MECHTRON 3K04

Group 26

Assignment 1

October 15, 2023

Simulink Documentation

This document defines the functions and operating characteristics that the system must perform and provides a description of the system's environmental performance parameters and critical interactions.

Part 1: Requirements and design

1.1 Requirements

These are all the requirements for the Simulink implementation of the pacemaker and its modes.

1.1.1 Overall Pacemaker System

The pacemaker should provide rate adaptive bradycardia pacing support, historical data on device implementation, and user diagnostics through brady analysis function. In addition, the bradycardia analysis functions should allow pacing measurements such as lead impedance, pacing threshold, P and R wave measurement, battery status, temporary brady pacing, motion sensor trending, and tests to be performed.

1.1.2 Device Operation

The proposed medical device is designed to meticulously monitor and manage a patient's heart rate, specifically focusing on the detection and provision of therapy for bradycardia. This pivotal device features programmable functionalities, with the ability to administer single-chamber, rate-adaptive pacing, and permanent state maintenance. Importantly, the device operates in tandem with the Device Controller-Monitor (DCM), facilitating programmable controls and oversight. Additionally, the device offers comprehensive historical data, including output rate histograms for both atrial and ventricular activities, as well as essential sensor output data, further enhancing its diagnostic and therapeutic capabilities.

1.1.3 Pulse Pacing (Atrial and Ventricular)

The device should result in pulses with programmable voltages and widths for the atrium and ventricle, which provide electrical heart-pacing stimulation.

1.1.3.1 Amplitude and Width

Both amplitude and width for pulse pacing should be independently programmable for each chamber.

1.1.3.2 Rate Sensing

Bipolar electrodes and a sensing circuit should operate rate sensing. Rate detection should be based on the measured cardiac cycle measurements of the sensed rhythm and assessed on an interval-by-interval basis.

1.1.4 Operation Modes

The DCM will be used to select a permanent bradycardia operating mode for the pacemaker at startup. At present, it will choose between the modes AOO, VOO, AAI, and VVI. Table 1.0 outlines the features present in each mode.

	LRL	URL	Atrial Amplitude	Ventricular Amplitude	Atrial Pulse With	Ventricular Pulse Width	Atrial Sensitivity	Ventricular Sensitivity	ARP	VRP
AOO	O	O	O		O					
VOO	O	O		O		O				
AAI	O	O	O		O		O		O	
VVI	O	O		O		O		O		O

Table 1: Programmable Parameters for AOO, VOO, AAI, and VVI modes

1.1.5 Bradycardia Therapy

1.1.5.1 Lower Rate Limit (LRL)

The number of generator pace pulses delivered (per minute) should be affected by following the requirements.

a) LRL should be the longest allowable definition of pacing interval.
b) The LRL interval should begin at a ventricular sensed or paced event in VII and VOO mode.
c) The LRL interval should begin at an atrial sensed or paced event in AII and AOO mode.

1.1.5.2 Upper Rate Limit (URL)

The Upper Rate Limit (URL) refers to the highest pace at which the heart's ventricles will follow the detected atrial signals. The URL interval represents the shortest duration between one ventricular event and the subsequent ventricular pacing.

1.1.5.3 Refractory Periods

a) Ventricular Refractory Period (VRP): It should be the set duration of time after a ventricular event during which neither the sensing of ventricular activity will prevent nor initiate ventricular pacing.
b) Atrial Refractory Period (ARP): In single-chamber atrial modes, it should be the preset time duration following an atrial event, within which atrial events will neither stop nor initiate pacing.
c) Post Ventricular Atrial Refractory Period (PVARP): It must be available in modes with ventricular pacing and atrial sensing. It is a customizable period of time after a ventricular event during which an atrial heart event should neither block an atrial pace nor activate a ventricular pace.

1.1.6 Programmable Parameters

Parameter	Programmable Values	Increment	Nominal	Tolerance
Modes	AOO	–	DDD	–
	VOO			
	AAI			
	VVI			
Lower Rate Limit	30-50 ppm	5 ppm	60 ppm	± 8 ms
	50-90 ppm	1 ppm		
	90-175 ppm	5 ppm		
Upper Rate Limit	50-175 ppm	5 ppm	120 ppm	± 8 ms
A or V Pulse Amplitude Regulated	Off, 0.5 – 3.2 V	0.1 V	3.5V	± 12 %
	3.5 – 7.0 V	0.5 V		
A or V pulse Width	0.05 ms	–	0.4 ms	0.2 ms
	0.1 – 1.9 ms	0.1 ms		
Ventricular Refractory Period	150 – 500 ms	10 ms	320 ms	± 8 ms
Atrial Refractory Period	150 – 500 ms	10 ms	250 ms	± 8 ms

Table 2: Programmable Parameters Values

1.2 Design decisions

One subsystem within the system's architecture is dedicated to the task of mapping input pins, which are responsible for conveying data used in the program, to their respective names as specified in Table 1 of the document entitled "Pacemaker Shield Explained." Another subsystem is employed to map output pins to their designated names from the same referenced table. This dual mapping approach serves to enhance program readability and obfuscate the underlying hardware complexities. By doing so, it facilitates the use of variable names like "ATR_CMP_DETECT" instead of generic identifiers such as "D0" throughout the codebase, thus fostering clarity and abstraction between the software and hardware components.

In pursuit of adaptability and ease of parameter adjustment, the program incorporates the usage of constants for programmable parameters. This design choice ensures that the values associated with these parameters can be modified with utmost simplicity, promoting versatility across different simulation runs. It is anticipated that in future iterations of the system, these parameter values will be dynamically supplied by the Device Controller-Monitor (DCM) through serial communication, thereby allowing for real-time adjustment and fine-tuning.

The system's operational modes are implemented using a stateflow diagram, which branches into the appropriate modes based on the input data provided. Furthermore, nested stateflows are employed to implement and manage the distinct states required for each pacing mode. This hierarchical state management approach enhances the overall system's organization and comprehensibility while ensuring the correct execution of various pacing functionalities.

