3K04 Assignment 2

Pacemaker Simulink Documentation

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1 Pacing Modes Implementation

1.1 Introduction

In the following section, the implementation of pacing modes AOO, VOO, DOO, AAI, VVI, AOOR, VOOR, DOOR, AAIR and VVIR [2] are discussed in terms of inputs, outputs, design decisions, testing, as well as future improvements to be made.

Within all pacing modes, Simulink was used to develop models in order for the pacemaker to operate. Within these models, several variables were used to control the beats per minute (BPM), corresponding circuits [1], states, voltages, and pulse width modulation (PWM). States were used in the system in which they were used for charging the main capacitor (C22), discharging the output capacitor (C21) [1], sensing the heart activity (when applicable), and inhibiting a pace to the heart. An input ranging from 0V to 5V was given to the amplitude of the pulse where a PWM signal was produced at a desired frequency and duty cycle. The pulse width as well as the lower rate limit (LRL) were inputs that controlled the timing between the two states along with LRL directly controlling the BPM.

For the rate adaptive modes [2], states and subsystems were created to perform calculations and obtain usable data from the accelerometer on the NX-FRDM-K64F board in order to observe the physical activity of the patient and inhibit a proper pace. Three different rates of rate adaptive pacing were implemented (rates are relative to LRL and MSR [2]): resting, walking, and running heart rates.

1.2 AOO

The AOO mode sends pulses to the atrium chambers of the heart with no sensing.

1.2.1 Inputs

NAME	DESCRIPTION	ALLOWED VALUES	TYPE/UNIT
Amplitude	Inputs a voltage for the PWM signal from 0-5V	0 - 5	V
Pulse Width	The desired width of the paced signal	0.1 - 1.9	msec
Lower Rate Limit (LRL)	The number of generated paced pulses delivered to the atrium	30 - 175	PPM
Upper Rate Limit (URL)	The maximum rate at which it will sense events	50 - 175	PPM

1.2.2 Outputs

NAME	DESCRIPTION	ALLOWED VALUES	TYPE/UNIT
ATR_PACE_CTRL	Enables pacing to atrium	true/false	boolean

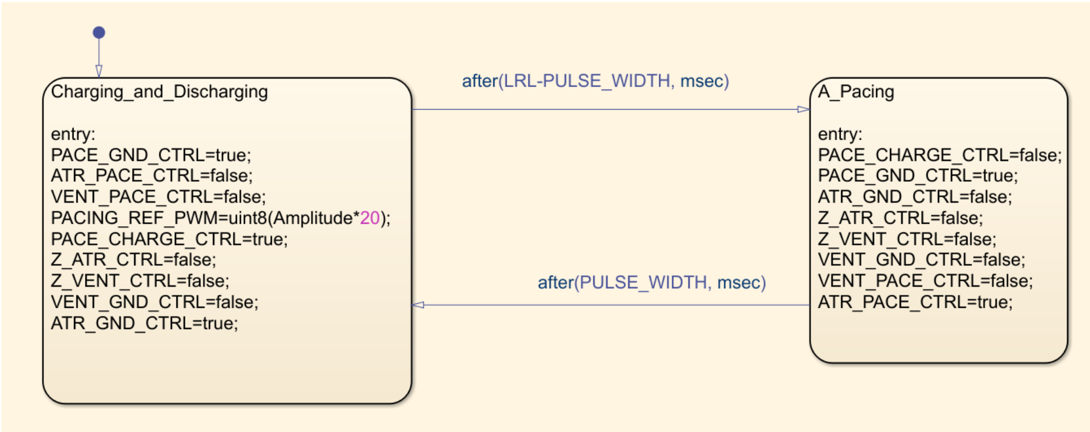
VENT_PACE_CTRL	Enables pacing to ventricle	true/false	boolean
PACING_REF_PWM	Signal that charges the C22 capacitor to then be sent to the heart	0 - 100	Duty Cycle (%)
PACE_CHARGE_CTRL	Allows the C22 capacitor to be charged	true/false	boolean
ATR_GND_CTRL	Discharges C21 in the atrium to avoid charge build up in the heart	true/false	boolean
Z_ATR_CTRL	Used for analysis on the impedance in the atrium	true/false	boolean
Z_VENT_CTRL	Used for analysis on the impedance in the ventricle	true/false	boolean
VENT_GND_CTRL	Discharges C21 in the ventricle to avoid charge build up in the heart	true/false	boolean
PACE_GND_CTRL	Allow current to flow to atrium or ventricle	true/false	boolean

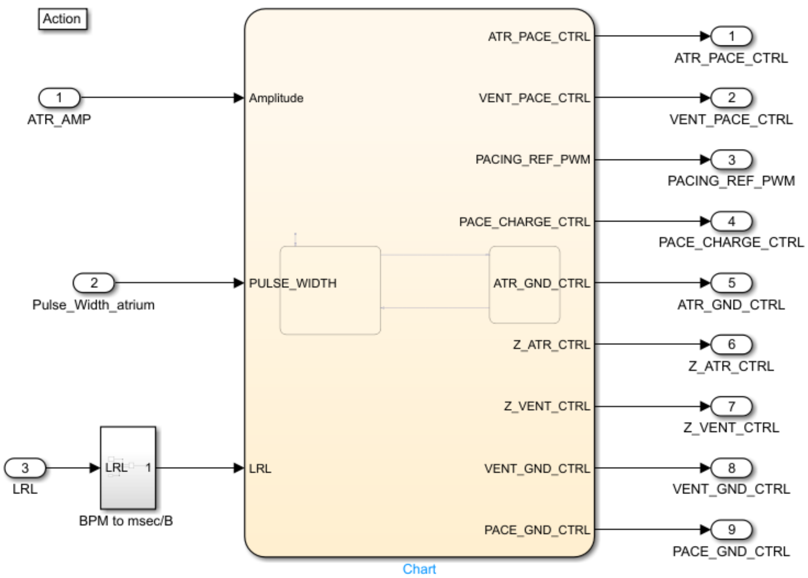
1.2.3 Design decisions

The decision was made to incorporate only two states because as long as there is a natural regular heartbeat, the system can remain in an idle state of charging the C22 capacitor. Only until there is an irregular/no heartbeat, will the system inhibit a pace to the heart in which it will do so at the desired rate.

Some things likely to change are the allowed values of certain parameters which may be specific to other pacemaker designs and implementations. For example the allowable ranges of the amplitude voltage, pulse width, LRL, and URL may be subject to change.

1.2.4 Simulink Schematics





1.3 VOO

The VOO mode sends pulses to the ventricle chambers of the heart with no sensing.

