SFWRENG 3K04: Software Development

Assignment 1 – Part 1

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Table of Contents

[Likely Requirement Changes 3](#_Toc23077569)

[Likely Design Decision Changes 3](#_Toc23077570)

[Modes Implemented\* 4](#_Toc23077571)

[Available Modes 4](#_Toc23077572)

[0. Initial State 4](#_Toc23077573)

[Initial State Configuration: 4](#_Toc23077574)

[1. AOO (Atrium Pacing, No Sensing and No Response) 5](#_Toc23077575)

[Charging of C22 Capacitor and Discharging of C21 Capacitor: 5](#_Toc23077576)

[Atrium Pacing: 5](#_Toc23077577)

[2. VOO (Ventricle Pacing, No Sensing and No Response) 6](#_Toc23077578)

[Charging of C22 Capacitor and Discharging of C21 Capacitor: 6](#_Toc23077579)

[Ventricle Pacing: 6](#_Toc23077580)

[3. AAI (Atrium Pacing, Atrium Sensing and Inhibited Response) 7](#_Toc23077581)

[4. VVI (Ventricle Pacing, Ventricle Sensing and Inhibited Response) 8](#_Toc23077582)

[Appendix 9](#_Toc23077583)

[Programmable Parameters 9](#_Toc23077584)

[Monitored Variables 10](#_Toc23077585)

[Controlled Variables 11](#_Toc23077586)

# Likely Requirement Changes

* Implement complex modes such as VOOR, AAIR and DOO
* Add rate modulation functionality for all the pacing modes
* Develop communication between DCM and the hardware
* The pulses (either artificial or natural) produced or sensed by the atrium must be at an offset to the ventricle pulses and vice-versa
  + This needs to be done in order to replicate the behavior of the naturally beating heart
* As pacemaker usage increases, muscle resistance is prone to increase, thus it will be vital to observe the impedance of the heart chambers
  + An increase in the impedance value would require adjustments in the threshold value for both pacing and sensing operations
* Produce an electrogram when requested by the DCM

# Likely Design Decision Changes

* Programmable parameter values, such as p\_pacingMode, will be received from the DCM
  + Communication protocol between the hardware and DCM must be established
* Add transitions to allow for the pacemaker to switch from atrium pacing to ventricle pacing and vice versa, when programmed live by the DCM
* Create subsystems for any mathematical calculations in the hardware hiding subsystem
* Addition of new conditions and variables to implement rate modulation

# Modes Implemented\*

## Available Modes

* AOO
* VOO
* AAI
* VVI

Currently, the design has two subsystems, namely the Pacemaker FSM and Hardware Hiding\*\*. These two subsystems interact with one another to implement one of the above pacing modes.

* For a detailed understanding of the pins and variables used in this design, please refer to the appendix section listed at the end of this document

## Initial State

The initial state ensures that any unwanted parameters are OFF and allows the FSM to branch into atrium or ventricle pacing. This state works as a *safety* net because it brings the system back to a known configuration and the physician can assume that there is no current flow through the heart.

### Initial State Configuration:

|  |  |
| --- | --- |
| c\_frontEndCtrl = true; | Enables the sensing circuitry. In this assignment, the sensing mode is activated, however this parameter can be set to false as well. |
| c\_pacingRefPWM = 0; | Turn OFF voltage supply |
| c\_paceChargeCtrl = false; | OPEN connection between the voltage supply and C22 capacitor. Stops charging of C22 capacitor. |
| c\_atrPaceCtrl = false; | OPEN connection between C22 capacitor and the atrium chamber. Halts any pacing in the atrium chamber. |
| c\_ventPaceCtrl = false; | OPEN connection between C22 capacitor and the ventricle chamber. Halts any pacing in the ventricle chamber. |
| c\_atrGNDCtrl = false; | OPEN connection between the atrium and GND |
| c\_ventGNDCtrl = false; | OPEN connection between the ventricle and GND |
| c\_paceGNDCtrl = false; | No discharging of C21 capacitor |
| c\_blueLED = false; | Built-in LED is off (used to indicate an event of artificial pacing in the atrium chamber) |
| c\_redLED = false; | Built-in LED is off (used to indicate an event of artificial pacing in the ventricle chamber) |

From the initial state, the pacemaker has two paths; atrium or ventricle pacing. Based on the programmed pacing mode, the state flow is guided in either direction.

* Currently, the pacing mode is statically set by adjusting the value of the p\_pacingMode variable.

\*Only one mode is implemented at a time.

\*\*This document explains the Pacemaker FSM design. For inquiries about the Hardware Hiding, please read ‘part3\_group5.docx’ document.

## AOO (Atrium Pacing, No Sensing and No Response)

To implement atrium pacing, set **p\_pacingMode == 0** in the Hardware Hiding Subsystem.