1.3 Simulink diagram and testing

1.3.1 Simulink Diagram

1.3.1.1 Inputs

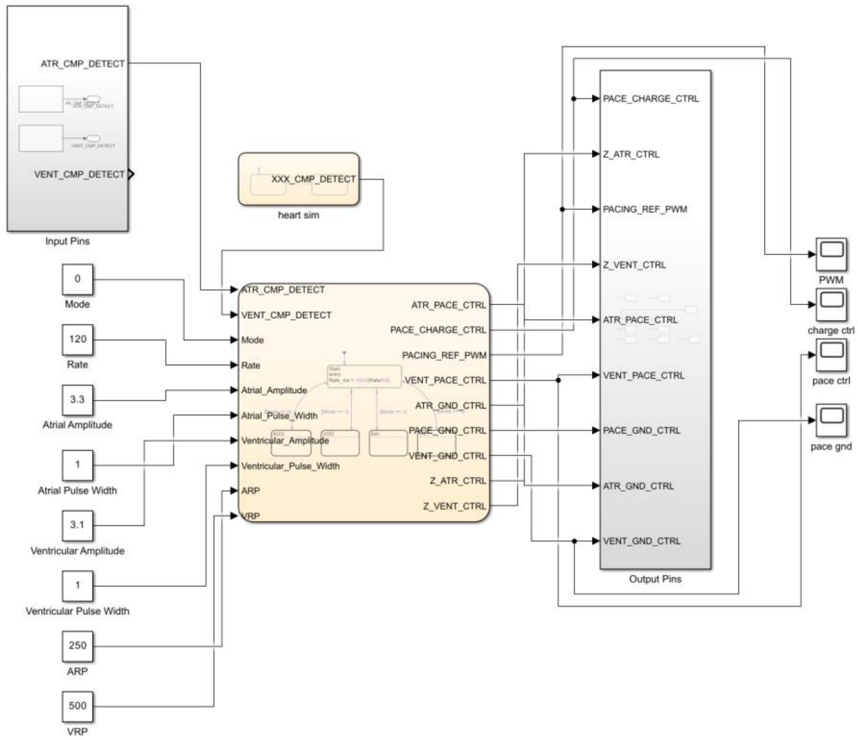

Figure 1: Overall Diagram

Our design encompasses nine distinct input parameters which are as follows: ATR_CMP_DETECT, VENT_CMP_DETECT, Mode, Rate, Atrial_Amplitude, Atrial_Pulse_Width, Ventricular_Amplitude, Ventricular_Pulse_Width, and ARP. The system produces nine corresponding output signals: ATR_PACE_CTRL, PACE_CHARGE_CTRL, PACING_REF_PWM, VENT_PACE_CTRL, ATR_GND_CTRL, PACE_GND_CTRL, VENT_GND_CTRL, Z_ATR_CTRL, and Z_VENT_CTRL.

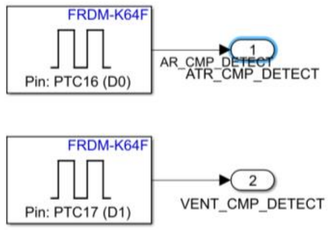

Figure 2: Input Pins

Among the input pins of the FRDM-K64F board the first pin, PTC16 (referred to as D0), with a sample time of -1, has been effectively linked to Port 1, serving the purpose of ATR_CMP_DETECT. Similarly, within the FRDM-K64F board's input pins, the second pin, PTC17 (referred to as D1), also configured with a sample time of -1, has been assigned to Port 2, designated as VENT_CMP_DETECT. These connections establish the critical link between the hardware and the software components of the system, allowing for the appropriate data acquisition and processing.

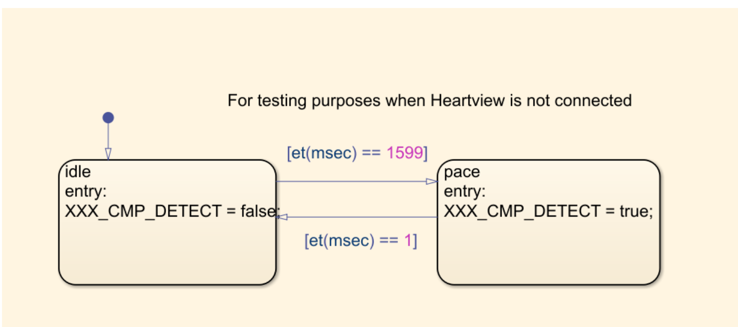

Figure 3: Heart Simulation without Heartview

As a constant value of the inputs are assigned by following values on the chart.

Constant Variable Name	Constant Value	Sample Time
Mode	0, 1, 2, 3	Inf
Rate	120	Inf
Atrial Amplitude	3.3	Inf
Atrial Pulse Width	1	Inf
Ventricular Amplitude	3.1	Inf
Ventricular Pulse Width	1	Inf
ART	250	Inf
VRP	500	Inf

Table 3: Constant Input Values

1.3.1.2 Outputs

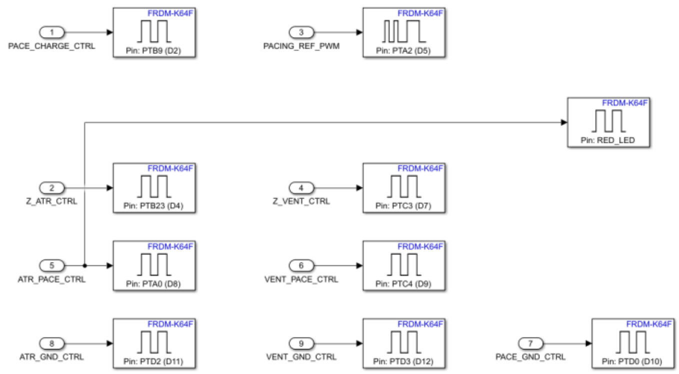

Figure 4: Output Pins

The system's output pins serve as the critical interface through which the device communicates and interacts with the hardware. These pins play a pivotal role in conveying vital information, control signals, and feedback to various components and systems.

1.3.1.3 Main Pacemaker State flow

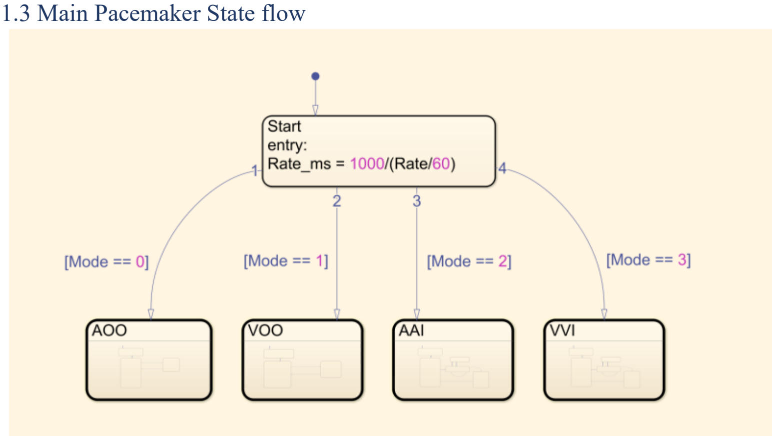

Figure 5: 4 Modes of the Main Peacemaker State

The primary Pacemaker stateflow diagram has been partitioned into four distinct subsystems, each of which corresponds to a specific pacing mode. These modes are configured with pacing rates determined by the formula 1000/(Rate/60) milliseconds, and they include AOO (mode 0), VOO (mode 1), AAI (mode 2), and VVI (mode 3). This deliberate division of the stateflow diagram facilitates a more organized and streamlined approach to managing and executing different pacing modes, ensuring precise and effective control over the device's operation based on the selected mode and associated pacing rate.

