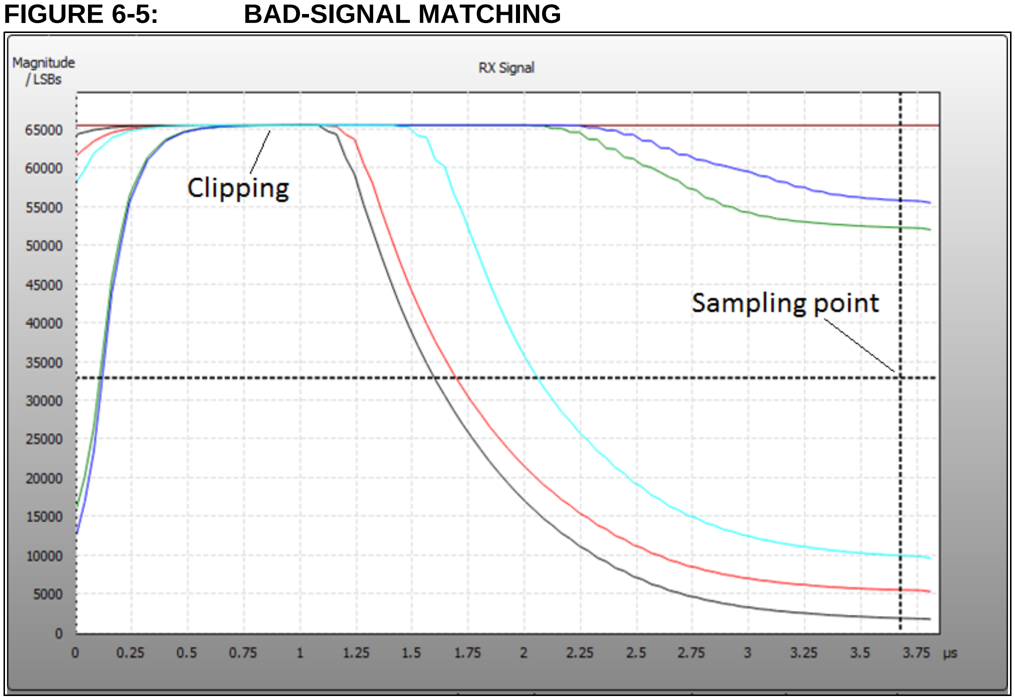


FIGURE 6-6: GOOD-SIGNAL MATCHING (OVER-SWING)

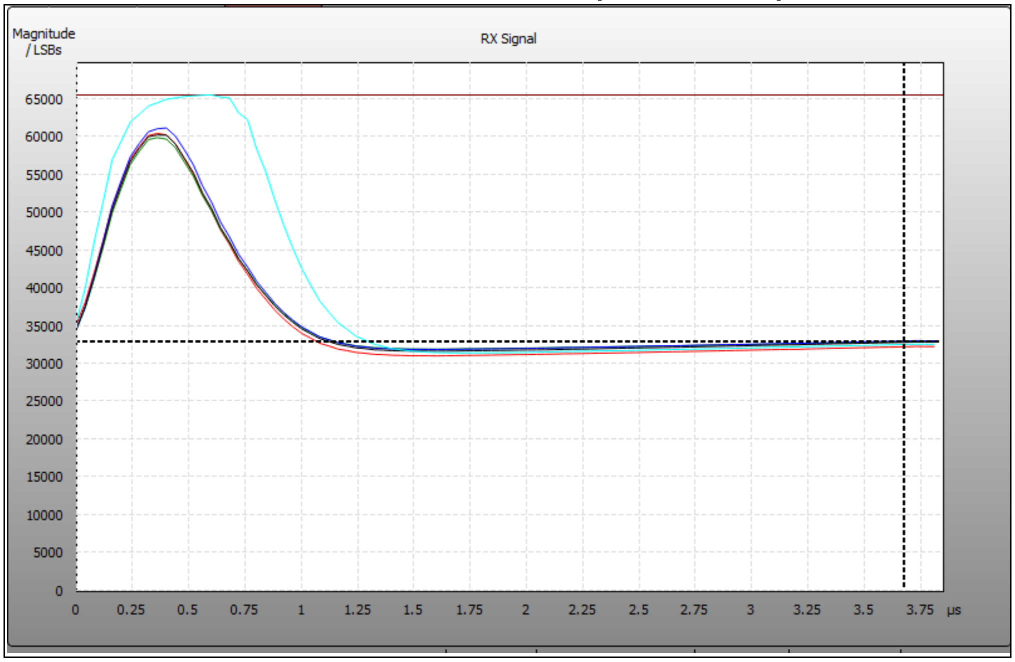
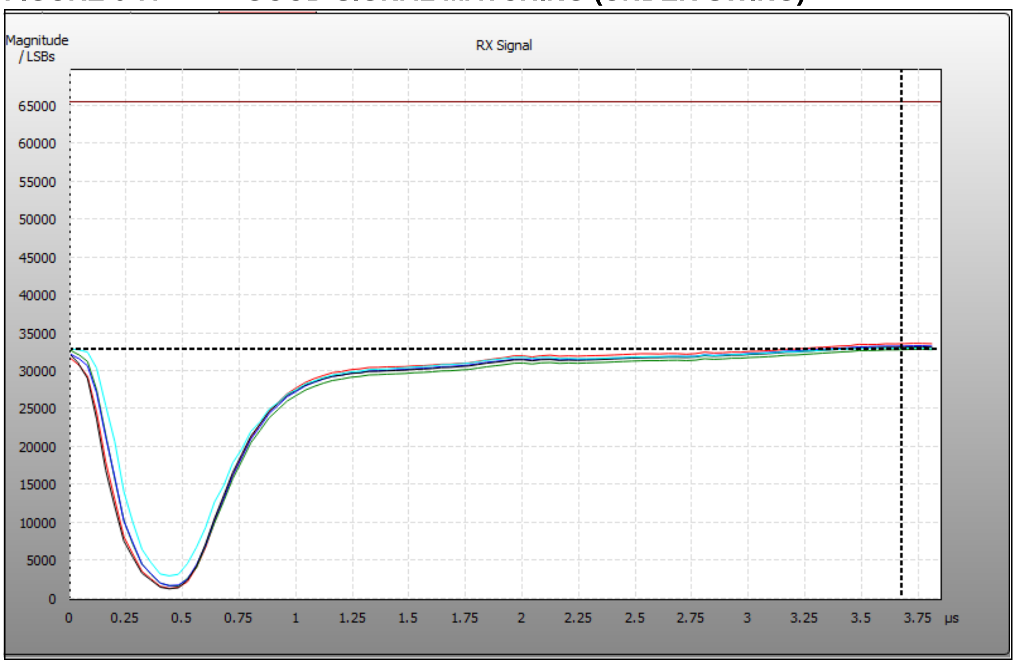


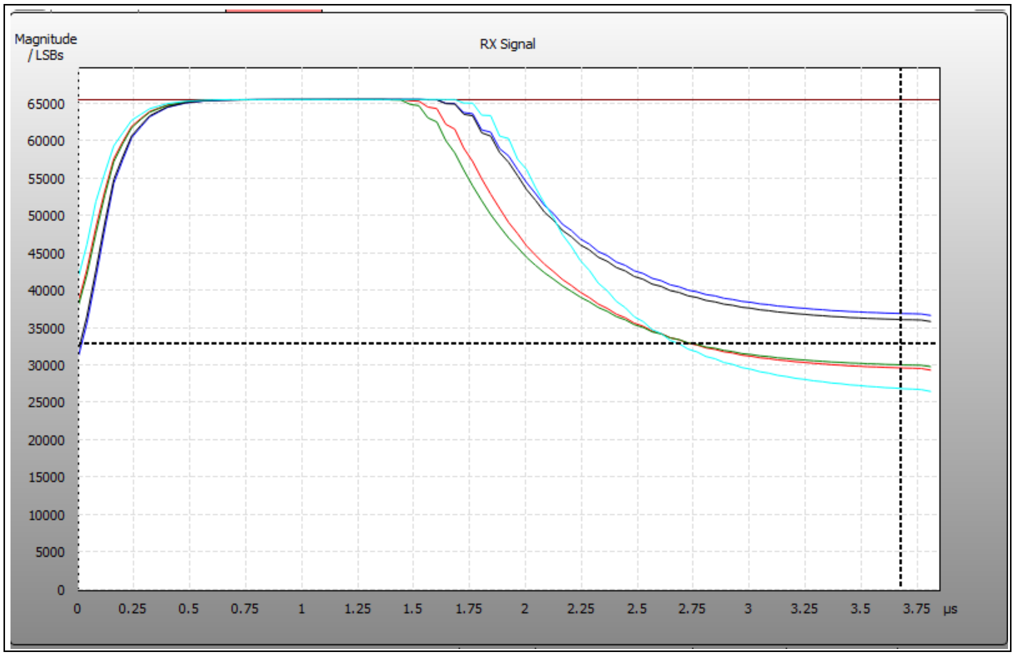
FIGURE 6-7: GOOD-SIGNAL MATCHING (UNDER-SWING)



Due to MGC3X30 AFE performance (fast operational amplifiers recovery time), some conditions can be tolerated as shown in Figure 6-8:

- Short clipping for less than 1 µs
- Small deviation from the $V_{DD}/2$ in the range of ±20%

FIGURE 6-8: SIGNAL MATCHING TOLERANCE



An electrode re-design may be required when, by varying the signal matching parameter, it is not possible to obtain a settled matching signal at about VDD/2 at the sampling point (e.g., when it is clipped and/or is ringing).

