Table of Contents

[1 Introduction 2](#_Toc54296129)

[2 Variables 2](#_Toc54296130)

[2.1 Measured 2](#_Toc54296131)

[2.2 Input 2](#_Toc54296132)

[2.3 Constant 2](#_Toc54296133)

[2.4 Controlled 3](#_Toc54296134)

[2.5 Internal 3](#_Toc54296135)

[2.6 Output 3](#_Toc54296136)

[3 Modes 4](#_Toc54296137)

[3.1 AOO 4](#_Toc54296138)

[3.1.1 Variables 4](#_Toc54296139)

[3.1.2 Requirements 4](#_Toc54296140)

[3.1.3 State Transitions 5](#_Toc54296141)

[3.1.4 State Transitions 5](#_Toc54296142)

[3.1.5 Design details 5](#_Toc54296143)

[3.1.6 Testing 5](#_Toc54296144)

[3.2 VOO 5](#_Toc54296145)

[3.2.1 Variables 5](#_Toc54296146)

[3.2.2 Requirements 5](#_Toc54296147)

[3.2.3 State Transitions 5](#_Toc54296148)

[3.2.4 Design details 6](#_Toc54296149)

[3.2.5 Testing 6](#_Toc54296150)

[3.3 AAI 6](#_Toc54296151)

[3.3.1 Variables 6](#_Toc54296152)

[3.3.2 Requirements 6](#_Toc54296153)

[3.3.3 State Transitions 6](#_Toc54296154)

[3.3.4 Design details 6](#_Toc54296155)

[3.3.5 Testing 6](#_Toc54296156)

[3.4 VVI 6](#_Toc54296157)

[3.4.1 Variables 6](#_Toc54296158)

[3.4.2 Initial Values 7](#_Toc54296159)

[3.4.3 Requirements 7](#_Toc54296160)

[3.4.4 State Transitions 8](#_Toc54296161)

[3.4.5 State details 9](#_Toc54296162)

[3.4.6 Testing 9](#_Toc54296163)

# Introduction

The following documentation gives a concise and general description tailored to the end-user, of Part 1 of the SFWRENG 3K04 Pacemaker Project. The aim of this project is to construct a working pacemaker that acts and reacts to its environment accordingly, as a normal pacemaker would. This documentation will solely focus on the State flow Implementation in MATLAB Simulink, which is used to simulate the 4 pacing/sensing modes (AOO, VOO, VVI, AAI) which are required for this early stage of the project. More pacing modes will be created in stage 2 of the project. A summary of these 4 modes will be introduced, but the documentation will provide a more in-depth analysis of each mode. But first, just to avoid any confusion, pacing refers to depolarization of the atria or ventricles. Sensing refers to detection of chamber signals. The VVI and AAI modes both provide sensing and pacing of the heart. VVI is used for the ventricles, while AAI is used for the Atrium. Those two modes act on an inhibited basis, meaning that the pacemaker is deactivated on a certain activity from the corresponding chamber. AOO and VOO only pace (no sensing) the atrium and ventricle, respectively.

# Variables

## Measured

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Units/Type** | **Description** | **Range** |
| t | ms | Time since last pulse | – |
| h\_atr\_pulse\_detected | boolean | Pulse detected in atrium | {true, false} |
| h\_vent\_pulse\_detected | boolean | Pulse detected in ventricle | {true, false} |

## Input

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Units/Type** | **Description** | **Range** |
| ATR\_CMP\_DETECT | boolean | Atrial signal voltage higher than threshold | {HIGH, LOW} |
| VENT\_CMP\_DETECT | boolean | Ventricular signal voltage higher than threshold | {HIGH, LOW} |