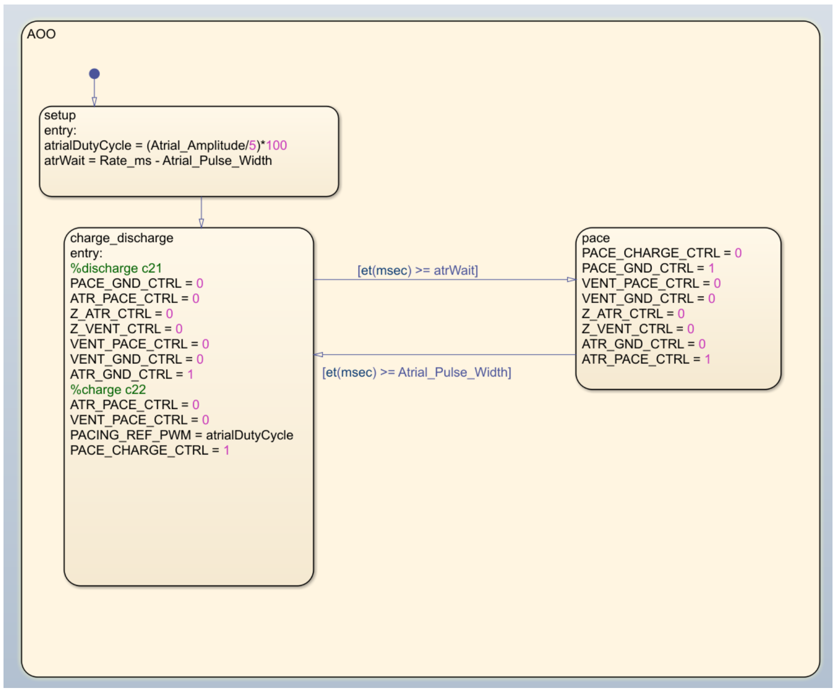

Figure 6: AOO (Mode 0) Stateflow

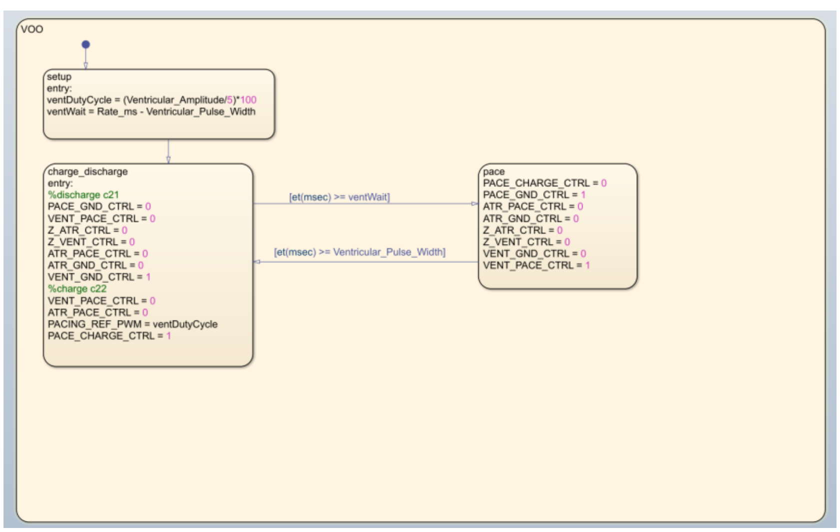

Figure 7: VOO (Mode 1) Stateflow

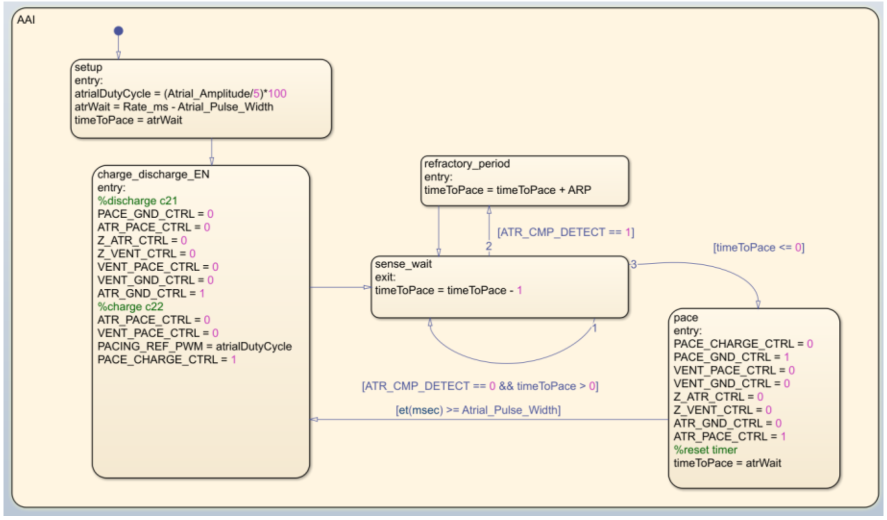

Figure 8: AAI (Mode 2) Stateflow

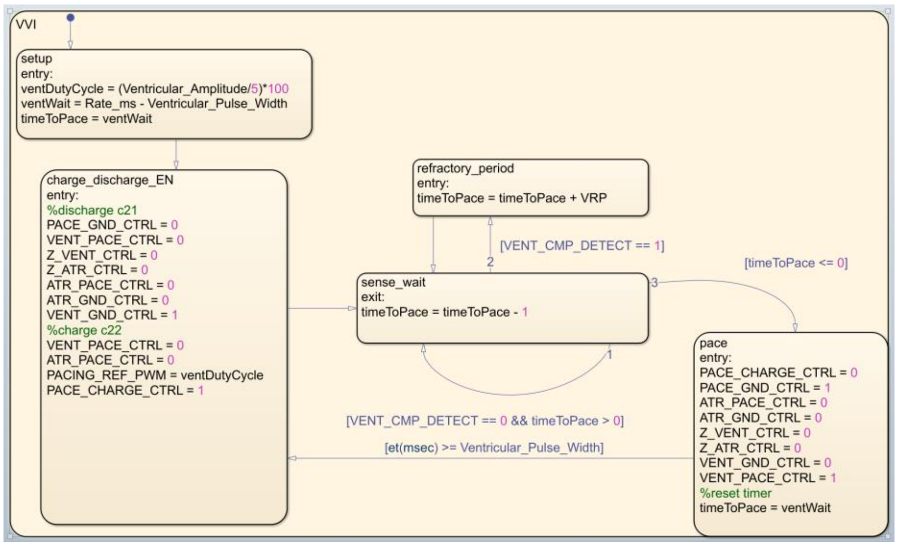

Figure 9: VVI (Mode 3) Stateflow

1.3.1.4 Scope

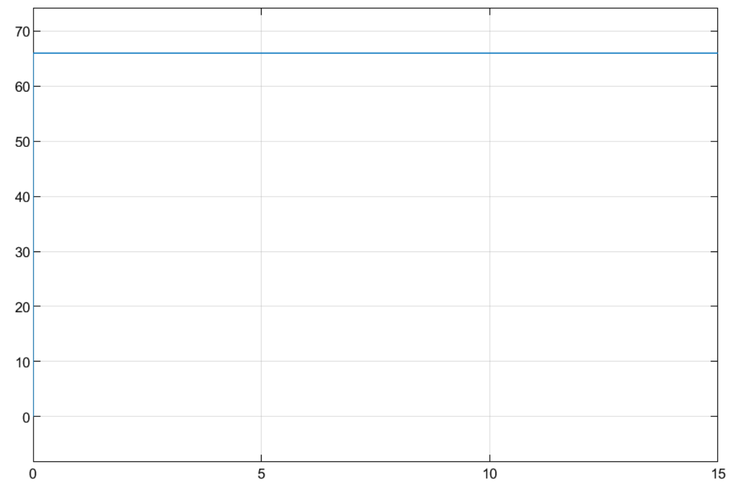

Figure 10: PWM Scope

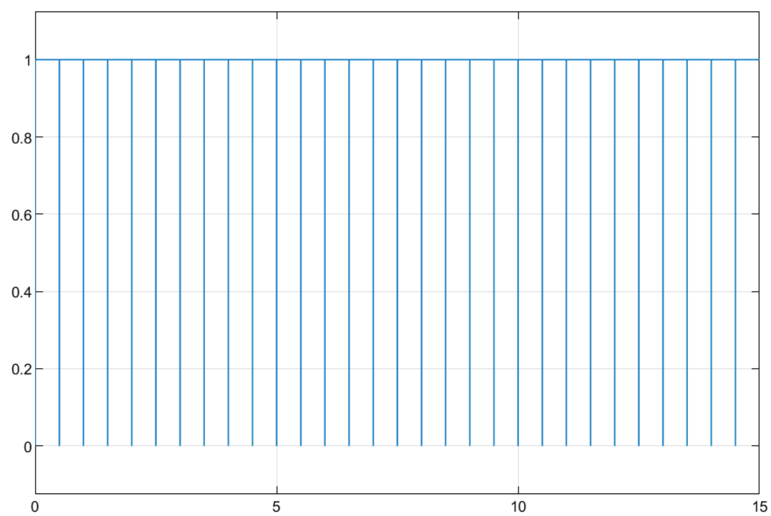

Figure 11: Charge CTRL Scope

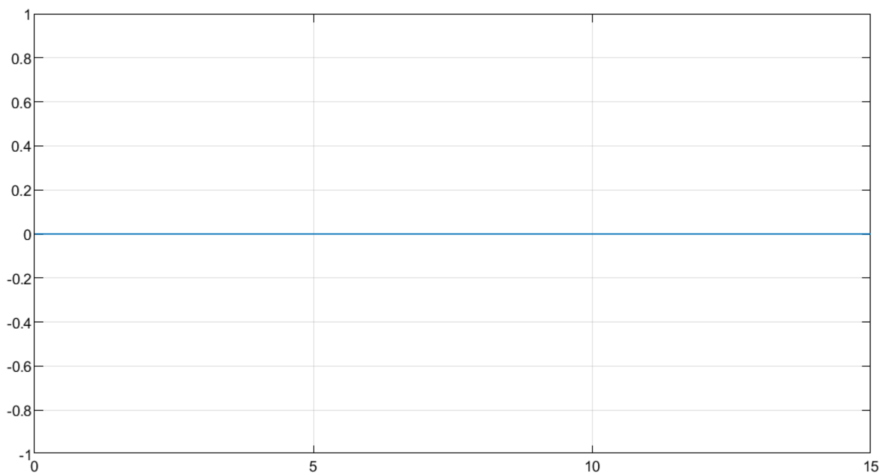

Figure 12: Pace CTRL Scope

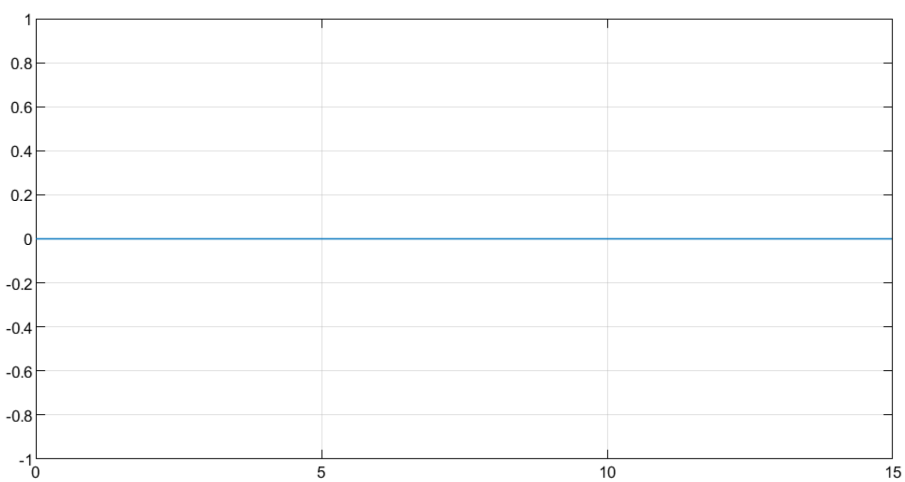

Figure 13: Pace GND Scope

1.3.2 Simulink Testing

1.3.2.1 AOO Test

We conducted two tests to see if the AOO mode works well. First, we checked that the Pacemaker operated properly when the Natural Atrium was ON and showed the