1.3.1 Inputs

NAME	DESCRIPTION	ALLOWED VALUES	TYPE/UNIT
Amplitude	Inputs a voltage for the PWM signal from 0-5V	0 - 5	V
Pulse Width	The desired width of the paced signal	0.1 - 1.9	msec
Lower Rate Limit (LRL)	The number of generated paced pulses delivered to the atrium	30 - 175	PPM

Upper Rate Limit (URL)	The maximum rate at which it will sense events	50 - 175	PPM

1.3.2 Outputs

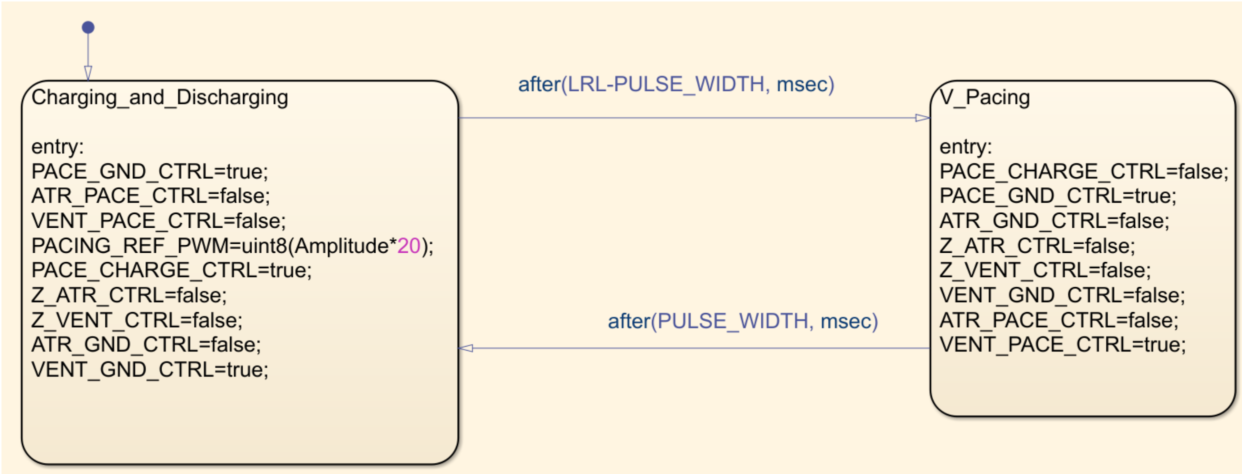
NAME	DESCRIPTION	ALLOWED VALUES	TYPE/UNIT
ATR_PACE_CTRL	Enables pacing to atrium	true/false	boolean
VENT_PACE_CTRL	Enables pacing to ventricle	true/false	boolean
PACING_REF_PWM	Signal that charges the C22 capacitor to then be sent to the heart	0 - 100	Duty Cycle (%)
PACE_CHARGE_CTRL	Allows the C22 capacitor to be charged	true/false	boolean
ATR_GND_CTRL	Discharges C21 in the atrium to avoid charge build up in the heart	true/false	boolean
Z_ATR_CTRL	Used for analysis on the impedance in the atrium	true/false	boolean
Z_VENT_CTRL	Used for analysis on the impedance in the ventricle	true/false	boolean
VENT_GND_CTRL	Discharges C21 in the ventricle to avoid charge build up in the heart	true/false	boolean
PACE_GND_CTRL	Allow current to flow to atrium or ventricle	true/false	boolean

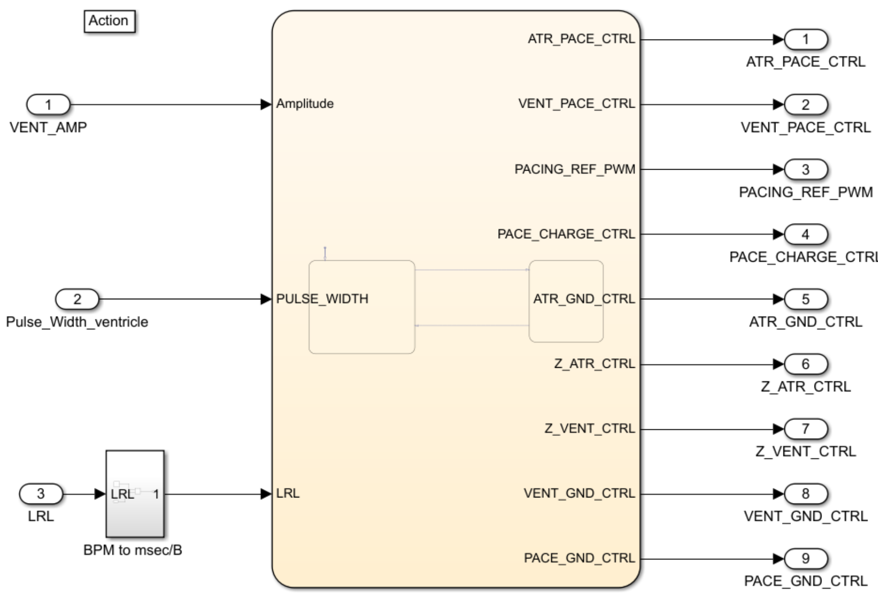
1.3.3 Design decisions

The decision was made to incorporate only two states because as long as there is a natural regular heartbeat, the system can remain in an idle state of charging the C22 capacitor. Only until there is an irregular/no heartbeat, will the system inhibit a pace to the heart in which it will do so at the desired rate.

Some things likely to change are the allowed values of certain parameters which may be specific to other pacemaker designs and implementations. For example the allowable ranges of the amplitude voltage, pulse width, LRL, and URL may be subject to change.

1.3.4 Simulink Schematics





1.4 AAI

Mode AAI senses activity in the atrium and inhibits pulses accordingly.

1.4.1 Inputs

NAME	DESCRIPTION	ALLOWED VALUES	TYPE/UNIT
Amplitude	Inputs a voltage for the PWM signal from 0-5V	0 - 5	V
Pulse Width	The desired width of the paced signal	0.1 - 1.9	msec
Lower Rate Limit (LRL)	The number of generated paced pulses delivered to	30 - 175	PPM

	the atrium		
Upper Rate Limit (URL)	The maximum rate at which it will sense events	50 - 175	PPM
SENSED/ATR_CMP_DETECT	Determines if there is a natural heartbeat	true/false	boolean
Atrial Refractory period (ARP)	Time interval in which no sensing/pacing occurs after a sensed atrium pace	150 - 500	msec
Post Ventricular Atrial Refractory Period (PVARP)	Time interval following a ventricular event when an atrial cardiac event shall not Inhibit an atrial pace	150 - 500	msec