The Signal Matching adjustment is an 8-bit field (RxDIFF <7:0>) allowing a smooth step tuning. The Signal Matching procedure is done automatically through the Aurea Control Software. For more details, please refer to "*Aurea Graphical User Interface User's Guide*" (DS40001681).

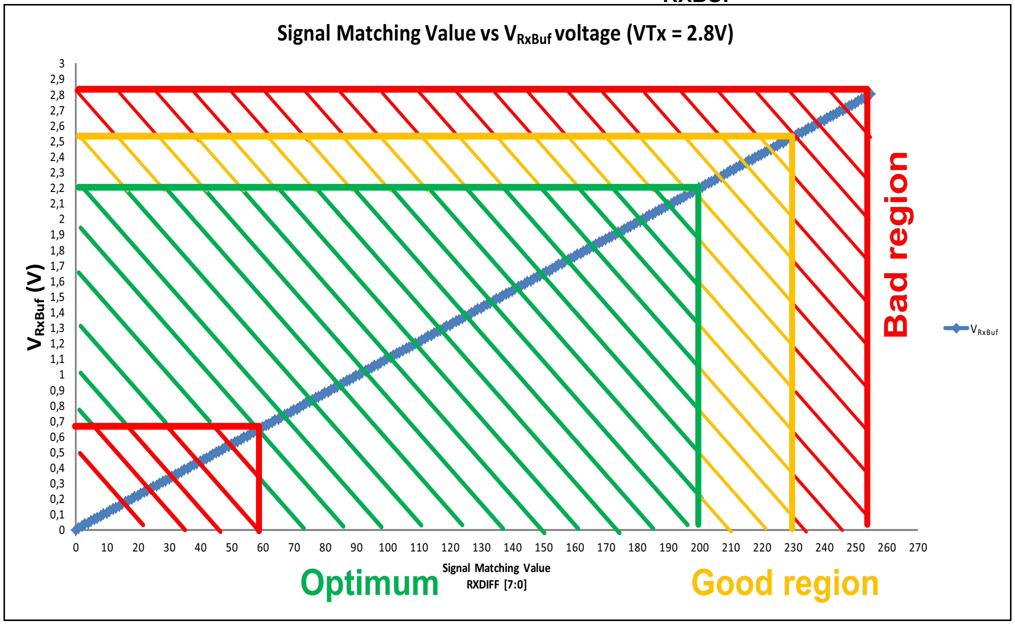
The V_{RxBuf} cannot be measured directly on the MGC3X30 Rx 4..0 pins, since the applied load from a voltage probe would be too high. Assuming a matched signal at the sampling point, V_{RxBuf} can be calculated according to the following formula:

EQUATION 6-1:

$$V_{RxBuf} = \frac{RXDIFF[7:0]}{255} \times V_{Tx}$$

Figure 6-9 shows the Rx signal matching value versus V_{RxBuf} voltage for a Tx amplitude equal to 2.8V. This figure also shows the recommended range for Rx buffer input, with RxDIFF less than 200.

FIGURE 6-9: SIGNAL-MATCHING VALUE vs. V_{RXBUF} VOLTAGE



The R_{xBuf} amplitude depends on the electrodes system capacitances and also on the Rx input capacitance. These different capacitances form a capacitance voltage divider at the Rx buffer input, as illustrated in Figure 4-5.

6.3 COLIBRI SUITE PARAMETERIZATION

The Colibri Suite parameterization comprises the setting of its core features: Position Tracking, Approach Detection and Gesture Recognition features (see Figure 6-1). The application decides which feature to be used and, thus, to be parameterized. Colibri Suite features are inclusive and the user can choose one or any combination of these features.

Each feature parameterization is described separately in the following sections. The Colibri Suite parameterization is fully supported by the Aurea Control Software and the user has no access to the GestIC Library internal parameters.

For more details, please refer to "*Aurea Graphical User Interface User's Guide*" (DS40001681).

6.4 POSITION TRACKING COLIBRI PARAMETERIZATION

The Position Tracking feature has to be adapted to the electrode dimensions and its characteristics. The Colibri Suite provides the parameters to be set according to the application design. These parameters are intended to adjust the sensitive area size and to equalize electrodes signals. These parameters are listed in Table 6-2:

TABLE 6-2: POSITION TRACKING PARAMETERS

Parameter Name	Description	Action
UN-EQUALIZED SENSING SPACE **ELECTRODE_XDISTANCE** [25,26,..,140]mm, default 95(5") **ELECTRODE_YDISTANCE** [25,26,..,140]mm, default 60(5")	Determines the system geometric parameters ELECTRODE_XDISTANCE and ELECTRODE_YDISTANCE.	By user
ELECTRODE WEIGHTING	Determines the system electrodes signal weighting. Five brick measurements are needed.	By user
E-FIELD LINEARIZATION	Determines the system electrodes linearization over distance. Four brick measurements are needed.	By user
SENSING SPACE PT_WESTPOS_MAX [-100,-99,..0,..,99,100], default -100 PT_EASTPOS_MAX [-100,-99,..0,..,99,100], default 100 PT_SOUTHPOS_MAX, [-100,-99,..0,..,99,100], default -100 PT_NORTHPOS_MAX [-100,-99,..0,..,99,100], default 100	Determines the application sensing space and defines the accessible x-y positions range.	By user
Z-POSITION ADJUSTMENT: PT_ZPOS_TOUCH [-128,-127,..,128]mm, default -10 PT_ZPOS_MAX [1,2,..,256]mm, default 58	Adjustment of the Z-position for typical interacting hand posture and definition of Z detection range (Z-position touch and maximum).	By user

6.4.1 Un-Equalized Sensing Space

The Sensor Dimension parameters depicted in Figure 6-10 and Figure 6-11 determine the physical dimensions of the electrodes and are measured at the inner edges of the frame.

FIGURE 6-10: UN-EQUALIZED SENSING SPACE OF STANDARD FRAME SHAPE

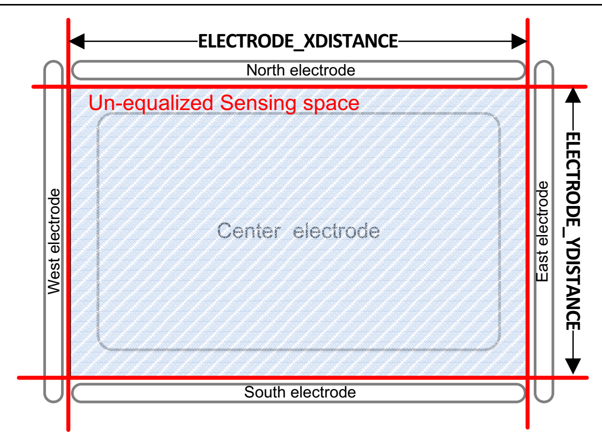
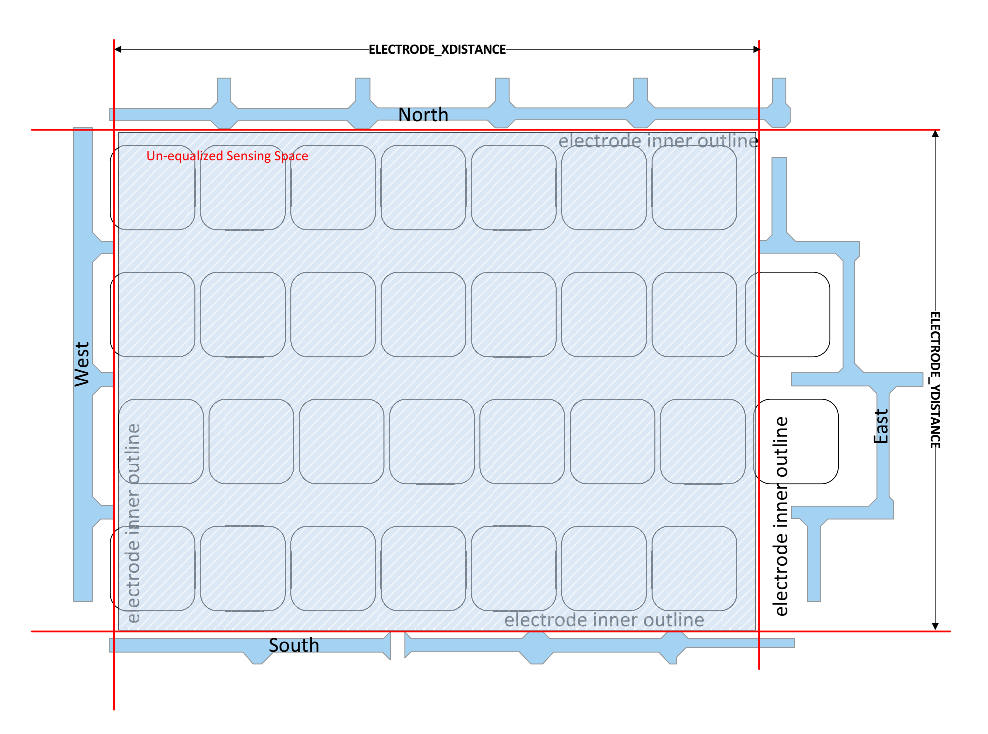


FIGURE 6-11: UN-EQUALIZED SENSING SPACE OF A KEYBOARD DESIGN



This first step determines the two system-dependent geometric parameters `ELECTRODE_XDISTANCE` and `ELECTRODE_YDISTANCE` (use the inner edge of the frame electrodes to identify the dimensions).