result value. Next, we tested Pacemaker's graph for the same result as the previous test case when both the Natural Atrium and Natural Ventricle were off. In AOO mode, the result value was confirmed as follows because the same value must be obtained even if both the Natural Atrium and Ventricle are turned off. The following shows the corresponding graph and the settings for Pacemaker and Heartview.

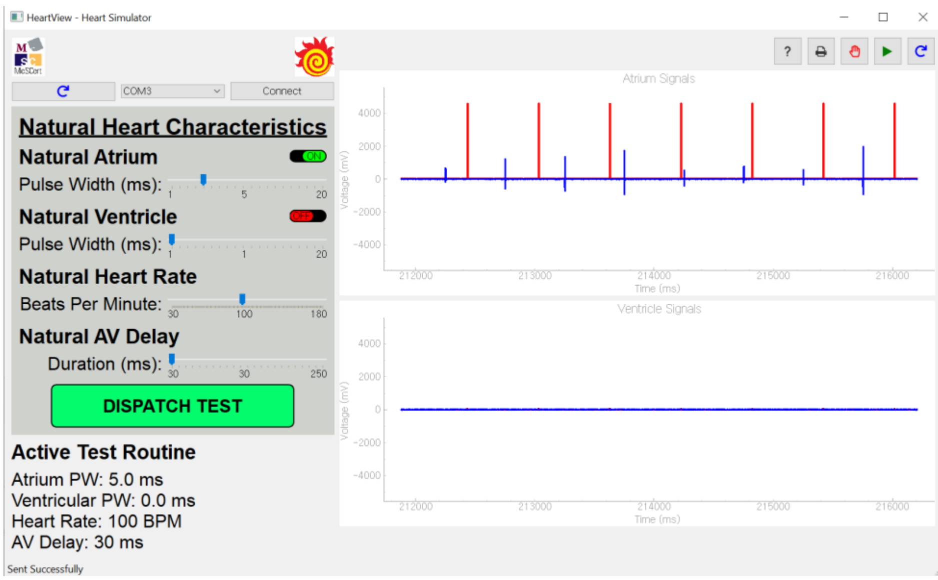

Figure 14: AOO Test with Natural Atrium ON

Pacemaker		Heartview	
Mode	Mode 0 (AOO)	Natural Atrium	ON (5ms)
Atrial Amplitude	3.3	Natural Ventricle	OFF
Atrial Pulse Width	1	Natural Heart Rate	100 bpm
Ventricular Amplitude	3.1	Natural AV Delay	30 ms
Ventricular Width	1		
Rate	120		
Result: Heartview result is as expected.			
Pass/Fail: Pass (no change)			