1.4.2 Outputs

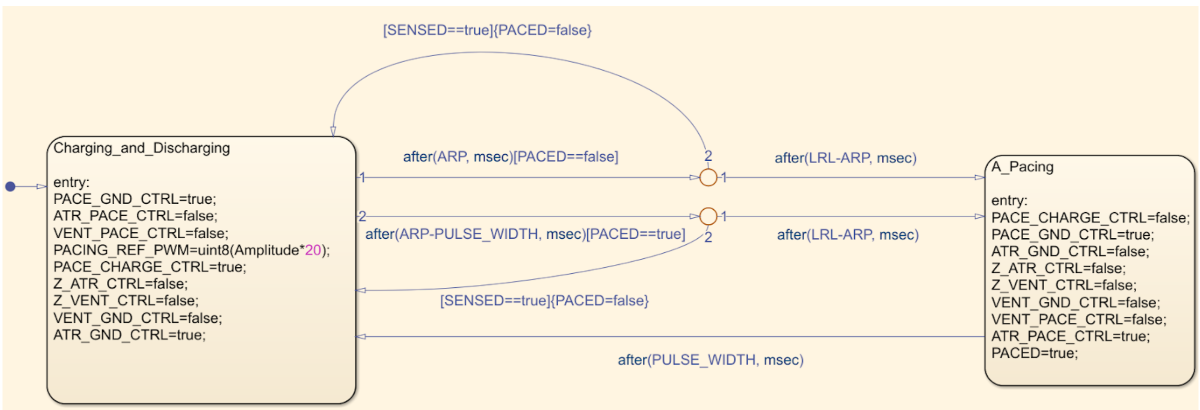
NAME	DESCRIPTION	ALLOWED VALUES	TYPE/UNIT
ATR_PACE_CTRL	Enables pacing to atrium	true/false	boolean
VENT_PACE_CTRL	Enables pacing to ventricle	true/false	boolean
PACING_REF_PWM	Signal that charges the C22 capacitor to then be sent to the heart	0 - 100	Duty Cycle (%)
PACE_CHARGE_CTRL	Allows the C22 capacitor to be charged	true/false	boolean
ATR_GND_CTRL	Discharges C21 in the atrium to avoid charge build up in the heart	true/false	boolean
Z_ATR_CTRL	Used for analysis on the impedance in the atrium	true/false	boolean
Z_VENT_CTRL	Used for analysis on the impedance in the ventricle	true/false	boolean
VENT_GND_CTRL	Discharges C21 in the ventricle to avoid charge build up in the heart	true/false	boolean
ATR_CMP_REF_PWM	Establishes the minimum threshold for atrium action potential to be sensed	0 - 100	Duty Cycle (%)

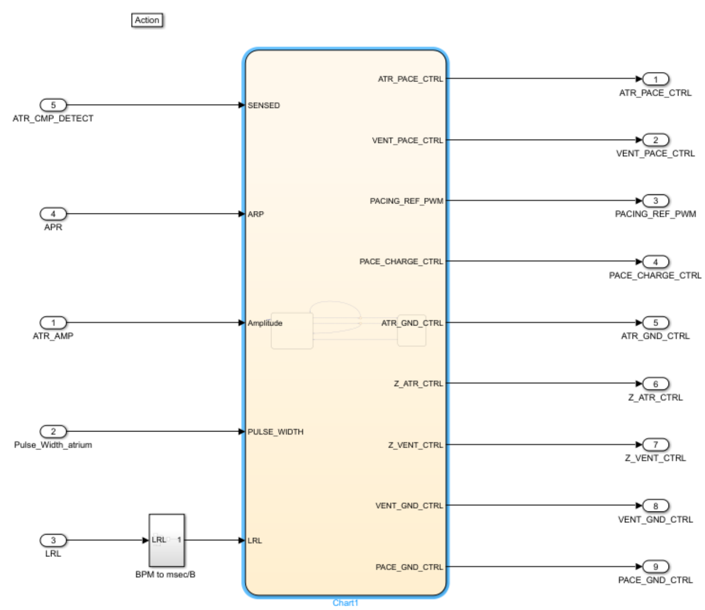
1.4.3 Design decisions

The decision was made to incorporate the ARP variable to properly inhibit pacing to the heart. Junctions were used in the implementation of ARP.

Some things likely to change are the allowed values of certain parameters which may be specific to other pacemaker designs and implementations. For example the allowable ranges of the amplitude voltage, pulse width, LRL, and URL may be subject to change. The changing of the hardware is also subject to change which will alter the design details but not the design structure.

1.4.4 Simulink Schematics





1.5 VVI

Mode VVI senses activity in the ventricle and inhibits pulses accordingly.

1.5.1 Inputs

NAME	DESCRIPTION	ALLOWED VALUES	TYPE/UNIT

Amplitude	Inputs a voltage for the PWM signal from 0-5V	0 - 5	V
Pulse Width	The desired width of the paced signal	0.1 - 1.9	msec
Lower Rate Limit (LRL)	The number of generated paced pulses delivered to the atrium	30 - 175	PPM
Upper Rate Limit (URL)	The maximum rate at which it will sense events	50 - 175	PPM
SENSED/VENT_CMP_DETECT	Determines if there is a natural heartbeat	true/false	boolean
Ventricle Refractory period (VRP)	Time interval in which no sensing/pacing occurs after a sensed ventricular pace	150 - 500	msec

1.5.2 Outputs

NAME	DESCRIPTION	ALLOWED VALUES	TYPE/UNIT
ATR_PACE_CTRL	Enables pacing to atrium	true/false	boolean
VENT_PACE_CTRL	Enables pacing to ventricle	true/false	boolean
PACING_REF_PWM	Signal that charges the C22 capacitor to then be sent to the heart	0 - 100	Duty Cycle (%)
PACE_CHARGE_CTRL	Allows the C22 capacitor to be charged	true/false	boolean
ATR_GND_CTRL	Discharges C21 in the atrium to avoid charge build up in the heart	true/false	boolean
Z_ATR_CTRL	Used for analysis on the impedance in the atrium	true/false	boolean
Z_VENT_CTRL	Used for analysis on the impedance in the ventricle	true/false	boolean
VENT_GND_CTRL	Discharges C21 in the ventricle to avoid charge build up in the heart	true/false	boolean

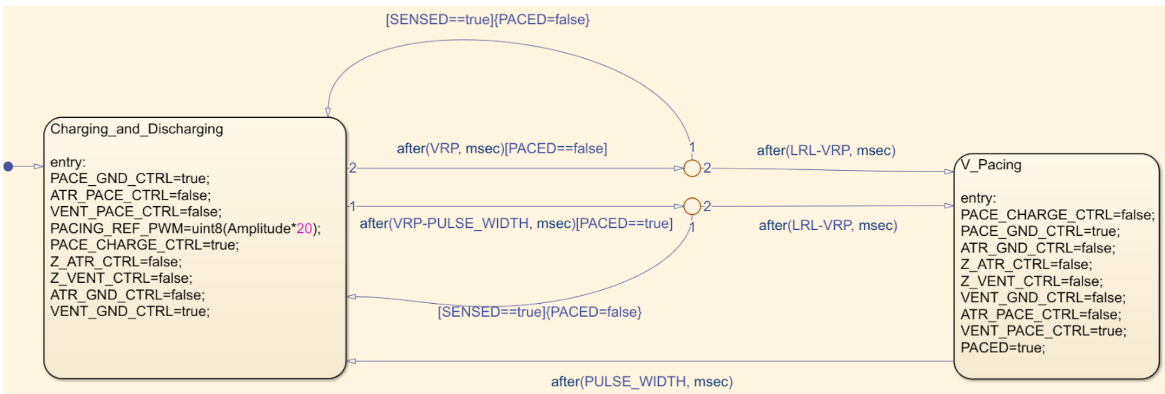
VENT_CMP_REF_PWM	Establishes the minimum threshold for ventricular action potential to be sensed	0 - 100	Duty Cycle (%)