6.4.2 Electrode Weighting (Horizontal Brick Measurement)

This step is intended to equalize the electrode signal strength. This is accomplished by five brick measurements. These measurements are conducted at a constant Z-level (z-level = 30 mm).

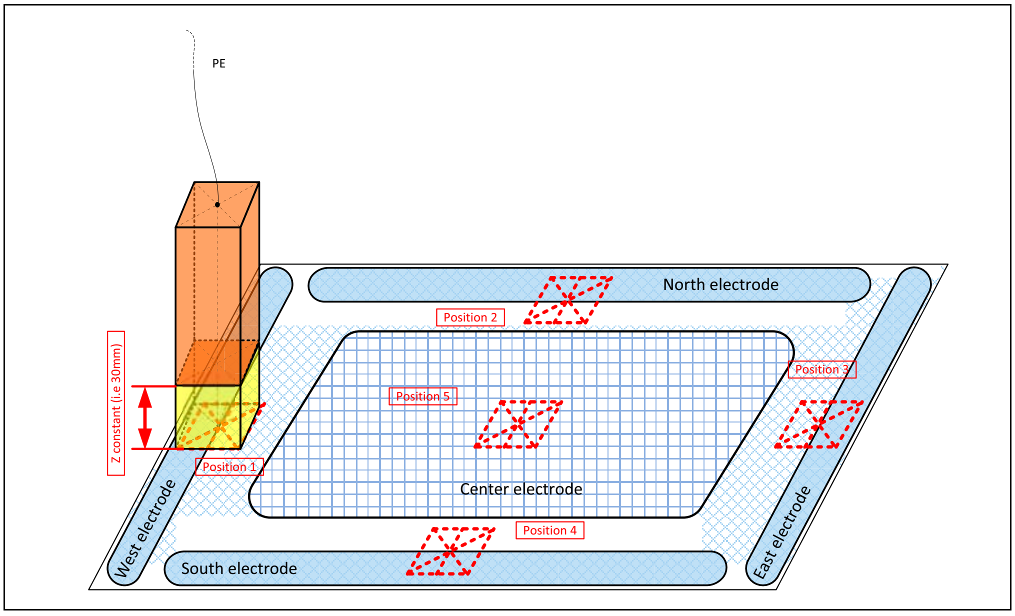
This step is made within the Aurea Control Software, which will record all electrodes signal deviation means (SDM) for all five measurement positions, and calculates the electrodes weighting parameters.

The five positions for the brick measurements are shown in Figure 6-12.

6.4.2.1 MEASUREMENT SETTINGS

- Use standard hand or finger brick for the measurements
- Use Styrofoam spacer to ensure constant z-level for all measurements
- Avoid even light pressure on the surface of the device

FIGURE 6-12: ELECTRODE WEIGHTING BRICK POSITIONS



6.4.3 E-Field Linearization (Vertical Brick Measurement)

This step is intended to measure the E-field nonlinearity. This is done by four different brick measurements at the center position (see Figure 6-13). These measurements are conducted at four different heights (mandatory Z-level = 10 mm, 30 mm, 50 mm, 80 mm). These measurements are necessary to ensure a linear 3D hand positioning.

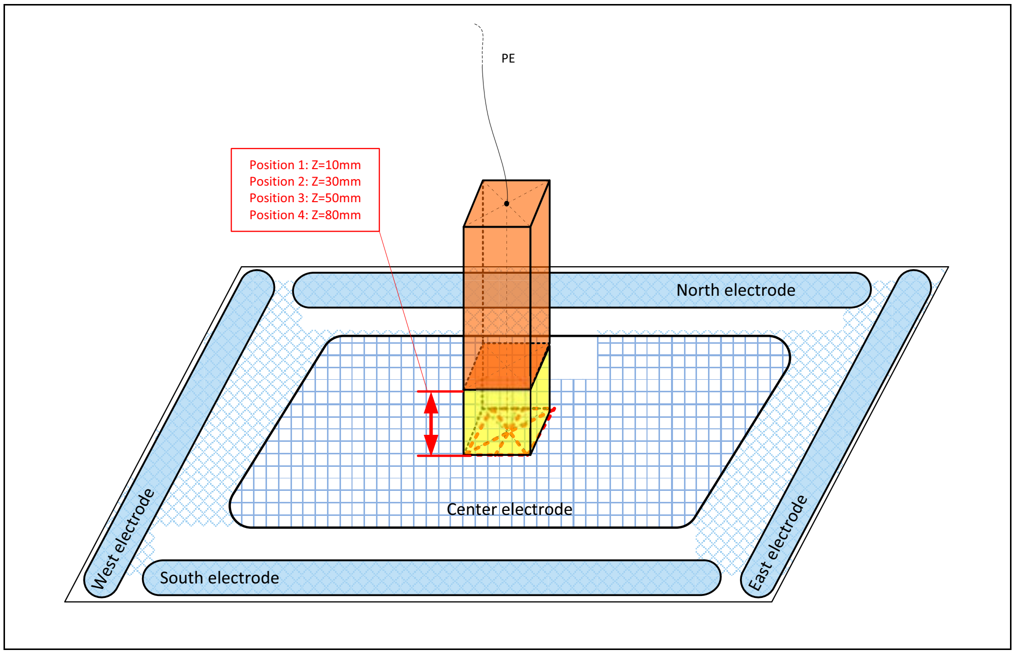
This step is made within the Aurea Control Software, which will record all electrodes signal deviation mean (SDM) values for all four measurement positions, and calculates the electrodes linearization parameters.

The four positions for the brick measurements are shown in Figure 6-13.

6.4.3.1 MEASUREMENT SETTINGS

- Use standard hand or finger brick for the measurements
- Use Styrofoam spacer to ensure defined z-level for all measurements (10 mm, 30 mm, 50 mm, 80 mm)
- Avoid even light pressure on the surface of the device

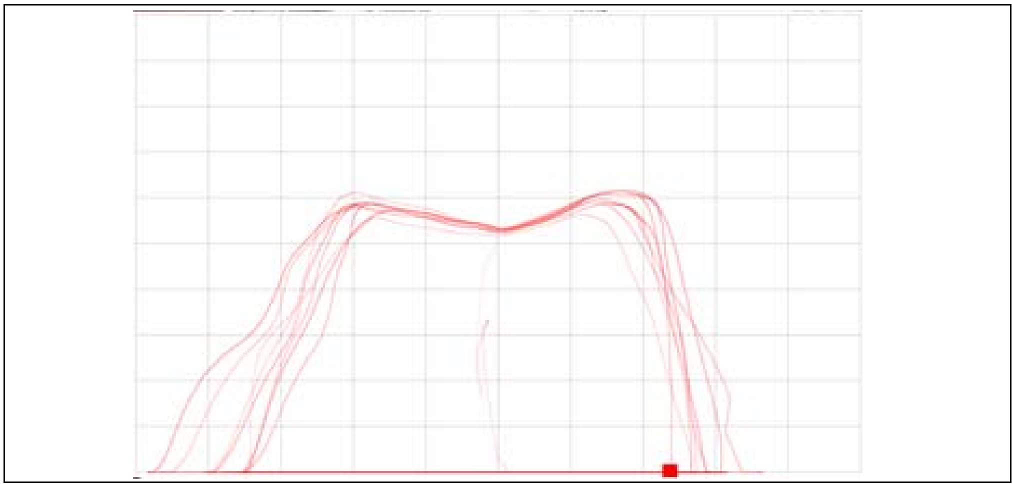
FIGURE 6-13: ELECTRODE LINEARIZATION BRICK POSITION



6.4.4 Sensing Space

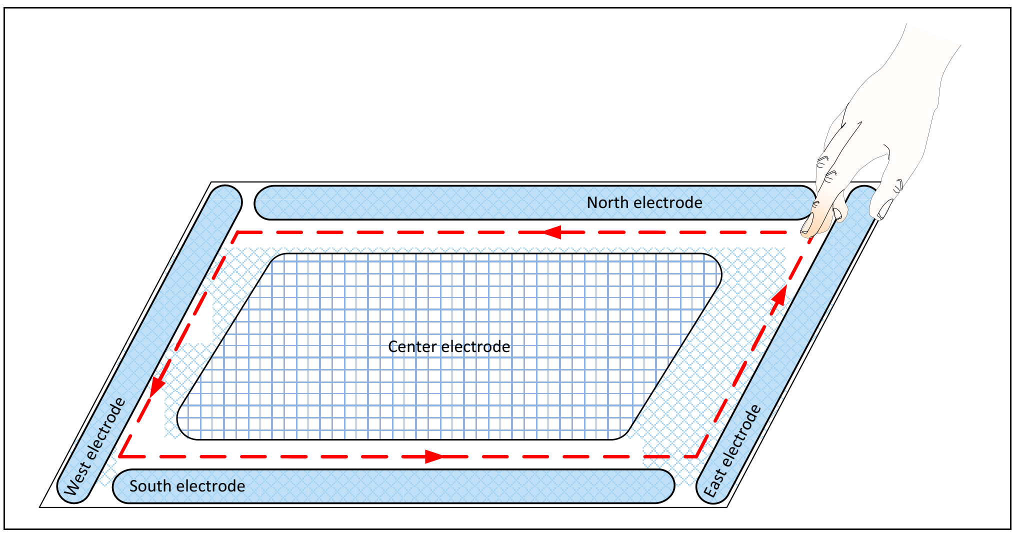
This step is intended to define the application sensing space. The operation supports access only to the x-y position ranges. A typical non-calibrated positioning range after the previous steps is depicted in Figure 6-14.