Table 4: AOO Test Overview with Natural Atrium ON

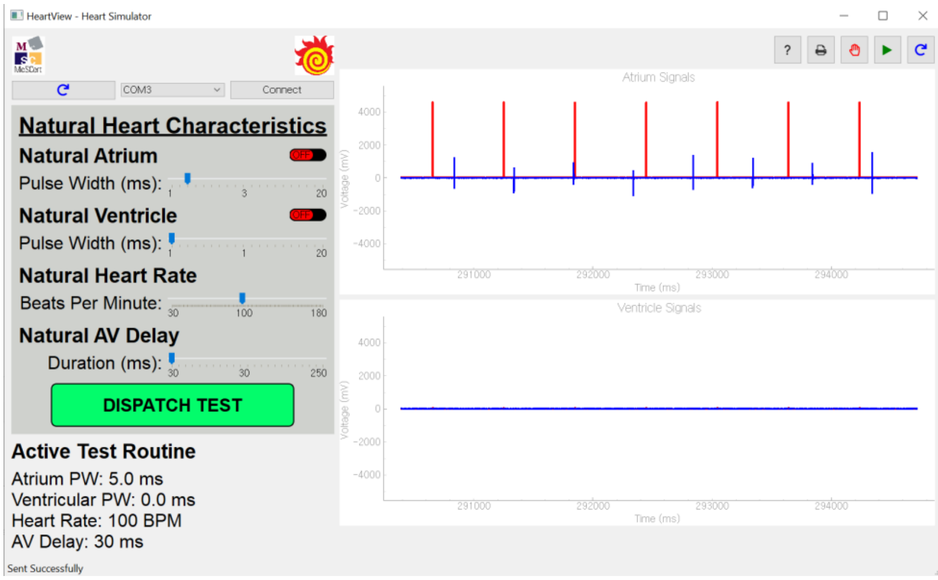

Figure 15: AOO Test with Natural Atrium and Ventricle Both OFF

Pacemaker		Heartview	
Mode	Mode 0 (AOO)	Natural Atrium	OFF
Atrial Amplitude	3.3	Natural Ventricle	OFF
Atrial Pulse Width	1	Natural Heart Rate	100 bpm
Ventricular Amplitude	3.1	Natural AV Delay	30 ms
Ventricular Width	1		
Rate	120		
Result: Heartview result is as expected.			
Pass/Fail: Pass (no change)			

Table 5: AOO Test Overview with Natural Atrium and Ventricle Both OFF

1.3.2.2 VOO Test

We conducted two tests to see if the VOO mode works well. First, we checked that the Pacemaker operated properly when the Natural Ventricle was ON and showed the result value. Next, we tested Pacemaker's graph for the same result as the previous test case when both the Natural Atrium and Natural Ventricle were off. In VOO mode, the result value was confirmed as follows because the same value must be obtained even if both the Natural Atrium and Ventricle are turned off. The following shows the corresponding graph and the settings for Pacemaker and Heartview.

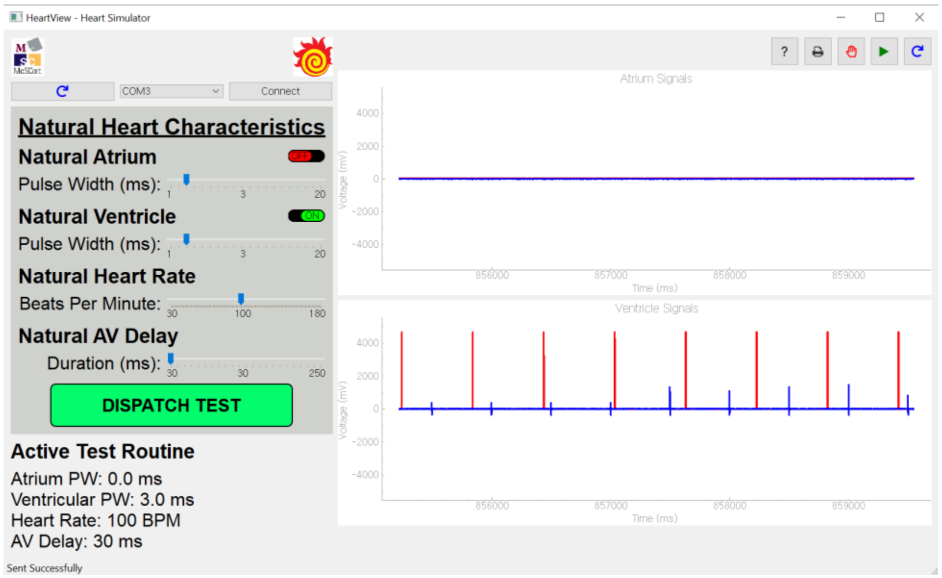

Figure 16: VOO Test with Natural Ventricle ON

Pacemaker		Heartview	
Mode	Mode 1 (VOO)	Natural Atrium	ON (3ms)
Atrial Amplitude	3.3	Natural Ventricle	OFF
Atrial Pulse Width	1	Natural Heart Rate	100 bpm
Ventricular Amplitude	3.1	Natural AV Delay	30 ms
Ventricular Width	1		
Rate	120		
Result: Heartview result is as expected.			
Pass/Fail: Pass (no change)			