This mode consists of two states:

1. The primary capacitor (C22) is charged and the blocking capacitor (C21) is discharged
2. Current flows from the primary capacitor to the blocking capacitor.

### Charging of C22 Capacitor and Discharging of C21 Capacitor:

|  |  |
| --- | --- |
| c\_atrCMPRefPWM = p\_atrThreshold; | Not needed in this mode (useful during sensing) |
| c\_pacingRefPWM = p\_atrPulseAmplitude; | Assigning the PWM reference value to a programmable variable to be able to control it with GUI |
| c\_paceGNDCtrl = true; | Discharge Step #1 – to drain the C21 capacitor (blocking capacitor) |
| c\_atrPaceCtrl = false; | Discharge Step #2 – blocks current to go back to C22 capacitor |
| c\_zAtrCtrl = false; | No measurement of impedance in the leads or atrium muscles |
| c\_zVentCtrl = false; | No measurement of impedance in the leads or ventricular muscles |
| c\_ventPaceCtrl = false; | Turns off ventricular response in this mode |
| c\_ventGNDCtrl = false; | Turns OFF ventricular GND connections |
| c\_atrGNDCtrl = true; | Discharge Step #3 – current from C21 flows to the GND |
| c\_paceChargeCtrl = true; | Charge Step #1 – since C22 is only connected to the voltage supply, it can independently charge the C22 capacitor |
| c\_blueLED = false; | Built-in LED is off (used to indicate an event of artificial pacing in the atrium chamber) |

* The atrium pacing amplitude and width can be determined using the Strength-Duration Curve
  + The testing atrium pace amplitude and width were set at 3000 mV and 2 ms

### Atrium Pacing:

After charging the C22 capacitor for a time programmed by p\_atrPaceDelay, the state flow transitions to the pacing stage.

|  |  |
| --- | --- |
| c\_paceChargeCtrl = false; | Now, we cut off the power supply to the C22 capacitor |
| c\_paceGNDCtrl = true; | Allows a direct connection between capacitor C22 and C21 |
| c\_ventPaceCtrl = false; | No involvement of ventricular modes |
| c\_ventGNDCtrl = false; | Limits the functionality available only for atrium chamber |
| c\_zAtrCtrl = false; | Not involving impedance as a factor in this case |
| c\_zVentCtrl = false; | Not involving impedance from any chambers |
| c\_atrGNDCtrl = false; | Makes sure that the current does not flow back to the GND terminal |
| c\_atrPaceCtrl = true; | Finally, switch activation to let the current flow from C22 to C21 capacitor |
| c\_blueLED = true; | Built-in LED is ON (used to indicate an event of artificial pacing in the atrium chamber) |

After a time programmed by p\_atrPulseWidth, the state flow resets back to the charging of C22 and discharging of C21. At this point, the FSM has gone through one complete cycle then repeats.

## VOO (Ventricle Pacing, No Sensing and No Response)

To implement ventricle pacing only, set **p\_pacingMode == 1** in the Hardware Hiding Subsystem. This mode involves a similar design as discussed for atrium pacing; however, it requires a few changes:

### Charging of C22 Capacitor and Discharging of C21 Capacitor:

|  |  |
| --- | --- |
| c\_ventCMPRefPWM = p\_ventThreshold; | Not needed in this mode (useful during sensing) |
| c\_pacingRefPWM = p\_ventPulseAmplitude; | Assigning the PWM reference value to a programmable variable to be able to control it with GUI |
| c\_paceGNDCtrl = true; | Discharge Step #1 – to drain the C21 capacitor (blocking capacitor) |
| c\_ventPaceCtrl = false; | Discharge Step #2 – blocks current to go back to C22 capacitor |
| c\_zAtrCtrl = false; | No measurement of impedance in the leads or atrium muscles |
| c\_zVentCtrl = false; | No measurement of impedance in the leads or ventricular muscles |
| c\_atrPaceCtrl = false; | Turns off atrium response in this mode |
| c\_atrGNDCtrl = false; | Turns OFF atrium GND connections |
| c\_ventGNDCtrl = true; | Discharge Step #3 – current from C21 flows to the GND |
| c\_paceChargeCtrl = true; | Charge Step #1 – since C22 is only connected to the voltage supply, it can independently charge the C22 capacitor |
| c\_redLED = false; | Built-in LED is off (used to indicate an event of artificial pacing in the ventricle chamber) |

* The ventricle pacing amplitude and width can be determined using the Strength-Duration Curve
  + The testing ventricle pace amplitude and width were set at 3000 mV and 2 ms

### Ventricle Pacing:

After charging the C22 capacitor for a time programmed by p\_ventPaceDelay, the state flow transitions to the pacing stage.