FIGURE 6-14: LIMITED X-Y POSITIONING RANGE



This step is assured by simple hand movement with the typical hand posture for your application (e.g., straight finger, vertical to the GestIC electrodes; hand in 45° angle) along the borderline of the system (~10 times, directly on the surface of the system), as illustrated in Figure 6-15.

FIGURE 6-15: SENSING SPACE HAND MOVEMENT



The result will be a deformed borderline as illustrated in Figure 6-16. Use the parameters PT_WESTPOS_MAX, PT_EASTPOS_MAX, PT_SOUTHPOS_MAX and PT_NORTH-POS_ MAX to decrease the borderline dimension until the rectangular shape fits into the deformed borderline (Figure 6-17).

FIGURE 6-16: DEFORMED BORDERLINE

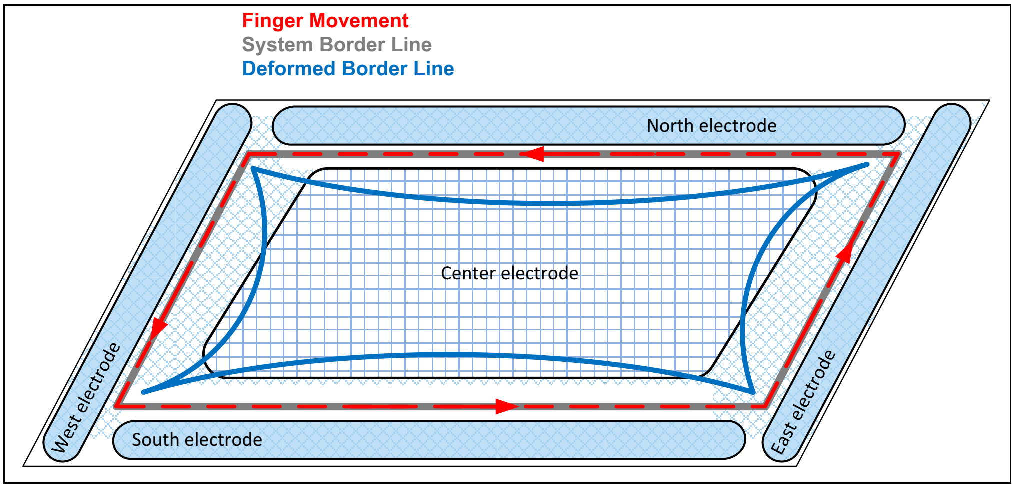
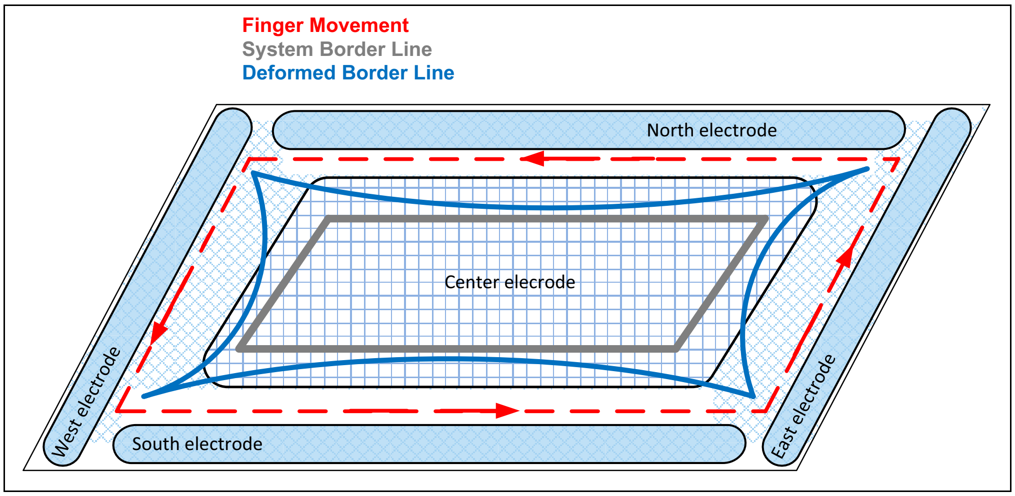


FIGURE 6-17: REDUCED MAXIMUM DIMENSIONS



Repeat this step until it is possible to access the whole x-y-range and also check different z-levels.

6.4.5 Z-Position Adjustment

The Z-position adjustment is required to adapt the system to the typical interacting hand posture (e.g., flat hand or pointing finger). It is also necessary to readjust the system entry height.

1. Z-position touch adjustment:
   a) Increase or decrease the parameter `PT_ZPOS_TOUCH` to adjust the Z-position estimation to the typical interacting hand posture.
   b) The Z-position should be 0 mm when the hand is touching the system surface in the desired hand posture.
2. Z-position maximum adjustment:
   a) Perform a slow approach from the top of the device.
   b) Reduce the parameter `PT_ZPOS_MAX` until this does not occur anymore.

This step is made within the Aurea Control Software. The 3D position should be tracked and the user has to adjust the Z-position accordingly.

6.5 APPROACH DETECTION COLIBRI PARAMETERIZATION

The Approach Detection feature has to be adjusted to select which electrodes will be used to wake-up the system from Self Wake-up mode, and to set different feature timings.

Five parameters are required for this feature. These parameters are listed in Table 6-3:

TABLE 6-3: APPROACH DETECTION PARAMETERS

Parameter Name	Description	Action
FEATURE ACTIVATION, default enabled	Defines the Approach Detection status after start-up	By user
SELF WAKE-UP ELECTRODES: APP_ACTIVATE_SOUTH [0,1], default 0 APP_ACTIVATE_WEST [0,1], default 0 APP_ACTIVATE_NORTH [0,1], default 0 APP_ACTIVATE_EAST [0,1], default 0 APP_ACTIVATE_CENTER [0,1], default 1	Defines which Rx channels are active during Approach Scan phase.	By user
WAKE-UP SENSITIVITY APP_ SENSITIVITY [1,2,..,100], default 76	Defines the electrode threshold to resume the system from Self Wake-up to operation mode.	By user
APPROACH SCAN INTERVAL APP_APPROACH_SCAN_INTERVAL [5,6,..,1024]ms, default 20 ms	Defines the time interval between two Approach Scans.	By user
IDLE TIME-OUT APP_IDLE_TIMEOUT [5,6,..,1024]s, default 5s	Defines the time-out when no hand is detected before going from operation mode to Self Wake-up mode.	By user

This step is made within the Aurea Control software.

6.5.1 Feature Activation

The Approach Detection can be enabled or disabled after start-up. When disabled, MGC3X30 can be woken-up only by IRQ lines.

6.5.2 Self Wake-Up Electrodes

During Self Wake-up mode, there is at least one electrode active for Approach Detection. The system will wake-up autonomously if an approach is detected.

One to five electrodes can be activated. Enabling multiple electrodes will increase the current consumption in Self Wake-up mode, but will allow faster wake-up for directions defined by the enabled electrodes.

6.5.3 Wake-up Sensitivity

The threshold of the signal deviation to wake-up the system has to be adjusted to the application needs. Low settings will lead to a low sensitivity; high settings will increase the possibility of false wake-ups. This threshold can be adjusted in the range of [1,2,..,100], default – 76.

6.5.4 Approach Scan Interval

The reaction time of Self Wake-up defines the time interval between two consecutive Approach Scans. This time can be adjusted in the range of [5,6,..,1024] ms, default – 20 ms. Using fast Approach Scans timing will increase the current consumption in Self Wake-up mode.

6.5.5 Idle Time-out

The system idle time is the time needed until the system enters Self Wake-up mode when no user is detected. This time can be adjusted in the range of [5,6,..,1024]s, default – 5s.

6.6 GESTURE RECOGNITION COLIBRI PARAMETERIZATION

This part will be supported in future versions.

NOTES:

Chapter 7. Performance Evaluation

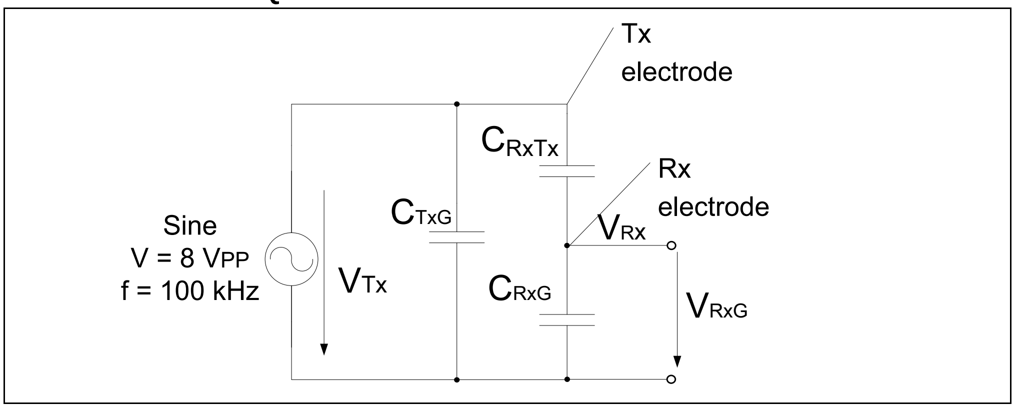
7.1 CAPACITANCE MEASUREMENT

Knowing the capacitances of the GestIC electrodes is important to tune the sensitivity. The measurement of the capacitances with standard capacitance measurement devices is difficult, because the Tx electrode shields the Rx electrode from ground, and the Rx ground capacitance typically is very low. The following procedure describes how to reliably measure the capacitances.