Table 6: VOO Test Overview with Natural Ventricle ON

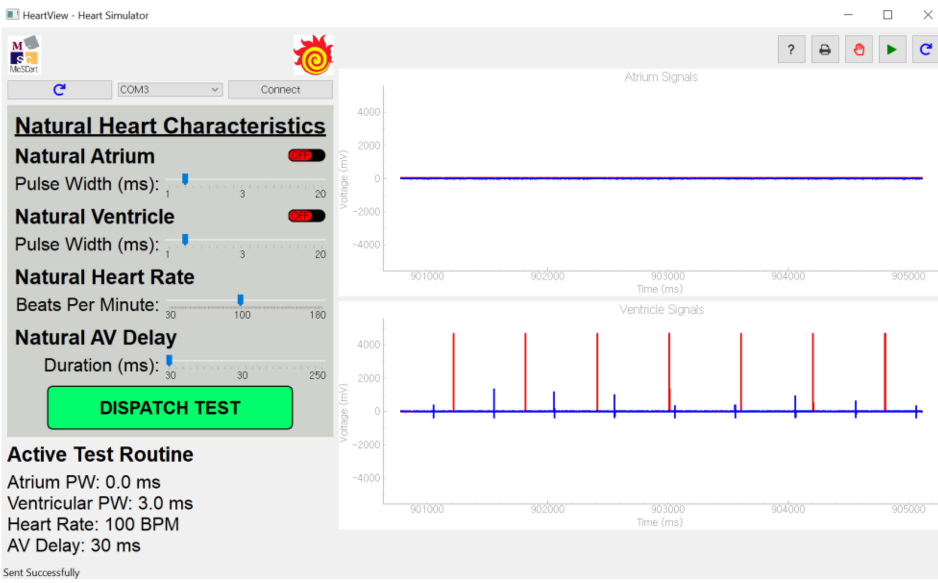

Figure 17: VOO Test with Natural Atrium and Ventricle Both OFF

Pacemaker		Heartview	
Mode	Mode 1 (VOO)	Natural Atrium	OFF
Atrial Amplitude	3.3	Natural Ventricle	OFF
Atrial Pulse Width	1	Natural Heart Rate	100 bpm
Ventricular Amplitude	3.1	Natural AV Delay	30 ms
Ventricular Width	1		
Rate	120		
Result: Heartview result is as expected.			
Pass/Fail: Pass (no change)			

Table 7: VOO Test Overview with Natural Atrium and Ventricle Both OFF

1.3.2.3 AAI Test

We conducted two tests to see if the AAI mode works well. First, when the Natural Atrium is ON, and the Natural Heart Rate exceeds 60 bpm, we check that the Pacemaker operates properly and shows the result value. Next, when the Natural Atrium is ON and the Natural Heart Rate is less than 60 bpm, the Pacemaker operates properly, and we check the result value. In the first test case, as a Natural Heart Rate, we used 126 bpm; in the second test case, we used 30 bpm. The following shows the corresponding graph and the settings for Pacemaker and Heartview.

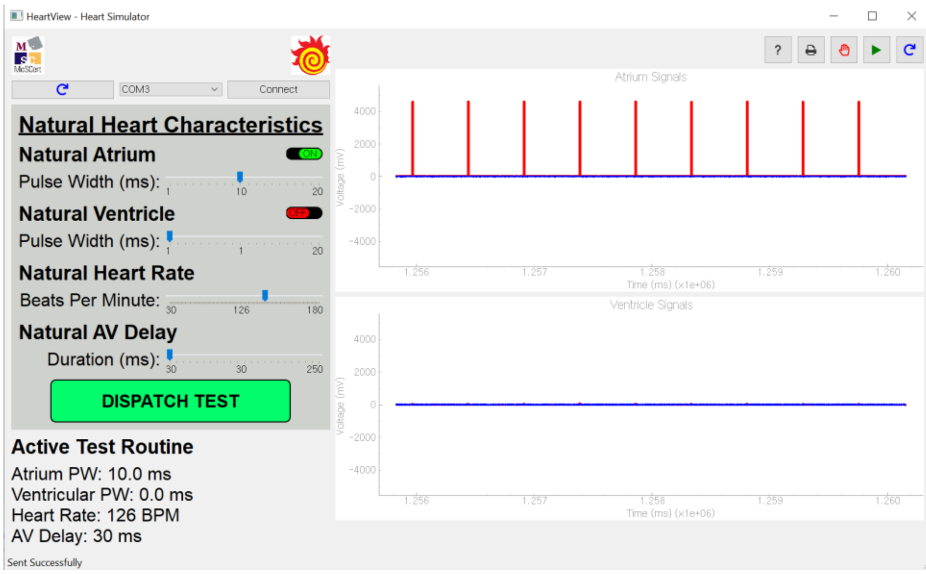

Figure 18: AAI Test with Natural Heart Rate at 126 BPM

Pacemaker		Heartview	
Mode	Mode 2 (AAI)	Natural Atrium	ON (10 ms)
Atrial Amplitude	3.3	Natural Ventricle	OFF
Atrial Pulse Width	1	Natural Heart Rate	126 bpm
Ventricular Amplitude	3.1	Natural AV Delay	30 ms
Ventricular Width	1		
Rate	120		
Result: Heartview result is as expected.			
Pass/Fail: Pass (no change)			

Table 8: AAI Test Overview with Natural Heart Rate at 126 BPM

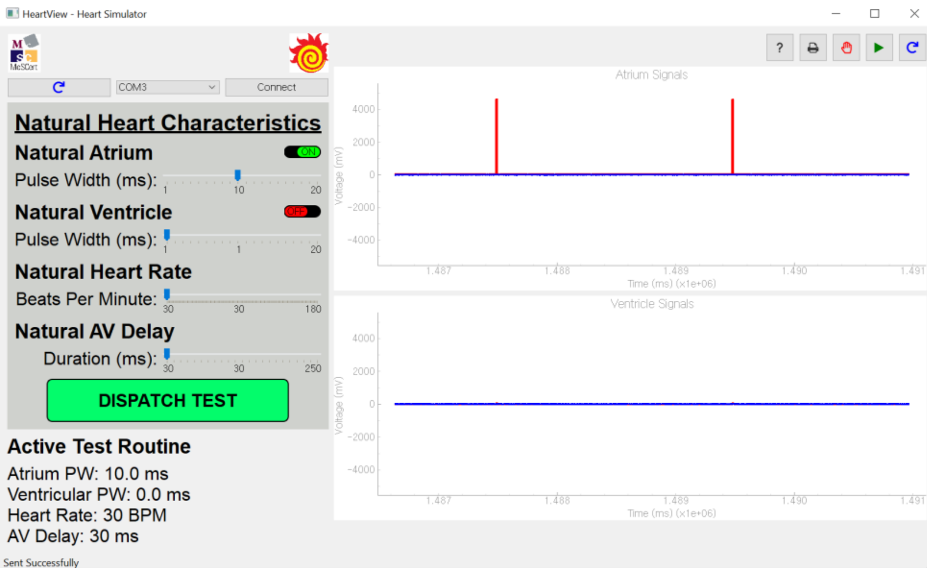

Figure 19: AAI Test with Natural Heart Rate at 30 BPM

Pacemaker		Heartview	
Mode	Mode 2 (AAI)	Natural Atrium	ON (10 ms)
Atrial Amplitude	3.3	Natural Ventricle	OFF
Atrial Pulse Width	1	Natural Heart Rate	30 bpm
Ventricular Amplitude	3.1	Natural AV Delay	30 ms
Ventricular Width	1		
Rate	120		
Result: Heartview result is as expected.			
Pass/Fail: Pass (no change)			

Table 9: AAI Test Overview with Natural Heart Rate at 30 BPM

1.3.2.4 VVI Test

We conducted two tests to see if the VVI mode works well. First, when the Natural Ventricle is ON, and the Natural Heart Rate exceeds 60 bpm, we check that the Pacemaker operates properly and shows the result value. Next, when the Natural Ventricle is ON and the Natural Heart Rate is less than 60 bpm, the Pacemaker operates properly, and we check the result value. In the first test case, as a Natural Heart Rate, we used 118 bpm; in the second test case, we used 30 bpm. The following shows the corresponding graph and the settings for Pacemaker and Heartview.