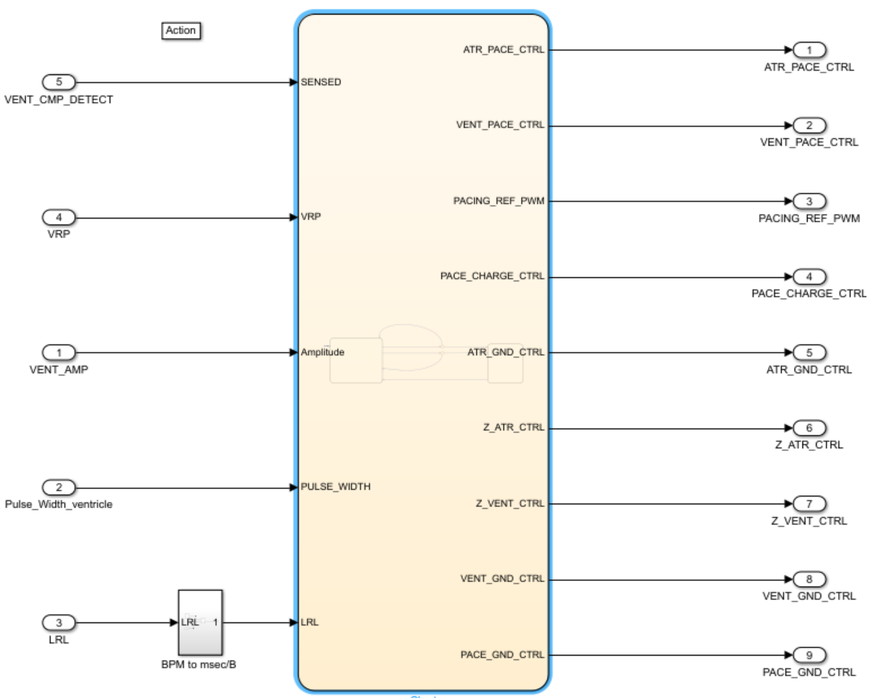
1.5.3 Design decisions

The decision was made to incorporate the VRP variable to properly inhibit pacing to the heart. Junctions were used in the implementation of VRP.

Some things likely to change are the allowed values of certain parameters which may be specific to other pacemaker designs and implementations. For example the allowable ranges of the amplitude voltage, pulse width, LRL, and URL may be subject to change. The changing of the hardware is also subject to change which will alter the design details but not the design structure.

1.5.4 Simulink Schematics





1.6 DOO

Mode DOO paces both the atrium and ventricle chambers with no sensing.

1.6.1 Inputs

ATR_AMP / VENT_AMP	Inputs a voltage for the PWM signal from 0-5V	0 - 5	V
Atrium_pulse_width Ventricular_pulse_width	The desired width of the paced signal	0.1 - 1.9	msec
Lower Rate Limit (LRL)	The number of generated paced pulses delivered to the atrium	30 - 175	PPM
Upper Rate Limit (URL)	The maximum rate at which it will sense events	50 - 175	PPM
AV_DELAY	Delay between atrium and ventricle pulses	70 - 300	msec

1.6.2 Outputs

NAME	DESCRIPTION	ALLOWED VALUES	TYPE/UNIT
ATR_PACE_CTRL	Enables pacing to atrium	true/false	boolean
VENT_PACE_CTRL	Enables pacing to ventricle	true/false	boolean
PACING_REF_PWM	Signal that charges the C22 capacitor to then be sent to the heart	0 - 100	Duty Cycle (%)
PACE_CHARGE_CTRL	Allows the C22 capacitor to be charged	true/false	boolean
ATR_GND_CTRL	Discharges C21 in the atrium to avoid charge build up in the heart	true/false	boolean
Z_ATR_CTRL	Used for analysis on the impedance in the atrium	true/false	boolean
Z_VENT_CTRL	Used for analysis on the impedance in the ventricle	true/false	boolean
VENT_GND_CTRL	Discharges C21 in the ventricle to avoid charge build up in the heart	true/false	boolean

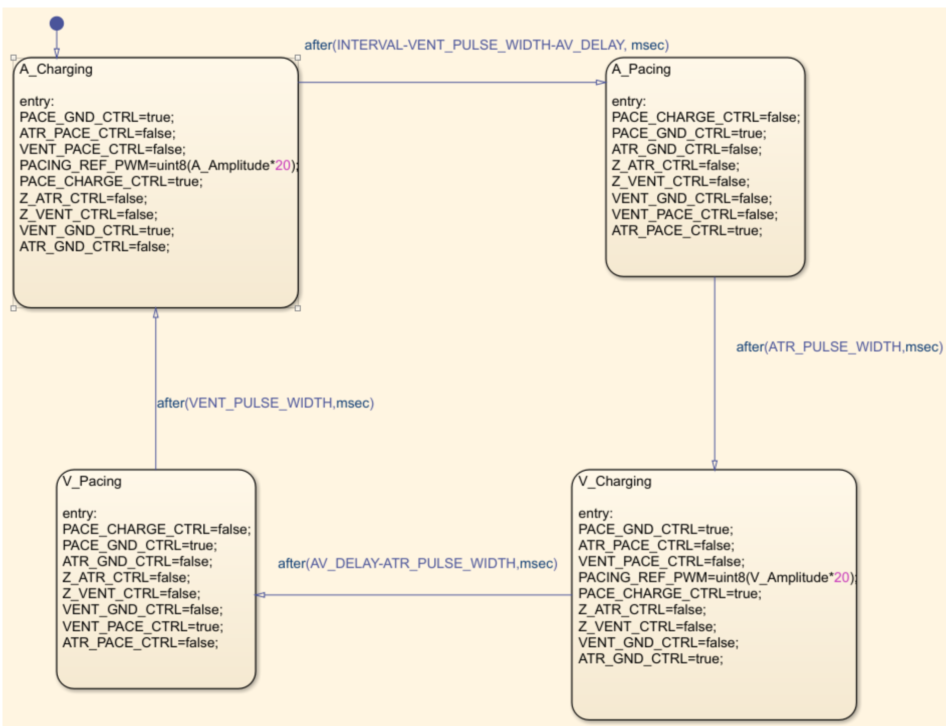
VENT_CMP_REF_PWM	Establishes the minimum threshold for ventricular action potential to be sensed	0 - 100	Duty Cycle (%)