7.1.1 Equivalent Circuits for Capacitance Measurements

Figure 7-1 shows the equivalent circuit of one GestIC electrode.

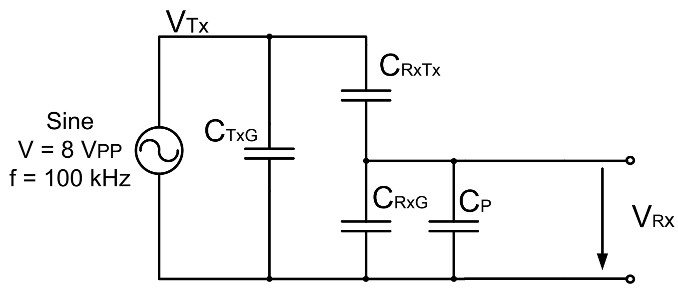
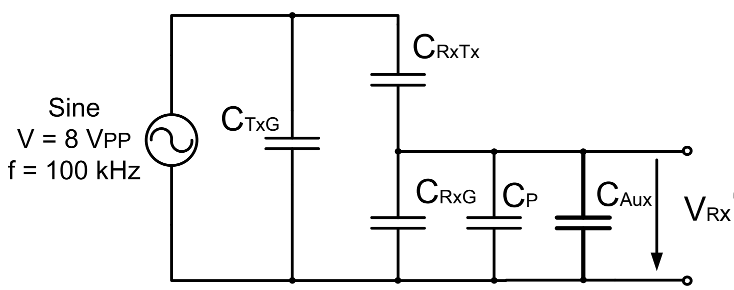
FIGURE 7-1: EQUIVALENT CIRCUIT OF GestIC ELECTRODE



The Tx to ground capacitance, C_{TxG}, can be measured with a standard LCR meter. It is recommended to disconnect C_{RxTx} and C_{RxG} capacitances for better accuracy. The capacitances of the C_{RxTx} and C_{RxG} can be determined via two voltage measurements with an oscilloscope:

1. The first measurement is done to find out the ratio of the capacitive voltage divider of C_{RxTx} and C_{RxG}. Figure 7-2 shows the equivalent circuit for measuring the voltage divider ratio. An oscilloscope with an active probe (low C_p < 1 pF) is used to measure the voltage.
2. The second measurement uses an auxiliary capacitor with a known value to find out the values of each capacitance. Figure 7-3 shows the equivalent circuit with C_{Aux}.

TABLE 7-1: EQUIVALENT CIRCUITS AND THE CORRESPONDING FORMULAS

FIGURE 7-2: EQUIVALENT CIRCUIT FOR MEASURING THE CAPACITIVE VOLTAGE DIVIDER  	(I) $\frac{V_{Rx}}{V_{Tx}} = \frac{C_{RxTx}}{C_{RxTx} + C_{RxG} + C_P}$
FIGURE 7-3: DETERMINATION OF THE CAPACITANCE VALUES VIA INSERTING AN AUXILIARY CAPACITOR  	(II) $\frac{V_{Rx}}{V_{Tx}} = \frac{C_{RxTx}}{C_{RxTx} + C_{RxG} + C_P + C_{Aux}}$

The abbreviations in the equivalent circuits are as follows:

V_{Tx}: Driven Input Voltage for Tx Signal

V_{Rx}: Voltage over C_{RxG}

V'_{Rx}: Voltage over C_{RxG} after placing C_{Aux}

C_{TxG}: Capacitance between Tx and GND

C_{RxTx}: Capacitance between Rx and Tx

C_{RxG}: Capacitance between Rx and GND

C_{Aux}: Auxiliary Capacitance for establishing the voltage divider

C_P: Input capacitance of probe

Rearrangement and substitution leads to the following formulas:

EQUATION 7-1:

$$C_{RxG} = C_{Aux} \bullet \frac{V'_{Rx} \bullet (V_{Tx} - V_{Rx})}{V_{Tx} \bullet (V_{Rx} - V'_{Rx})} - C_P$$

$$C_{RxTx} = (C_{RxG} + C_P) \bullet \frac{V_{Rx}}{V_{Tx} - V_{Rx}}$$

7.1.2 Choosing the Appropriate Auxiliary Capacitor

To reach a good measurement result, the auxiliary capacitor should reduce the voltage V_{Rx} to about half of its original value.

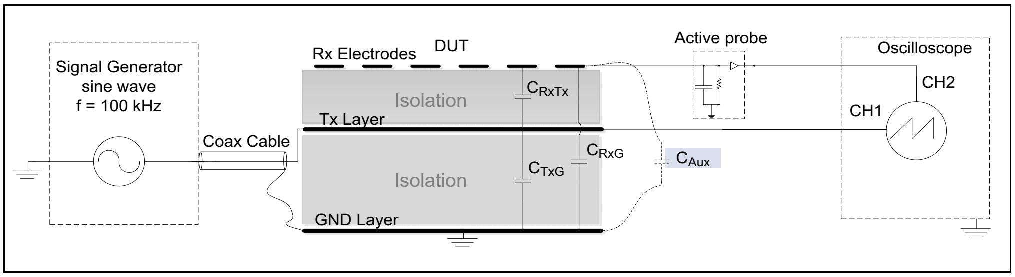
Proceed as follows:

1. Start by choosing an auxiliary capacitor in the range between 10 pF – 40 pF; measure the real capacitance value of the auxiliary capacitor with an LCR meter before soldering it to the circuitry
2. Measure V'_{Rx}
3. The auxiliary capacitor is good if $V'_{Rx} = V_{Rx}/2$; otherwise, choose a lower/higher value and repeat steps 2 – 3.

7.1.3 Measurement Setup

Figure 7-4 shows the general measurement setup for the capacitance measurement.

FIGURE 7-4: CONNECTION AND DEVICE OVERVIEW FOR CAPACITANCE MEASUREMENT



Note 1:	Always keep the feeding lines for C_{Aux} as short as possible (for best results, solder an SMD capacitor).
2:	MGC3X30 must be disconnected from the electrodes during measurement.

TABLE 7-2: OVERVIEW OF EQUIPMENT

Type of Equipment	Configuration Setup	Usage
Signal Generator	Waveform: Sine Frequency: 100 kHz Voltage: the higher the voltage, the more accurate the measurement result (typ. 8 VPP). Take care about the maximum voltage of the active probe!	Provides V_{Tx}
Coaxial Cable for Signal in	—	Connects DUT with Signal Generator
Oscilloscope	12-bit resolution recommended	—
Active Probe	Input capacitance ≤ 1 pF Input resistance ≥ 1 MΩ	Measures V'_{Rx} and V_{Rx} Measures V_{Tx} on the DUT's input
Auxiliary Capacitor	Capacitance needs to be known	Allocates and associates the voltage levels of the respective capacitances
LCR Meter	f = 100 kHz	C_{TxG} measurement Determines the exact C_{Aux} capacitor value before usage. Do **NOT** use LCR meter for measuring C_{RxG} or C_{TxG} (only for discrete C_{Aux} capacitor)!

7.1.4 The Measurement Process Step-by-Step

1. Measure C_{TxG} with LCR meter.
2. Connect all devices shown in Figure 7-4 **without** C_{Aux}.
3. Allocate the active probe's input capacitance, C_P, value and note it.
4. Measure V_{Rx} with the active probe.
5. Choose a start value for C_{test} in the range between 15 pF – 40 pF and insert C_{Aux}.
6. Measure V'_{Rx} with the active probe.
7. If $V'_{Rx} = V_{Rx}/2$, proceed with step 8; otherwise, increase/decrease C_{Aux} and repeat step 6 and step 7.
8. Measure V_{Tx} (passive probe).
9. Calculate C_{RxG}:

$$C_{RxG} = C_{Aux} \bullet \frac{V'_{Rx} \bullet (V_{Tx} - V_{Rx})}{V_{Tx} \bullet (V_{Rx} - V'_{Rx})} - C_P$$

10. Calculate C_{RxTx}:

$$C_{RxTx} = (C_{RxG} + C_P) \bullet \frac{V_{Rx}}{V_{Tx} - V_{Rx}}$$

11. Repeat steps 4-10 for every GestIC channel.

7.2 SENSITIVITY PROFILE MEASUREMENT

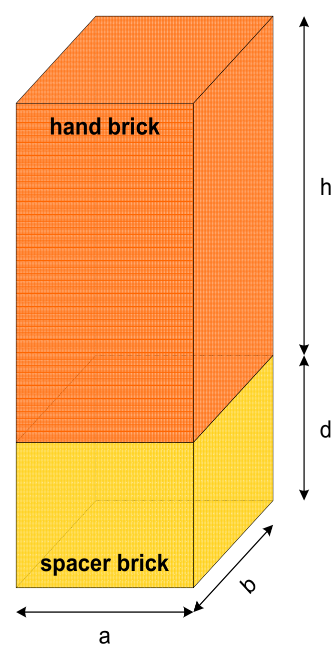
The GestIC sensitivity is defined as the measured signal deviation with and without the hand. To standardize the measuring procedure, an artificial hand is defined that can be moved to exact positions within the GestIC sensing area. Moving the artificial hand in a certain direction and measuring the signal deviation per position gives a so-called sensitivity profile.