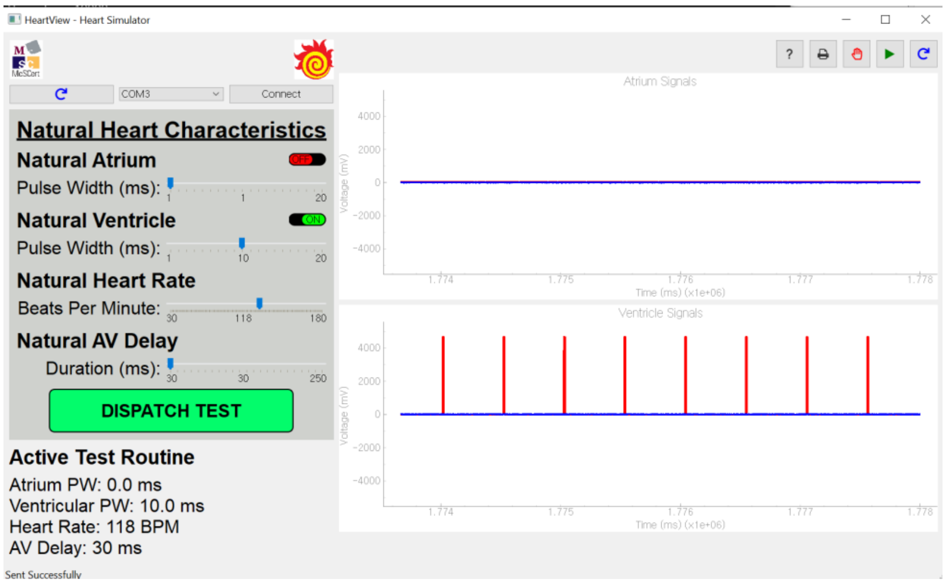

Figure 20: VVI Test with Natural Heart Rate at 118 BPM

Pacemaker		Heartview	
Mode	Mode 3 (VVI)	Natural Atrium	OFF
Atrial Amplitude	3.3	Natural Ventricle	ON (10 ms)
Atrial Pulse Width	1	Natural Heart Rate	118 bpm
Ventricular Amplitude	3.1	Natural AV Delay	30 ms
Ventricular Width	1		
Rate	120		
Result: Heartview result is as expected.			
Pass/Fail: Pass (no change)			

Table 10: VVI Test Overview with Natural Heart Rate at 118 BPM

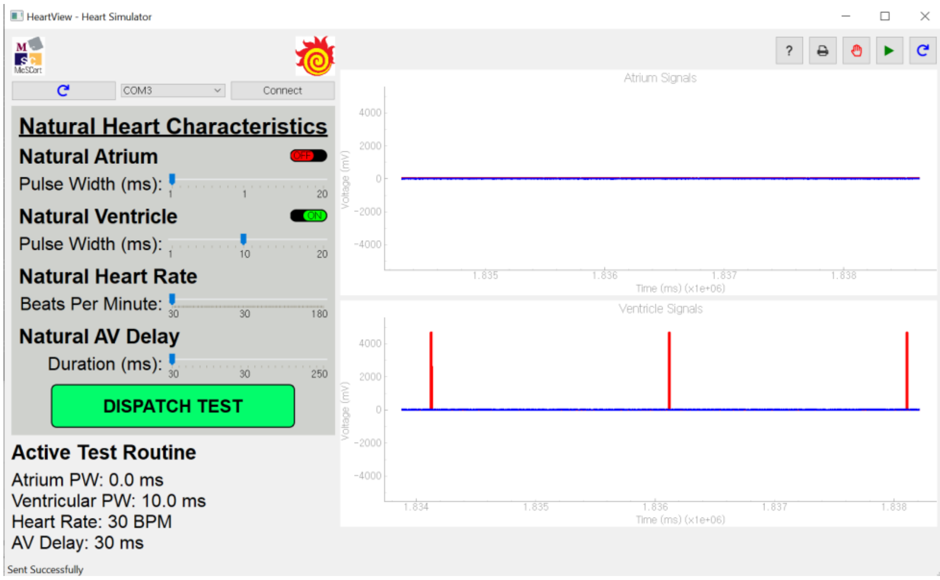

Figure 21.0 VVI Test with Natural Heart Rate at 30 bpm

Pacemaker		Heartview	
Mode	Mode 3 (VVI)	Natural Atrium	OFF
Atrial Amplitude	3.3	Natural Ventricle	ON (10 ms)
Atrial Pulse Width	1	Natural Heart Rate	30 bpm
Ventricular Amplitude	3.1	Natural AV Delay	30 ms
Ventricular Width	1		
Rate	120		
Result: Heartview result is as expected.			
Pass/Fail: Pass (no change)			

Table 11: VVI Test Overview with Natural Heart Rate at 30 BPM

Part 2: Future Flexibility and Modules

2.1 Requirements likely to change

In the future, more modes will need to be added. Subsystems are used to encapsulate the different operating modes to make it easier to add new ones.

2.2 Design decisions likely to change

The decision to use constants for user values will change in Assignment 2 as there will be serial communication between the DCM and Simulink model, allowing those values to be provided through a GUI.

2.3 MIS and MID

2.3.1 Module Interface Specification

Describes the purpose, public functions, and black-box behaviour of each function.

2.3.1.1 Input Pins Subsystem

Maps MCU input pins to more descriptive internal variables to enable hardware hiding.

Input	Type	Output	Type
PTC16 (D0)	bool	ATR_CMP_DETECT	bool
PTC17 (D1)	bool	VENT_CMP_DETECT	bool

Table 12: MCU input pins

2.3.1.2 Output Pins Subsystem

Maps internal variables to MCU output pins to enable hardware hiding.

Input	Type	Output	Type
PACE_CHARGE_CTRL	bool	PTB9 (D2)	bool
Z_ATR_CTRL	bool	PTB23 (D4)	bool
PACING_REF_PWM	single	PTA2 (D5)	single
Z_VENT_CTRL	bool	PTC3 (D7)	bool
ATR_PACE_CTRL	bool	PTA0 (D6)	bool
VENT_PACE_CTRL	bool	PTC4 (D9)	bool
PACE_GND_CTRL	bool	PTD0 (D10)	bool
ATR_GND_CTRL	bool	PTD2 (D11)	bool
VENT_GND_CTRL	bool	PTD3 (D12)	bool

Table 13: MCU output pins

2.3.1.3 Main Stateflow

Allows the program to branch to different operating modes. Organizes sub-stateflows and is extensible for future modes.