## Constant

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Units/Type** | **Description** | **Range** |
| p\_mode | mode | Pacemaker operational mode | {AOO,VOO,AAI,VVI} |
| p\_lower\_rate\_limit | ms | Lowest allowable heart rate | 343–2000 ± 8 ms |
| p\_upper\_rate\_limit | ms | Highest allowable heart rate | 343–1200 ± 8ms |
| p\_atr\_pulse\_amplitude | V | Desired amplitude of paced atrial pulses | 0.5–7.0 ± 12% |
| p\_vent\_pulse\_amplitude | V | Desired amplitude of paced ventricular pulses | 0.5–7.0 ± 12% |
| p\_atr\_pulse\_width | ms | Desired pulse width of paced atrial pulses | 0.05–1.9 ± 0.2 ms |
| p\_vent\_pulse\_width | ms | Desired pulse width of paced ventricular pulses | 0.05–1.9 ± 0.2 ms |
| p\_atr\_sensitivity | mV | Threshold voltage for sensing spontaneous atrial pulses | 0.25–10 ± 20% |
| p\_vent\_sensitivity | mV | Threshold voltage for sensing spontaneous ventricular pulses | 0.25–10 ± 20% |
| p\_vrp | ms | Ventricular Refractory Period | 150–500 ± 8 ms |
| p\_arp | ms | Atrial Refractory Period | 150–500 ± 8 ms |
| p\_pvarp | ms | Post-Ventricular Atrial Refractory Period | 150–500 ± 8 ms |
| p\_hysteresis\_enable | boolean | Hysteresis mode enabled | {true, false} |
| p\_hysteresis\_rate\_limit | ms | Hysteresis rate limit | 343–2000 ± 8 ms |
| p\_rate\_smoothing\_enable | boolean | Rate smoothing enabled | {true, false} |
| p\_rate\_smoothing\_down | percent | Maximum allowable pacing rate decrease | 3–25 ± 1% |
| p\_rate\_smoothing\_up | percent | Maximum allowable pacing rate increase | 3–25 ± 1% |

## Controlled

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Units/Type** | **Description** | **Range** |
| c\_start\_pulse | boolean | Commence paced pulse | {true, false} |

## Internal

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Units/Type** | **Description** | **Range** |
| i\_last\_period | ms | Last period between pulses | – |

## Output

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Units/Type** | **Description** | **Range** |
| PACE\_CHARGE\_CTRL | boolean | PWM connected to primary capacitor | {HIGH, LOW} |
| ATR\_PACE\_CTRL | boolean | Atrial ring connected to primary capacitor | {HIGH, LOW} |
| VENT\_PACE\_CTRL | boolean | Ventricular ring connected to primary capacitor | {HIGH, LOW} |
| ATR\_GND\_CTRL | boolean | Atrial ring connected to ground | {HIGH, LOW} |
| VENT\_GND\_CTRL | boolean | Ventricular ring connected to ground | {HIGH, LOW} |
| PACE\_GND\_CTRL | boolean | Atrial and Ventricular tip connected to blocking capacitor | {HIGH, LOW} |
| Z\_ATR\_CTRL | boolean | Impedance circuit connected to atrial ring | {HIGH, LOW} |
| Z\_VENT\_CTRL | boolean | Impedance circuit connected to ventricular ring | {HIGH, LOW} |
| PACING\_REF\_PWM | PWM | Reference PWM for primary capacitor | 0–100% |
| ATR\_CMP\_REF\_PWM | PWM | Reference PWM for atrial signal comparator | 0–100% |
| VENT\_CMP\_REF\_PWM | PWM | Reference PWM for ventricular signal comparator | 0–100% |

# Modes

## AOO

### Variables

#### Measured

#### Constant

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| p\_lower\_rate\_limit | LRL |  |
| p\_upper\_rate\_limit | URL |  |

#### Controlled

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| A\_pace\_start | PS |  |

### Requirements

|  |  |  |
| --- | --- | --- |
| **Last pulse Type** | **t** | **Pace** |
| X | t<URL | False |
| Sensed (no sensing in AOO) | X | X |
| Paced | t<LRL | False |
| t=LRL | True |

### State Transitions

### State Transitions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Next State  Current State | INITIAL | PACED | UPPER RATE LIMIT | LOWER RATE LIMIT |
| INITIAL | – | t = LRL | – | – |
| PACED | – | – | – | **????** |
| UPPER RATE LIMIT | – | t = URL | – | – |
| LOWER RATE LIMIT | – | t = LRL | – | – |

### Design details

### Testing

## VOO

### Variables

#### Measured

#### Constant

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| p\_lower\_rate\_limit | LRL |  |
| p\_upper\_rate\_limit | URL |  |

#### Controlled

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| V\_pace\_start | PS |  |

### Requirements

|  |  |  |
| --- | --- | --- |
| **Last pulse Type** | **t** | **Pace** |
| X | t<URL | False |
| Sensed (no sensing in VOO) | X | X |
| Paced | t<LRL | False |
| t=LRL | True |

### State Transitions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Next State  Current State | INITIAL | PACED | UPPER RATE LIMIT | LOWER RATE LIMIT |
| INITIAL | – | t = LRL | – | – |
| PACED | – | – | – | **????** |
| UPPER RATE LIMIT | – | t = URL | – | – |
| LOWER RATE LIMIT | – | t = LRL | – | – |

### Design details

### Testing

## AAI

### Variables

#### Measured

#### Constant

#### Controlled

### Requirements

#### With Hysteresis and Rate Smoothing enabled

### State Transitions

### Design details

### Testing

## VVI

### Variables

#### Measured

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| h\_vent\_pulse\_detected | PD |  |