7.2.1 Artificial Hand

To check the sensitivity profile of the GestIC system, a measurement setup is defined using an artificial hand. This setup is detailed in the following sections.

To simulate Human Hand effect, a reference brick can be used. This artificial hand brick is made of a Styrofoam block covered with light copper and has a fixed size, as illustrated in Figure 7-5. Spacer bricks (Styrofoam block without copper layer) are used to position the hand brick in different heights to the electrode. Because of a $\varepsilon_r \approx 1$ of Styrofoam, the spacer brick does not influence the measurement results.

FIGURE 7-5: ARTIFICIAL HAND BRICK STRUCTURE



Hand Brick: Styrofoam block with copper foil (35 µm) on each side (a·b·h)

Spacer Brick: Styrofoam block (a·b·d)

Length: a = 40 mm

Width: b = 40 mm

Height: h = 70 mm

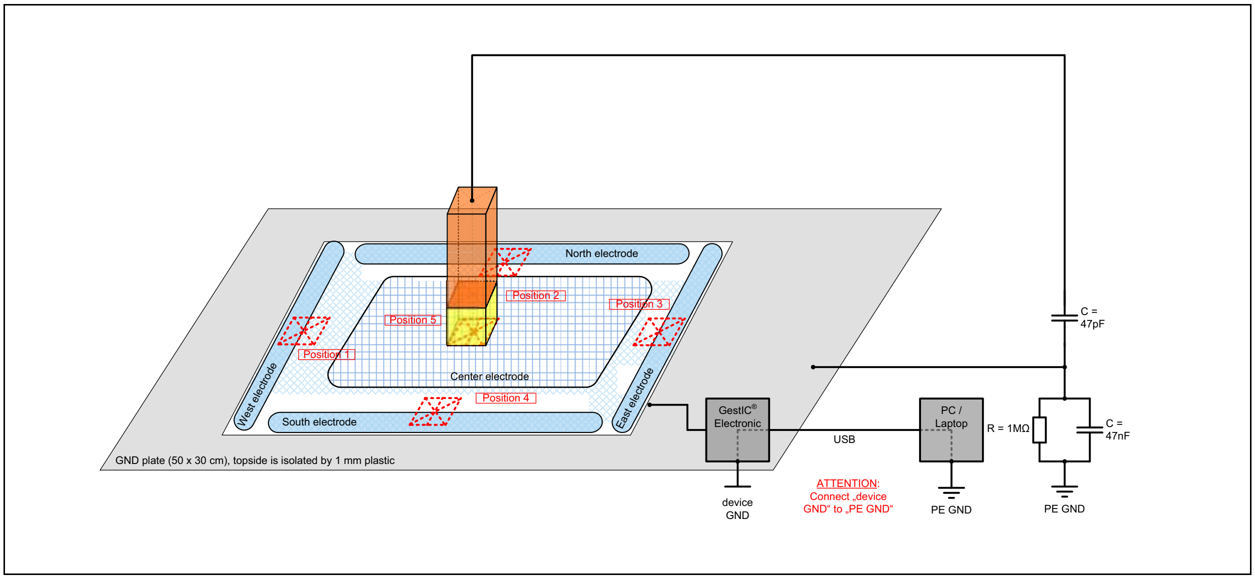
Distance: d = 10, 20, 30, 50, 80 and 120 mm

The hand brick is placed centric on the spacer brick, so only one hand brick is necessary for various distances. Typically, a sensitivity profile is measured with a distance of 30 mm above the electrode.

7.2.2 Standard Test Setup

The standard test setup is used for MGC3X30 controller sensitivity. Measurements are illustrated in Figure 7-6.

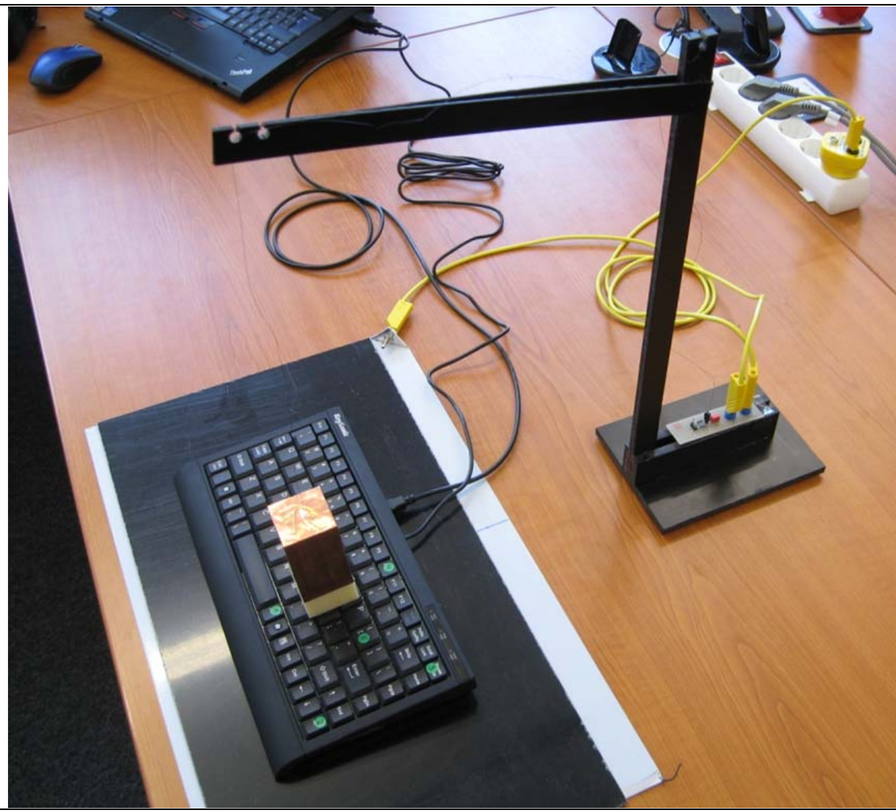
FIGURE 7-6: STANDARD MEASUREMENT SETUP



Place the ***Device Under Test*** (DUT) in the middle of a GND plate to get constant ground capacitance conditions. The GND plate is made of 50 x 30 x 1,5 mm Aluminum and a 1 mm plastic plate (e.g., PC-ABS, Plexiglas, etc.) over the metal plate to avoid accidental short circuit. The connection from the GND plate to the Protected Earth (PE) GND is made via 1 MΩ‖47 nF. Use a modified ESD plug (refer to **Appendix**). The capacitor is inserted to limit eventual occurring fault current and the resistor avoids static charge.

The feeding line is routed from the top of the brick via Ø 0.16 mm enameled wire and a coupling capacitor (47 pF), that represents the body-earth capacitance, to Protected Earth (PE) GND. Use Boom-Construction for routing the feeding line to the brick. The feeding line is sensitive and must not be touched during measurement and must not be routed close to GND or Protected Earth (PE) devices.

FIGURE 7-7: COMPLETE MEASUREMENT SETUP



> **Note:** The 1 mm plastic isolation on the GND plate was selected to show both the GND plate and the isolation (see Figure 7-7).

7.2.3 Positioning on Standard Electrode Structures

The sensitivity profile measurement principle is to move the hand brick in a certain direction (e.g., north to south or west to east).

Figure 7-8 and Figure 7-9 measure for each intermediate position the signal deviation through the Aurea Control Software. The sensitivity diagram can then be drawn as in the example of Figure 7-11.

7.2.3.1 POSITIONING RULES SUMMARY

- Use inner outline and place the brick in the middle
- Use at least three positions between the start and end positions
- Add a minimum of one position outside the sensing space
- Use equivalent distance between different positions