Input	Type	Output	Type
ATR_CMP_DETECT	bool	PACE_CHARGE_CTRL	bool
VENT_CMP_DETECT	bool	Z_ATR_CTRL	bool
Mode	int8	PACING_REF_PWM	single
Rate	single	Z_VENT_CTRL	bool
Atrial_Amplitude	single	ATR_PACE_CTRL	bool
Atrial_Pulse_Width	single	VENT_PACE_CTRL	bool

Ventricular_Amplitude	single	PACE_GND_CTRL	bool
Ventricular_Pulse_Width	single	ATR_GND_CTRL	bool
ARP	single	VENT_GND_CTRL	bool
VRP	single		

Table 14: Programmable Parameters in Main Stateflow

2.3.1.4 AOO Stateflow

Implements the AOO operating mode, taking in appropriate programmable parameters, and controlling its outputs accordingly to create paces.

Input	Type	Output	Type
Atrial_Amplitude	single	PACE_CHARGE_CTRL	bool
Atrial_Pulse_Width	single	Z_ATR_CTRL	bool
Rate_ms	single	PACING_REF_PWM	single
		Z_VENT_CTRL	bool
		ATR_PACE_CTRL	bool
		VENT_PACE_CTRL	bool
		PACE_GND_CTRL	bool
		ATR_GND_CTRL	bool
		VENT_GND_CTRL	bool

Table 15: Programmable Parameters in AOO Stateflow

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서식 있음: 표준

2.3.1.5 VOO Stateflow

Implements the VOO operating mode, taking in appropriate programmable parameters, and controlling its outputs accordingly to create paces.

Input	Type	Output	Type
Ventricular_Amplitude	single	PACE_CHARGE_CTRL	bool
Ventricular_Pulse_Width	single	Z_ATR_CTRL	bool
Rate_ms	single	PACING_REF_PWM	single
		Z_VENT_CTRL	bool
		ATR_PACE_CTRL	bool
		VENT_PACE_CTRL	bool
		PACE_GND_CTRL	bool
		ATR_GND_CTRL	bool
		VENT_GND_CTRL	bool

Table 16: Programmable Parameters in VOO Stateflow

2.3.1.6 AAI Stateflow

Implements the AAI operating mode, taking in appropriate programmable parameters, and controlling its outputs accordingly to create and respond to paces.

Input	Type	Output	Type
Atrial_Amplitude	single	PACE_CHARGE_CTRL	bool
Atrial_Pulse_Width	single	Z_ATR_CTRL	bool
Rate_ms	single	PACING_REF_PWM	single

ATR_CMP_DETECT	bool	Z_VENT_CTRL	bool
ARP	single	ATR_PACE_CTRL	bool
		VENT_PACE_CTRL	bool
		PACE_GND_CTRL	bool
		ATR_GND_CTRL	bool
		VENT_GND_CTRL	bool

Table 17: Programmable Parameters in AAI Stateflow

2.3.1.7 VVI Stateflow

Implements the AAI operating mode, taking in appropriate programmable parameters, and controlling its outputs accordingly to create and respond to paces.

Input	Type	Output	Type
Ventricular_Amplitude	single	PACE_CHARGE_CTRL	bool
Ventricular_Pulse_Width	single	Z_ATR_CTRL	bool
Rate_ms	single	PACING_REF_PWM	single
VENT_CMP_DETECT	bool	Z_VENT_CTRL	bool
VRP	single	ATR_PACE_CTRL	bool
		VENT_PACE_CTRL	bool
		PACE_GND_CTRL	bool
		ATR_GND_CTRL	bool
		VENT_GND_CTRL	bool

Table 18: Programmable Parameters in VVI Stateflow

2.3.2 Module Internal Design

Describes the state variables, private functions, and internal behaviour of all functions.

2.3.2.1 Input Pins Subsystem

Assigns the input from pin D0 to the boolean variable ATR_CMP_DETECT, and the input from pin D1 to the boolean variable VENT_CMP_DETECT.

2.3.2.2 Output Pins Subsystem

Assigns the boolean variables PACE_CHARGE_CTRL, Z_ATR_CTRL, Z_VENT_CTRL, ATR_PACE_CTRL, VENT_PACE_CTRL, PACE_GND_CTRL, ATR_GND_CTRL, and VENT_GND_CTRL to pins D2, D4, D7, D8, D9, D10, D11, and D12 respectively as digital outputs. Assigns PACING_REF_PWM to pin D5 as a digital PWM output.

2.3.2.3 Main Stateflow

Creates the state variable Rate_ms. This is a single that holds the conversion of the input variable Rate from paces per minute to milliseconds. Then, based on the value of the int8 Mode, it branches into either AOO, VOO, AAI, or VVI if the value is 0,1,2, or 3 respectively.

2.3.2.4 AOO Stateflow

Defines the variable of type single atrialDutyCycle, converting Atrial_Amplitude into a PWM signal referenced from 5V. Also defines atrWait using Rate_ms and Atrial_Pulse_Width to designate how long to wait in between pulses. Then enters two looping states, charge_discharge and pace. The former assigns all the necessary output variables to discharge C21 and charge C22 (as outlined in Pacemaker Shield

Explained) for pacing the atrium. After spending time atrWait in this state, it will then move to the state pace, where C22 will be discharged into C21 through the atrium using the output values as defined in Pacemaker Shield Explained. After Atrial_Pulse_Width milliseconds have passed, it will return to charge_discharge.

2.3.2.5 VOO Stateflow

This acts identically to AOO, except all references to the atrium are replaced with the ventricle, and vice versa. Local state variables are ventDutyCycle and ventWait.

2.3.2.6 AAI Stateflow

Defines the variable of type single atrialDutyCycle, converting Atrial_Amplitude into a PWM signal referenced from 5V. Also defines atrWait using Rate_ms and Atrial_Pulse_Width to designate how long to wait in between pulses. Assigns the state variable timeToPace to be equal to atrWait upon entry, then moves to state charge_discharge. This state performs the same assignments as in AOO, but then immediately moves to state sense_wait. This state decrements timeToPace by 1 millisecond every millisecond whenever timeToPace is positive and ATR_CMP_DETECT is 0. If ATR_CMP_DETECT is 1, then state refractory_period is entered, which increases timeToPace by ARP milliseconds. Sense_wait is then re-entered. If in sense_wait timeToPace ever falls below or equal to 0, then it will enter the state pace. This state performs the same as in AOO, except it also assigns timeToPace to be equal to atrWait. Pace is exited after Atrial_Pulse_Width milliseconds and moves back to charge_discharge.

2.3.2.7 VVI Stateflow

This acts identically to AAI, except all references to the atrium are replaced with the ventricle, and vice versa. Local state variables are ventDutyCycle, ventWait, and timeToPace. Note that ARP is replaced with VRP.