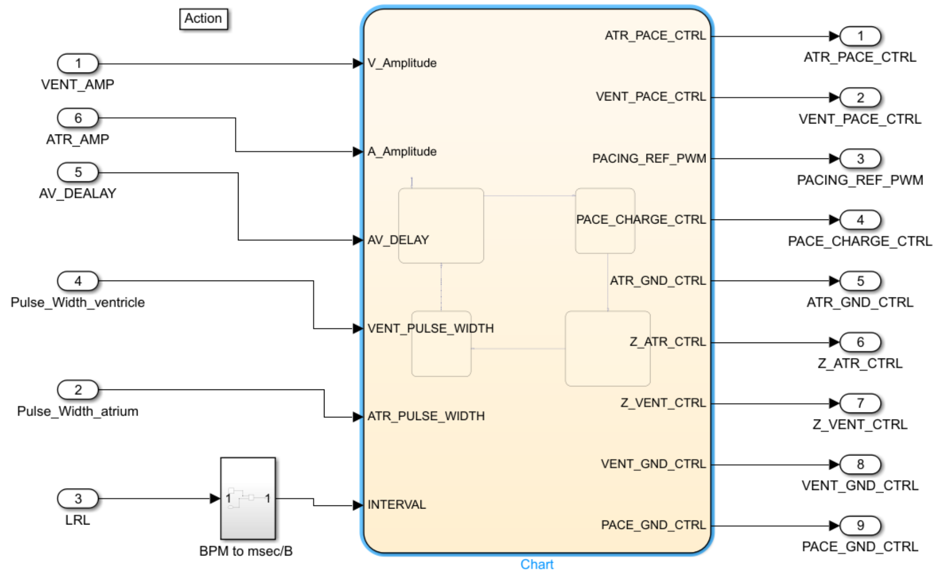
1.6.3 Design decisions

The decision was made to incorporate four states for DOO. There is a state for charging and pacing for each of the halves of the heart (atrium and ventricle) in which their pulses are offset by a time delay based upon the AV_DELAY variable.

Some things likely to change are the allowed values of certain parameters which may be specific to other pacemaker designs and implementations. For example the allowable ranges of the amplitude voltage, pulse width, LRL, URL and AV delay may be subject to change. The changing of the hardware is also subject to change which will alter the design details but not the design structure.

1.6.4 Simulink Schematics





1.7 Rate adaptive modes

In the design of this pacemaker, additions have been made to all the modes above (sections 1.2 - 1.6) to incorporate rate adaptive modes. Rate adaptive modes dynamically pace the heart according to the external metabolic demand. Compared with the normal pacing modes, the rate adaptive ones do not determine the pacing rate depending on the LRL, instead they fetch the data generated from the accelerometer (attached to the heart) to determine the desired pacing rate.

1.7.1 Inputs

The variables for the rate adaptive modes are similar to those of the normal modes with some new additions.

NAME	DESCRIPTION	ALLOWED VALUES	TYPE/UNIT
ATR_AMP / VENT_AMP	Inputs a voltage for the PWM signal from 0-5V	0 - 5	V
Atrium_pulse_width / ventricle_pulse_width	The desired width of the paced signal	0.1 - 1.9	msec
Lower Rate Limit (LRL)	The number of generated paced pulses delivered to the atrium/ventricle	30 - 175	PPM
Upper Rate Limit (URL)	The maximum rate at which it will sense events	50 - 175	PPM

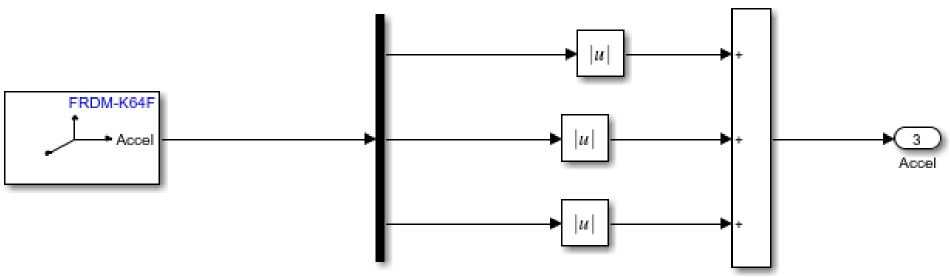
Maximum Sensor Rate (MSR)	The max pacing rate during rate adaptive pacing modes	50 - 175	PPM
ACTIVITY_THRESHOLD	Threshold for different levels of patient activity	1 (low) - 7 (high)	double
Reaction_time	How quickly the pacemaker responds to increased movement	10 - 50	sec
Recovery_time	How quickly the pacemaker responds to decreased movement	2 - 16	min
Response_factor	The steepness of slope/response time	1 - 16	uint8
SENSED/ATR_CMP_DETECT	Determines if there is a natural heartbeat	true/false	boolean
Atrial Refractory period (ARP) / Ventricle Refractory period (VRP)	Time interval in which no sensing/pacing occurs after a sensed pace	150 - 500	msec
Post Ventricular Atrial Refractory Period (PVARP)	Time interval following a ventricular event when an atrial cardiac event shall not Inhibit an atrial pace	150 - 500	msec
AV_DELAY	Delay between atrium and ventricle pulses	70 - 300	msec

1.7.2 Outputs

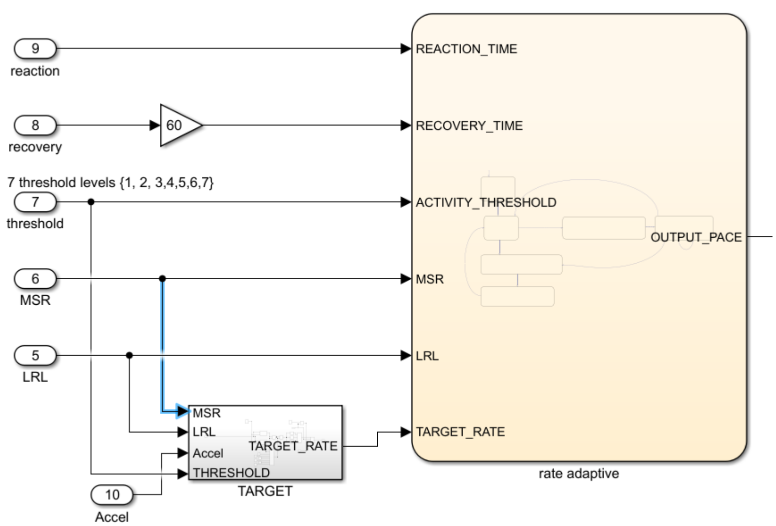
NAME	DESCRIPTION	ALLOWED VALUES	TYPE/UNIT
ATR_PACE_CTRL	Enables pacing to atrium	true/false	boolean
VENT_PACE_CTRL	Enables pacing to ventricle	true/false	boolean
PACING_REF_PWM	Signal that charges the C22 capacitor to then be sent to the heart	0 - 100	Duty Cycle (%)
PACE_CHARGE_CTRL	Allows the C22 capacitor to be charged	true/false	boolean
ATR_GND_CTRL	Discharges C21 in the atrium to avoid charge build up in	true/false	boolean

	the heart		
Z_ATR_CTRL	Used for analysis on the impedance in the atrium	true/false	boolean
Z_VENT_CTRL	Used for analysis on the impedance in the ventricle	true/false	boolean
VENT_GND_CTRL	Discharges C21 in the ventricle to avoid charge build up in the heart	true/false	boolean
VENT_CMP_REF_PWM / ATR_CMP_REF_PWM	Establishes the minimum threshold for atrium action potential to be sensed	0 - 100	Duty Cycle (%)