FIGURE 7-8: POSITIONING ON STANDARD ELECTRODE STRUCTURES NORTH-SOUTH

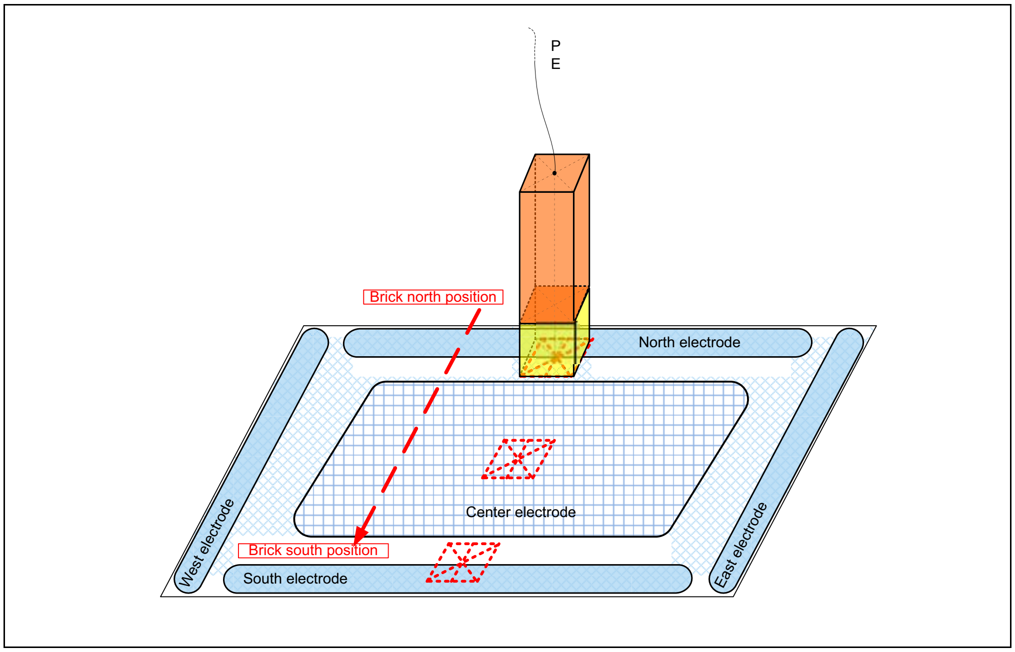
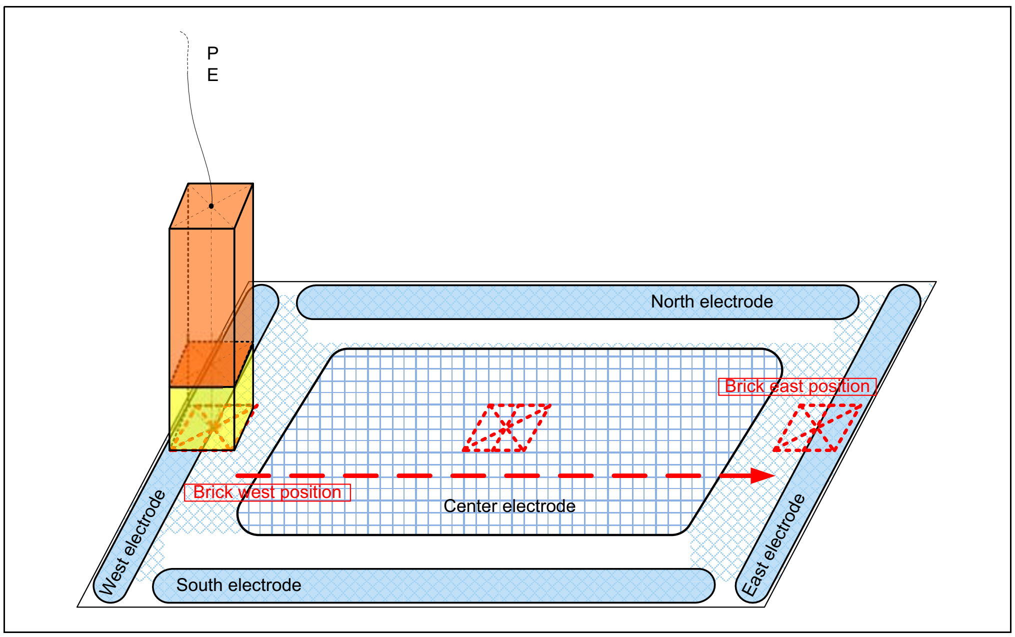


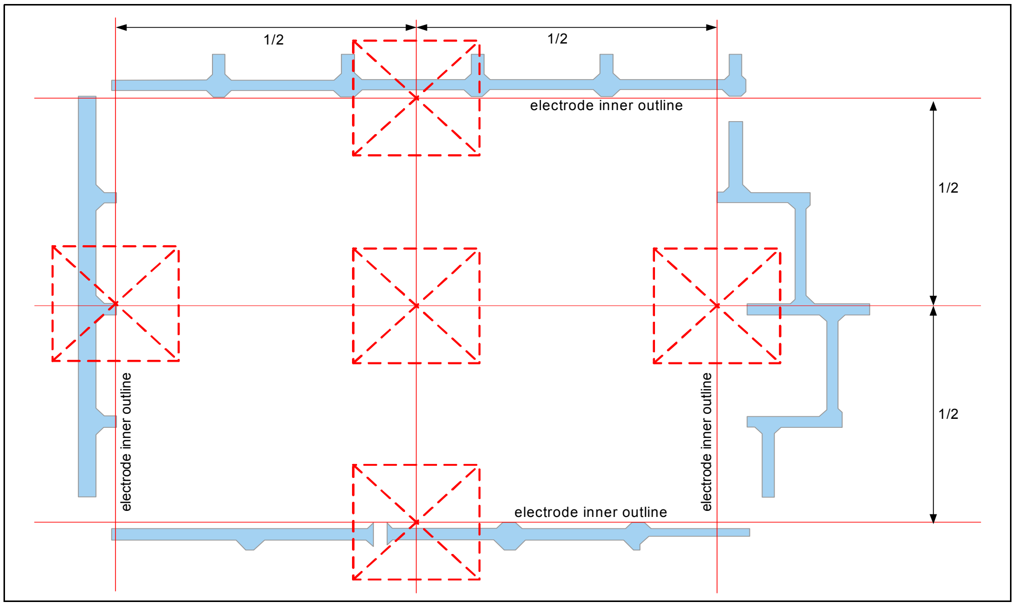
FIGURE 7-9: POSITIONING ON STANDARD ELECTRODE STRUCTURES WEST-EAST



7.2.4 Positioning on Complex Electrode Structures

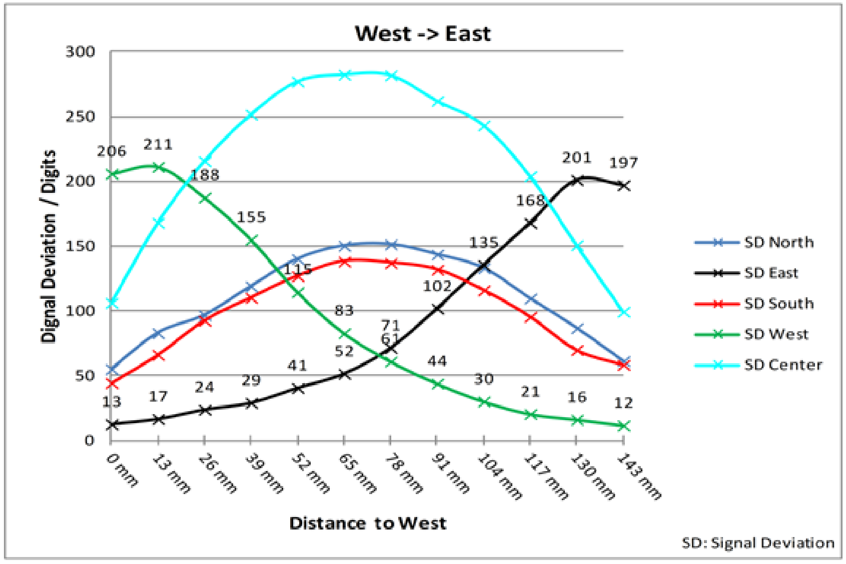
For complex electrode structures, take the inner outline of each electrode and place the brick in the middle (see Figure 7-10). Then, use the same measurement procedure defined previously to draw the sensitivity profile.

FIGURE 7-10: POSITIONING ON COMPLEX ELECTRODE STRUCTURES



7.2.5 Sensitivity Profile

FIGURE 7-11: STANDARD ELECTRODE SENSITIVITY PROFILE



For a good performance, the setup should fulfill the following requirements:

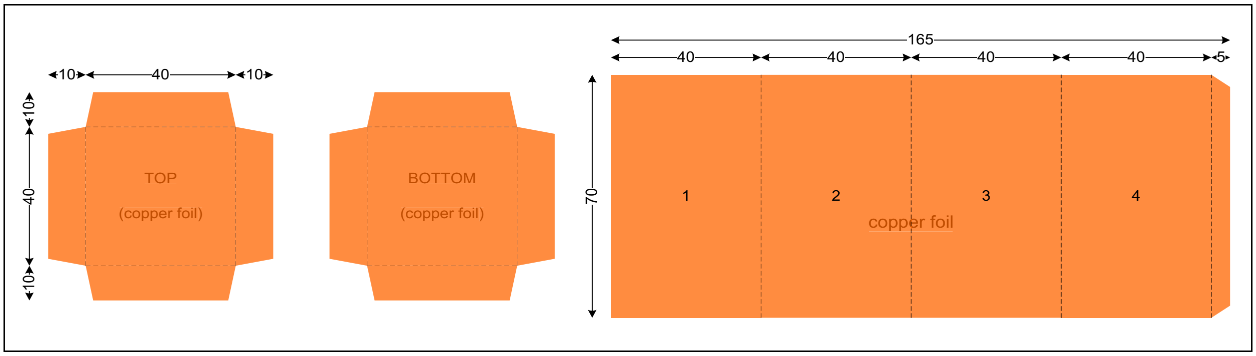
- The signal deviation with a hand 3 cm above the electrode must be ≥ 200 digits
- The signal deviation on the far electrode must be ≥ 25 digits (e.g., the north electrode is measured while the hand brick is above the south electrode)
- The signal deviation must change more than ten digits if the hand brick position varies 1 cm relative to the electrode. This must be valid for every position.
  - Example: Varying the hand position 1 cm to the north, the north electrode must measure at least ten digits higher signal deviation and the south electrode must measure at least ten digits less signal deviation.
- The curvature/bend must always be in the same direction. There must be no change from left to right curvature and vice versa.
- The curve should approximately follow a $1/r^2$ function
- The derivative of the signal deviation with respect to the position must be monotony-decreasing and must not be 0 at any position
- The curve must be smooth, without discontinuities

Appendix

A.1 HOW TO BUILD A HAND BRICK

Cut the copper foil (d = 35 µm) into the right shapes (see Figure A-1).