#### Constant

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| p\_lower\_rate\_limit | LRL |  |
| p\_upper\_rate\_limit | URL |  |
| p\_vrp | VRP |  |
| p\_hysteresis\_enable | HE |  |
| p\_hysteresis\_limit | HL |  |
| p\_rate\_smoothing\_enable | RSE |  |
| p\_rate\_smoothing\_down | RSD |  |
| p\_rate\_smoothing\_up | RSU |  |

#### Controlled

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| V\_pace\_start | PS |  |

#### Internal

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| i\_last\_period | LP |  |

### Initial Values

V\_pace\_start = false

|  |  |
| --- | --- |
| **p\_hysteresis\_enable** | **i\_last\_period** |
| true | p\_hysteresis\_limit |
| false | p\_lower\_rate\_limit |

### Requirements

#### Hysteresis and Rate Smoothing Disabled

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Last Pulse Type | Last Period | t | Spontaneous pulse resets timer | PS |
| X | X |  | false | false |
|  | true | false |
|  | true |

#### Hysteresis Disabled and Rate Smoothing Enabled

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Last Pulse Type | Last Period | t | Spontaneous pulse resets timer | PS |
| X | X |  | false | false |
| X |  | true | false |
|  |  | true |
|  |  | false |
|  | true |
|  |  | false |
|  | true |

#### Hysteresis Enabled and Rate Smoothing Disabled

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Last Pulse Type | Last Period | t | Spontaneous pulse resets timer | PS |
| X | X |  | false | false |
|  | true | false |
| Sensed |  | false |
|  | true |
| Paced |  | false |
|  | true |

#### Hysteresis and Rate Smoothing Enabled

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Last Pulse Type | Last Period | t | Spontaneous pulse resets timer | PS |
| X | X |  | false | false |
| X |  | true | false |
| Sensed |  |  | true |
|  |  | false |
|  | true |
|  |  | false |
|  | true |
| Paced |  |  | false |
|  | true |
|  |  | false |
|  | true |
|  |  | false |
|  | true |

### State Transitions

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Next State  Current State | INITIAL | PACED | SENSED | UPPER RATE LIMIT | LOWER RATE LIMIT | HYSTERESIS LIMIT | RATE SMOOTHING DOWN | RATE SMOOTHING UP |
| INITIAL | – | HE = true  t = HL  **or**  HE = false  t = LRL | PD = true | – | – | – | – | – |
| PACED | – | – | – | – | RSE = true  LP ≥ LRL(1-RSD)  LP ≤ LRL(1+RSU)  **or**  RSE = false | – | RSE = true  LP < LRL(1-RSD) | RSE = true  LP > LRL(1+RSU) |
| SENSED | – | – | – | RSE = true  LP≤URL(1-RSD) | HE = false  RSE = false  **or**  HE = false  RSE = true  LP≥ LRL(1-RSD) | HE = true  RSE = true  LP≥HL(1-RSD)  **or**  HE = true  RSE = false | HE = true  RSE = true  LP > URL(1-RSD)  LP < HL(1-RSD)  **or**  HE = false  RSE = true  LP > URL(1-RSD)  LP < LRL(1-RSD) | – |
| UPPER RATE LIMIT | – | t = URL | PD = true | – | – | – | – | – |
| LOWER RATE LIMIT | – | t = LRL | PD = true | – | – | – | – | – |
| HYSTERESIS LIMIT | – | t = HL | PD = true | – | – | – | – | – |
| RATE SMOOTHING DOWN | – | t=LP(1+RSD) | PD = true | – | – | – | – | – |
| RATE SMOOTHING UP | – | t=LP(1-RSD) | PD = true | – | – | – | – | – |

### State details

|  |  |
| --- | --- |
| **State** | **Description** |
| INITIAL | If hysteresis is enabled, pacemaker listens for sensed pulses until p\_hysteresis\_limit before pacing.  If hysteresis is not enabled, pacemaker listens for sensed until p\_lower\_rate\_limit before pacing. |
| PACED | Sends a 10 ms pulse on V\_pace\_start and waits for the duration of p\_vrp |
| SENSED | Waits for the duration of p\_vrp |
| UPPER RATE LIMIT | Listens for sensed pulses until p\_upper\_rate\_limit |
| LOWER RATE LIMIT | Listens for sensed pulses until p\_lower\_rate\_limit |
| HYSTERESIS LIMIT | Listens for sensed pulses until p\_hysteresis\_limit |
| RATE SMOOTHING DOWN | Listens for sensed pulses until limit defined by maximum allowable rate decrease |
| RATE SMOOTHING UP | Listens for sensed pulsed until limit defined by maximum allowable rate increase |

### Testing