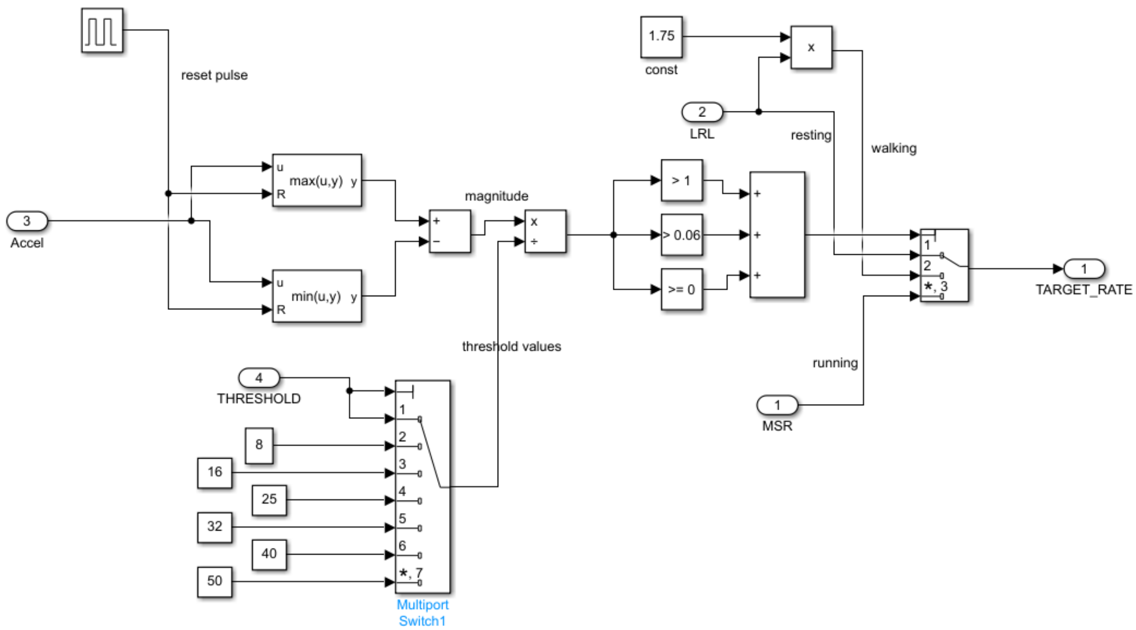
1.7.3 Design decisions



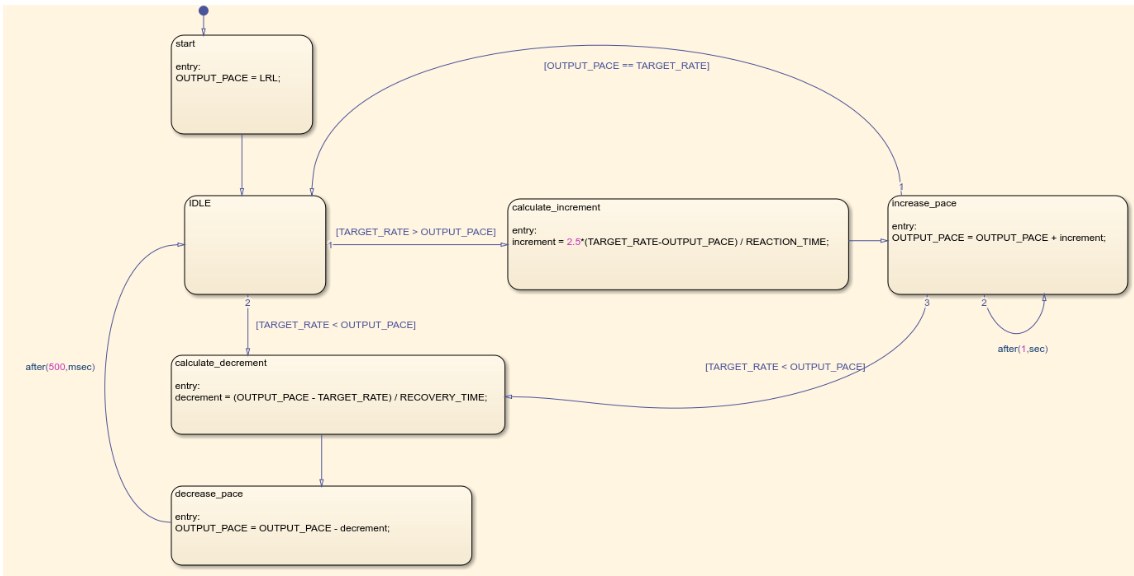
As seen in the above diagram, the first step in calculating the pace in rate adaptive modes was to separate the 3 signals, take the absolute values, and combine them together to generate one signal with scalar values.



In the overall rate adaptive system can be seen above in which calculations are performed to set the LRL (BPM) of the pacemaker.



Above is the calculation of the target pacing rate for the implementation of rate adaptive modes. After obtaining usable data from the accelerometer, it is passed through a maximum and minimum running resettable blocks to obtain the magnitude (difference between max and min) of the signal within a given timeframe. A pulse with a 2.5% duty cycle is used as the reset which has a period of 2 seconds to allow for decreasing values of magnitude rather than just increasing. After the magnitude has been calculated, the values are divided by a constant controlled by a switch to incorporate different activity threshold levels. The levels of activity between resting, walking, and running are calibrated with the according conditional statements and put into an adder. If the sum is 1, then it will take the value in position 1 (LRL). When the activity exceeds all the conditions (position 3), it will provide a target rate equal to the maximum sensor rate (MSR).



Once the target rate has been calculated, it is fed into the chart that controls increasing and decreasing pace. Increments/decrements are calculated with respective output pace, target rate, reaction time, and recovery time. The stateflow will then output the live calculated pace to the pacing state machine in which it will replace the LRL (from non-rate adaptive modes).