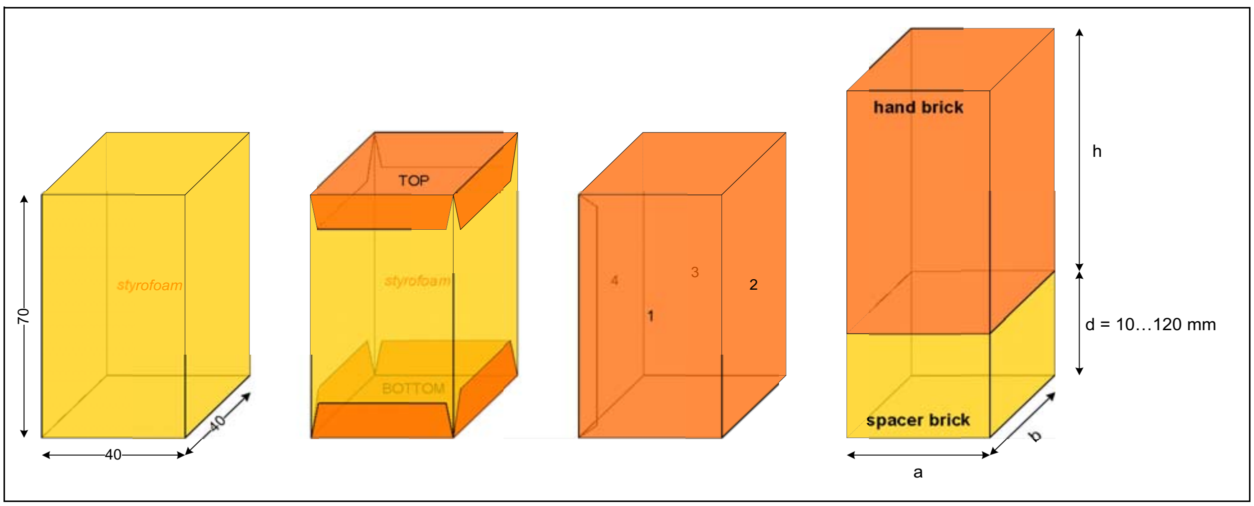
FIGURE A-1: HAND BRICK COPPER FOILS



Take the Styrofoam block (70x40x40 mm) and stick the copper foil (as shown in Figure A-2) on the Styrofoam block.

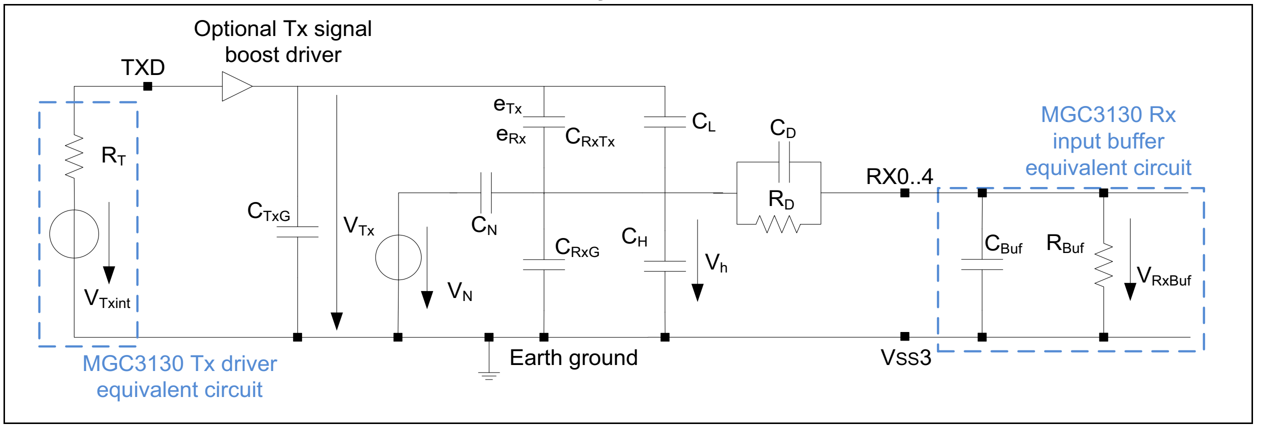
Make sure that the resistance between the top and bottom is below 1Ω.

FIGURE A-2: HAND BRICK BUILD-UP



A.2 EXTENDED ELECTRODE EQUIVALENT CIRCUIT WITH OPTIONAL BOOST AMPLIFIER (DEALING WITH HIGH-NOISE ENVIRONMENT)

FIGURE A-3: EXTENDED ELECTRODE EQUIVALENT CIRCUIT



Where:

V_{Txint}	Internal MGC3X30 Tx voltage
V_{Tx}	Tx electrode voltage
V_{RxBuf}	MGC3X30 Rx buffer input voltage
V_h	Auxiliary voltage to derive V_{RxBuf}
V_N	External noise voltage to be injected to the receiving electrode E_{RX}
e_{Tx}	Transmitting Tx electrode of the system
e_{Rx}	Receiving Rx electrode of the system
C_{TxG}	Capacitance from Tx electrode to ground
C_{RxTx}	Capacitance between Rx and Tx electrode
C_L	Rx feeding line capacitance to Tx
C_{RxG}	Capacitance from Rx electrode to ground
C_H	Capacitance between hand and Rx
C_D	Voltage divider capacitance
C_{Buf}	Input capacitance of MGC3X30 Rx input buffer
R_D	Voltage divider resistor for frequency compensation
R_{Buf}	Input resistor of MGC3X30 Rx input buffer
TxD	Pin 25 of MGC3X30
Rx0..4	Pins 4..8 of MGC3X30
Vss3	Pin 10 of MGC3X30

An external capacitance, C_D, and resistor R_D can be used to reduce the input voltage, V_{RxBuf}, to a defined level so that under high noise conditions the input buffer is not overloaded. The resistor R_D is used to realize a frequency compensated voltage divider.

The condition for this frequency divider (probe head circuit principle) is:

EQUATION A-1: FREQUENCY DIVIDER CONDITION

$$R_D \bullet C_D = R_{Buf} \bullet C_{Buf}$$

It is not desirable to reduce the Tx output voltage of the chip. Best signal-to-noise ratios are achieved with maximum Tx signal, as shown later. When required, an external Tx signal-boost amplifier can be considered.

A.2.1 System Parameters

A.2.1.1 RECEIVER INPUT SIGNAL

It is assumed that the buffer input resistance has a much lower effect than the buffer input capacitance in the relevant frequency range of 70-130 kHz, as shown in Equation A-2.

EQUATION A-2: RECEIVER VOLTAGE DIVIDER ASSUMPTION

$$R_{RxBuf} = R_D = \infty$$

EQUATION A-3: RECEIVER INPUT SIGNAL

$$V_{RxBuf} = a\left[\frac{V_{Tx}}{1 + \frac{C_N + C_{RxG} + a \bullet C_{Buf} + C_H}{C_{RxTx} + C_L}} + \frac{V_N}{1 + \frac{C_{RxTx} + C_L + C_{RxG} + a \bullet C_{Buf} + C_H}{C_N}}\right]$$

where $a = \frac{C_P}{C_{Buf} + C_P}$ is the attenuation factor of the introduced voltage divider. In case no voltage divider is used, a = 1 C_P is replaced by a short circuit.

A.2.2 Receiver Signal Sensitivity

The receiver signal sensitivity regarding the hand influence is defined as the signal delta with and without the hand capacitance at noise free conditions ($V_N = 0$).

EQUATION A-4:

$$\Delta S = V_{RxBuf}\big|_{C_H = 0} - V_{RxBuf}\big|_{C_H = C_{Hand}}$$

$$\Delta S = V_{Tx} \bullet a\left[\frac{C_{Hand}}{C_{RxTx} + C_L + 2(C_{RxG} + a \bullet C_{Buf}) + (C_N + C_{RxG} + a \bullet C_{Buf})^2/(C_{RxTx} + C_L)}\right]$$

where ΔS is approximately a linear function of the hand capacitance, C_{Hand}.

A.2.3 Signal Deviation

The signal deviation, S_D, to the user's hand in a GestIC system is the receiver signal sensitivity amplified by the receiver gain, g_{PGA}, and referenced to the analog voltage range of the chip of VDDA = 3.0V. When C_{Hand} is small compared to the Tx-Rx electrode capacitance:

EQUATION A-5: SIGNAL DEVIATION

$$S_D = a \bullet 10V_{Tx}\frac{2^{15}}{3V}\left[\frac{C_{Hand}}{C_{RxTx} + C_L + 2(C_N + C_{RxG} + a \bullet C_{Buf}) + (C_N + C_{RxG} + a \bullet C_{Buf})^2 \S (C_{RxTx} + C_L)}\right]$$

SD is given in LSbs (Lowest Significant bit) of a 16-bit integer value.

A.2.4 Signal-To-Noise Ratio

The receiver input signal-to-noise ratio, SNR, is defined as the ratio between the signal and the noise term of Equation A-3 and is:

EQUATION A-6: SIGNAL-TO-NOISE RATIO

$$SNR = \frac{V_{Tx}}{V_N} \bullet \frac{C_{RxTx} + C_L}{C_N}$$

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