|  |  |
| --- | --- |
| c\_paceChargeCtrl = false; | Now, we cut off the power supply to the C22 capacitor |
| c\_paceGNDCtrl = true; | Allows a direct connection between capacitor C22 and C21 |
| c\_atrPaceCtrl = false; | No involvement of atrium modes |
| c\_atrGNDCtrl = false; | Limits the functionality available only for ventricle chamber |
| c\_zAtrCtrl = false; | Not involving impedance as a factor in this case |
| c\_zVentCtrl = false; | Not involving impedance from any chambers |
| c\_ventGNDCtrl = false; | Makes sure that the current does not flow back to the GND terminal |
| c\_ventPaceCtrl = true; | Finally, switch activation to let the current flow from C22 to C21 capacitor |
| c\_redLED = true; | Built-in LED is ON (used to indicate an event of artificial pacing in the ventricle chamber) |

After a time programmed by p\_ventPulseWidth, the state flow resets back to the charging of C22 and discharging of C21. At this point, the FSM has gone through one complete cycle and then repeats.

## AAI (Atrium Pacing, Atrium Sensing and Inhibited Response)

To implement atrium pacing and sensing, set **p\_pacingMode == 2** in the Hardware Hiding Subsystem. This mode adds a sensing feature to atrium pacing, thus the important distinction between this mode and AOO, is the inclusion of a sensory transition.

* NOTE: The pacing mode works the same as described in Mode 1 (AOO)

The following details focus on the sensing behavior of the FSM:

* In the initial state, **c\_frontEndCtrl == true**
  + This activates the sensing circuitry on the microcontroller
* In the charging of C22 and discharging of C21 state, there is a self-pointing transition:

**[after(p\_arpDelay, msec) && p\_pacingMode == 2 && m\_atrCMPDetect == true || m\_pushButton == true]**

The above condition declares that the pacemaker should inhibit an atrium pace if:

1. Pacemaker has waited for the atrium refractory period, p\_arpDelay
2. Pacing mode is set to AAI
3. Microcontroller has registered a natural pace in the atrium chamber
   * Microcontroller stores a natural pace by setting the pin D0 to high, and this pin goes to high only when an atrium threshold sensitivity is exceeded

The condition also declares that the pacemaker should inhibit an atrium pace if:

1. The push button is currently activated, which is incorporated as a bonus functionality

* NOTE: Criteria 1-3 must be satisfied in conjunction with one another; however, if condition 4 is independently true, the device will remain in the C22 charging state

If after a time interval, p\_atrPaceDelay, m\_atrCMPDetect is false, an artificial pace is induced in the atrium by the pacemaker.

## VVI (Ventricle Pacing, Ventricle Sensing and Inhibited Response)

To implement ventricle pacing and sensing, set **p\_pacingMode == 3** in the Hardware Hiding Subsystem. This mode adds a sensing feature to ventricle pacing, thus the important distinction between this mode and VOO, is the inclusion of a sensory transition.

* NOTE: The pacing mode works the same as described in Mode 2 (VOO)

The following details focus on the sensing behavior of the FSM:

* In the initial state, **c\_frontEndCtrl == true**
  + This activates the sensing circuitry on the microcontroller
* In the charging of C22 and discharging of C21 state, there is a self-pointing transition:

**[after(p\_vrpDelay, msec) && p\_pacingMode == 3 && m\_ventCMPDetect == true) || m\_pushButton == true]**

The above condition declares that the pacemaker should inhibit a ventricle pace if:

1. Pacemaker has waited for the ventricle refractory period, p\_vrpDelay
2. Pacing mode is set to VVI
3. Microcontroller has registered a natural pace in the ventricle chamber
   * Microcontroller stores a natural pace by setting the pin D1 to high, and this pin goes to high only when a ventricle threshold sensitivity is exceeded

The condition also declares that the pacemaker should inhibit a ventricle pace if:

1. The push button is currently activated, which is incorporated as a bonus functionality

* NOTE: Criteria 1-3 must be satisfied in conjunction with one another; however, if condition 4 is independently true, the device will remain in the C22 charging state

If after a time interval, p\_ventPaceDelay, m\_ventCMPDetect is false, an artificial pace is induced in the ventricle by the pacemaker.