1.8 Testing

1.8.1 AOO Testing

Pacemaker inputs	Heartview inputs	Expected output	Test result (PASS/FAIL)
Amplitude = 1V Pulse width = 1ms BPM = 60	NA	Paced heartbeat at 1 beat/second with the max amplitude at 1V	PASS
Amplitude = 3V Pulse width = 1ms BPM = 90	NA	Paced heartbeat at 90BPM with the max amplitude at 3V	PASS
Amplitude = 3V Pulse width = 5ms BPM = 90	NA	Paced heartbeat at 90BPM with wider signal pulse	PASS
Amplitude = 1V Pulse width = 1ms BPM = 120	Pulse width = 1ms BPM = 60	Natural heartbeat and faster paced heartbeat; no sensing	PASS
Amplitude = 3V	Pulse width = 1ms	Large delay between	PASS

Pulse width = 100ms BPM = 90	BPM = 90	paced voltage and recovery voltage	
Amplitude = 10V Pulse width = 5ms BPM = 60	Pulse width = 1ms BPM = 120	No pacing since amplitude is out of bounds; natural beats	PASS

1.8.2 VOO Testing

Pacemaker inputs	Heartview inputs	Expected output	Test result (PASS/FAIL)
Amplitude = 1V Pulse width = 1ms BPM = 60	NA	Paced heartbeat at 1 beat/second with the max amplitude at 1V	PASS
Amplitude = 3V Pulse width = 1ms BPM = 90	NA	Paced heartbeat at 90BPM with the max amplitude at 3V	PASS
Amplitude = 3V Pulse width = 5ms BPM = 90	NA	Paced heartbeat at 90BPM with wider signal pulse	PASS
Amplitude = 1V Pulse width = 1ms BPM = 120	Pulse width = 1ms BPM = 60	Natural heartbeat and faster paced heartbeat; no sensing	PASS
Amplitude = 3V Pulse width = 100ms BPM = 90	Pulse width = 1ms BPM = 90	Large delay between paced voltage and recovery voltage	PASS
Amplitude = 10V Pulse width = 5ms BPM = 60	Pulse width = 1ms BPM = 120	No pacing since amplitude is out of bounds; natural beats	PASS

1.8.3 AAI Testing

Pacemaker inputs	Heartview inputs	Expected output	Test result (PASS/FAIL)
Amplitude = 1V Pulse width = 1ms BPM = 60 ARP = 0	NA	Normal paced heartbeat at 1 beat/second with the max amplitude at 1V	PASS
Amplitude = 3V Pulse width = 1ms BPM = 120 ARP = 0	Pulse width = 1ms BPM = 60	Pacing to help the heart beat at 120 BPM (pace every other natural heartbeat)	PASS

Amplitude = 3V Pulse width = 1ms BPM = 90 ARP = 0	Pulse width = 1ms BPM = 90	No pacing since heart is beating fast enough	PASS
Amplitude = 1V Pulse width = 1ms BPM = 60 ARP = 150	Pulse width = 1ms BPM = 90	No pacing since heart is beating fast enough	PASS
Amplitude = 3V Pulse width = 1ms BPM = 90 ARP = 200	Pulse width = 1ms BPM = 90	Pacing with the waiting ARP implementation	PASS
Amplitude = 3V Pulse width = 5ms BPM = 90 ARP = 200	Pulse width = 1ms BPM = 30	Pacing with the waiting ARP implementation	PASS

1.8.4 VVI Testing

Pacemaker inputs	Heartview inputs	Expected output	Test result (PASS/FAIL)
Amplitude = 1V Pulse width = 1ms BPM = 60 VRP = 0	NA	Normal paced heartbeat at 1 beat/second with the max amplitude at 1V	PASS
Amplitude = 3V Pulse width = 1ms BPM = 120 VRP = 0	Pulse width = 1ms BPM = 60	Pacing to help the heart beat at 120 BPM (pace every other natural heartbeat)	PASS
Amplitude = 3V Pulse width = 1ms BPM = 90 VRP = 0	Pulse width = 1ms BPM = 90	No pacing since heart is beating fast enough	PASS
Amplitude = 1V Pulse width = 1ms BPM = 60 VRP = 150	Pulse width = 1ms BPM = 90	No pacing since heart is beating fast enough	PASS
Amplitude = 3V Pulse width = 1ms BPM = 90 VRP = 200	Pulse width = 1ms BPM = 90	Pacing with the waiting VRP implementation	PASS

Amplitude = 3V Pulse width = 5ms BPM = 90 VRP = 200	Pulse width = 1ms BPM = 30	Pacing with the waiting VRP implementation	PASS

1.8.5 DOO Testing

Pacemaker inputs	Heartview inputs	Expected output	Test result (PASS/FAIL)
Amplitude = 1V Pulse width = 1ms BPM = 60 AV delay = 150	NA	Paced heartbeat at 1 beat/second with the max amplitude at 1V	PASS
Amplitude = 3V Pulse width = 1ms BPM = 120 AV delay = 150	Pulse width = 1ms BPM = 60	Paced heartbeat at 90BPM with the max amplitude at 3V	PASS
Amplitude = 3V Pulse width = 1ms BPM = 90 AV delay = 150	Pulse width = 1ms BPM = 90	Paced heartbeat at 90BPM with wider signal pulse	PASS
Amplitude = 1V Pulse width = 1ms BPM = 60 AV delay = 150	Pulse width = 1ms BPM = 90	Natural heartbeat and faster paced heartbeat; no sensing	PASS
Amplitude = 3V Pulse width = 1ms BPM = 90 AV delay = 200	Pulse width = 1ms BPM = 90	Large delay between paced voltage and recovery voltage	PASS
Amplitude = 3V Pulse width = 5ms BPM = 90 AV delay = 200	Pulse width = 1ms BPM = 30	No pacing since amplitude is out of bounds; natural beats	PASS

1.8.6 AOOR Testing

Pacemaker inputs	Heartview inputs	Expected output	Test result (PASS/FAIL)
Amplitude = 1V Pulse width = 1ms Rate adaptive: rest	NA	Paced atrium at the LRL	PASS

Amplitude = 3V Pulse width = 1ms Rate adaptive: rest	Pulse width = 1ms BPM = 60	Paced atrium at LRL with natural heartbeat	PASS
Amplitude = 3V Pulse width = 1ms Rate adaptive: walking	Pulse width = 1ms BPM = 90	Paced atrium at walking pace (relative to LRL)	PASS
Amplitude = 1V Pulse width = 1ms Rate adaptive: walking	Pulse width = 1ms BPM = 90	Paced atrium at walking pace (relative to LRL)	PASS
Amplitude = 3V Pulse width = 1ms Rate adaptive: running	Pulse width = 1ms BPM = 90	Paced atrium at running pace (MSR)	PASS
Amplitude = 3V Pulse width = 5ms Rate adaptive: running	Pulse width = 1ms BPM = 30	Paced atrium at running pace (MSR)	PASS