# Appendix

## Programmable Parameters

All programmable parameters are inputs to the Pacemaker FSM system.

|  |  |  |
| --- | --- | --- |
| Name | Datatype | Description |
| p\_pacingMode | uint8 | Selects a mode based on the assigned value,  0 – AOO  1 – VOO  2 – AAI  3 – VVI  This value can be updated in the ‘Hardware Hiding’ subsystem |
| p\_atrPulseAmplitude | uint8 | Amplitude of the atrium pulse calculated for a certain frequency and duty cycle |
| p\_ventPulseAmplitude | uint8 | Amplitude of the ventricle pulse calculated for a certain frequency and duty cycle |
| p\_atrPaceDelay | uint16 | Determines for how long (in ms) the C22 capacitor is charged for atrium pacing |
| p\_atrPulseWidth | uint8 | Time during which the atrium chamber is paced |
| p\_ventPaceDelay | uint16 | Determines for how long (in ms) the C22 capacitor is charged for ventricle pacing |
| p\_ventPulseWidth | uint8 | Time during which the ventricle chamber is paced |
| p\_atrThreshold | uint8 | Used to sense activity in the atrium chamber. Value which sufficiently provides evidence of a natural pulse. Currently, set at 80% duty cycle. |
| p\_ventThreshold | uint8 | Used to sense activity in the ventricle chamber. Value which sufficiently provides evidence of a natural pulse. Currently, set at 80% duty cycle. |
| p\_arpDelay | uint16 | Defines the refractory period for the atrium |
| p\_vrpDelay | uint16 | Defines the refractory period for the ventricle |

## Monitored Variables

These variables are inputs to the Pacemaker FSM subsystem. These variables are outputs of certain pins on the microcontroller, and the values of these pins are monitored to cause a change in the Pacemaker FSM system. For example, whenever pin D0 is read as HIGH, the Pacemaker FSM System understands that the heart induced a natural heartbeat in the atrium.

|  |  |  |
| --- | --- | --- |
| Name | Datatype | Description |
| m\_atrCMPDetect | Input (∵, pin’s value is read from the microcontroller to observe natural pacing) | Used in the sensing circuitry. When a signal higher than threshold voltage is detected in the atrium chamber, pin D0 is set to HIGH, and OFF otherwise (includes 5mV hysteresis). |
| m\_ventCMPDetect | Input (∵, pin’s value is read from the microcontroller to observe natural pacing) | Used in the sensing circuitry. When a signal higher than threshold voltage is detected in the ventricular chamber, pin D1 is set to HIGH, and OFF otherwise (includes 5mV hysteresis). |
| m\_pushButton | Input (goes to HIGH when the button is pressed) | Used to achieve the push-button pace inhibition feature. Implemented in FSM to detect if the push button is activated. |

## Controlled Variables

These variables are outputs of the Pacemaker FSM subsystem and inputs to the Hardware Hiding subsystem.

|  |  |  |
| --- | --- | --- |
| Name | Datatype | Description |
| c\_atrPaceCtrl | Boolean | When this controllable switch is closed, the current in the primary capacitor can drain and potentially, induce a contraction in atrium.  Remember to turn OFF c\_paceChargeCtrl to avoid connecting the atrium directly with the PWM signal. |
| c\_ventPaceCtrl | Boolean | When this controllable switch is closed, the current in the primary capacitor can drain and potentially, induce a contraction in ventricle.  Remember to turn OFF c\_paceChargeCtrl to avoid connecting the atrium directly with the PWM signal. |
| c\_pacingRefPWM | uint8 | Controls the charge of the primary capacitor with duty cycle controlling the capacitor’s voltage |
| c\_paceChargeCtrl | Boolean | Required to charge the primary capacitor for pacing capabilities. To achieve this, set pin D2 to HIGH.  Make sure to turn OFF pin D8 or D9, before setting pin D2 to HIGH. |
| c\_paceGNDCtrl | Boolean | This is the final link in the chain of inducing a heartbeat. If this variable is left ON, along with either of the c\_...PaceCtrl, then a pulse is created in the respective chamber. |
| c\_atrGNDCtrl | Boolean | Used to discharge excess charge buildup at the tip of the electrode in the atrium. |
| c\_ventGNDCtrl | Boolean | Used to discharge excess charge buildup at the tip of the electrode in the ventricle. |
| c\_zAtrCtrl | Boolean | Used to monitor the impedance of the atrium chamber. Impedance can be measured at Z\_signal pin A2. |
| c\_zVentCtrl | Boolean | Used to monitor the impedance of the ventricle chamber. Impedance can be measured at Z\_signal pin A2. |
| c\_frontEndCtrl | Boolean | Deployed in activating the sensing modes. This variable stays OFF unless sensing of the heartbeat is required. |
| c\_atrCMPRefPWM | uint8 | Used to set a threshold voltage for sensing in the atrium chamber. |
| c\_ventCMPRefPWM | uint8 | Used to set a threshold voltage for sensing in the ventricle chamber. |
| c\_blueLED | Boolean | Used to flash a blue LED when the atrium is paced artificially. |
| c\_redLED | Boolean | Used to flash a red LED when the ventricle is paced artificially. |