1.8.7 VOOR Testing

Pacemaker inputs	Heartview inputs	Expected output	Test result (PASS/FAIL)
Amplitude = 1V Pulse width = 1ms Rate adaptive: rest	NA	Paced ventricle at the LRL	PASS
Amplitude = 3V Pulse width = 1ms Rate adaptive: rest	Pulse width = 1ms BPM = 60	Paced ventricle at LRL with natural heartbeat	PASS
Amplitude = 3V Pulse width = 1ms Rate adaptive: walking	Pulse width = 1ms BPM = 90	Paced ventricle at walking pace (relative to LRL)	PASS
Amplitude = 1V Pulse width = 1ms Rate adaptive: walking	Pulse width = 1ms BPM = 90	Paced ventricle at walking pace (relative to LRL)	PASS
Amplitude = 3V Pulse width = 1ms Rate adaptive: running	Pulse width = 1ms BPM = 90	Paced ventricle at running pace (MSR)	PASS
Amplitude = 3V Pulse width = 5ms Rate adaptive: running	Pulse width = 1ms BPM = 30	Paced ventricle at running pace (MSR)	PASS

1.8.8 AAIR Testing

Pacemaker inputs	Heartview inputs	Expected output	Test result (PASS/FAIL)
Amplitude = 1V Pulse width = 1ms Rate adaptive: rest ARP = 0	NA	Normal paced heartbeat at 1 beat/second with the max amplitude at 1V	PASS
Amplitude = 3V Pulse width = 1ms Rate adaptive: rest ARP = 0	Pulse width = 1ms BPM = 60	Pacing to help the heart beat at 120 BPM (pace every other natural heartbeat)	PASS
Amplitude = 3V Pulse width = 1ms Rate adaptive: walking ARP = 0	Pulse width = 1ms BPM = 90	No pacing since heart is beating fast enough	PASS
Amplitude = 1V Pulse width = 1ms Rate adaptive: walking ARP = 200	Pulse width = 1ms BPM = 90	No pacing since heart is beating fast enough	PASS
Amplitude = 3V Pulse width = 1ms Rate adaptive: running ARP = 200	Pulse width = 1ms BPM = 90	Pacing with the waiting ARP implementation	PASS
Amplitude = 3V Pulse width = 5ms Rate adaptive: running ARP = 200	Pulse width = 1ms BPM = 30	Pacing with the waiting ARP implementation	PASS

1.8.9 VVIR Testing

Pacemaker inputs	Heartview inputs	Expected output	Test result (PASS/FAIL)
Amplitude = 1V Pulse width = 1ms Rate adaptive: rest VRP = 0	NA	Normal paced heartbeat at 1 beat/second with the max amplitude at 1V	PASS
Amplitude = 3V Pulse width = 1ms Rate adaptive: rest ARP = 0	Pulse width = 1ms BPM = 60	Pacing to help the heart beat at 120 BPM (pace every other natural heartbeat)	PASS
Amplitude = 3V	Pulse width = 1ms	No pacing since heart is	PASS

Pulse width = 1ms Rate adaptive: walking VRP = 0	BPM = 90	beating fast enough	
Amplitude = 1V Pulse width = 1ms Rate adaptive: walking VRP = 200	Pulse width = 1ms BPM = 90	No pacing since heart is beating fast enough	PASS
Amplitude = 3V Pulse width = 1ms Rate adaptive: running VRP = 200	Pulse width = 1ms BPM = 90	Pacing with the waiting VRP implementation	PASS
Amplitude = 3V Pulse width = 5ms Rate adaptive: running VRP = 200	Pulse width = 1ms BPM = 30	Pacing with the waiting VRP implementation	PASS

1.8.10 DOOR Testing

Pacemaker inputs	Heartview inputs	Expected output	Test result (PASS/FAIL)
Amplitude = 1V Pulse width = 1ms Rate adaptive: rest AV delay = 50	NA	Paced atrium and ventricle at the LRL	PASS
Amplitude = 3V Pulse width = 1ms Rate adaptive: rest AV delay = 50	Pulse width = 1ms BPM = 60	Paced atrium and ventricle at LRL with natural heartbeat	PASS
Amplitude = 3V Pulse width = 1ms Rate adaptive: walking AV delay = 150	Pulse width = 1ms BPM = 90	Paced atrium and ventricle at walking pace (relative to LRL)	PASS
Amplitude = 1V Pulse width = 1ms Rate adaptive: walking AV delay = 150	Pulse width = 1ms BPM = 90	Paced atrium and ventricle at walking pace (relative to LRL)	PASS
Amplitude = 3V Pulse width = 1ms Rate adaptive: running AV delay = 200	Pulse width = 1ms BPM = 90	Paced atrium and ventricle at running pace (MSR)	PASS

Amplitude = 3V Pulse width = 5ms Rate adaptive: running AV delay = 200	Pulse width = 1ms BPM = 30	Paced atrium and ventricle at running pace (MSR)	PASS

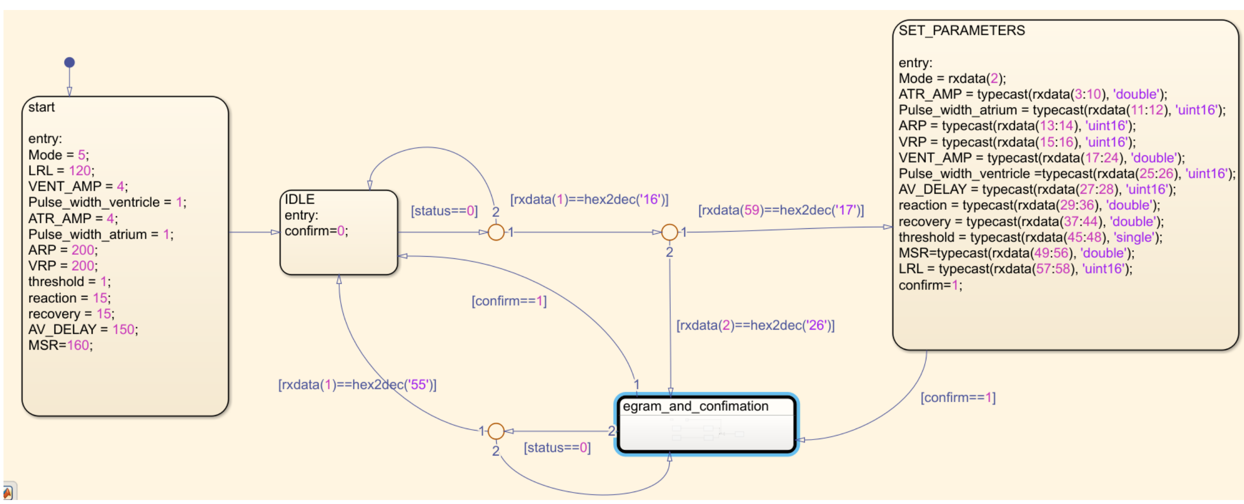
2 Combinational Logic Implementation

2.1 Introduction

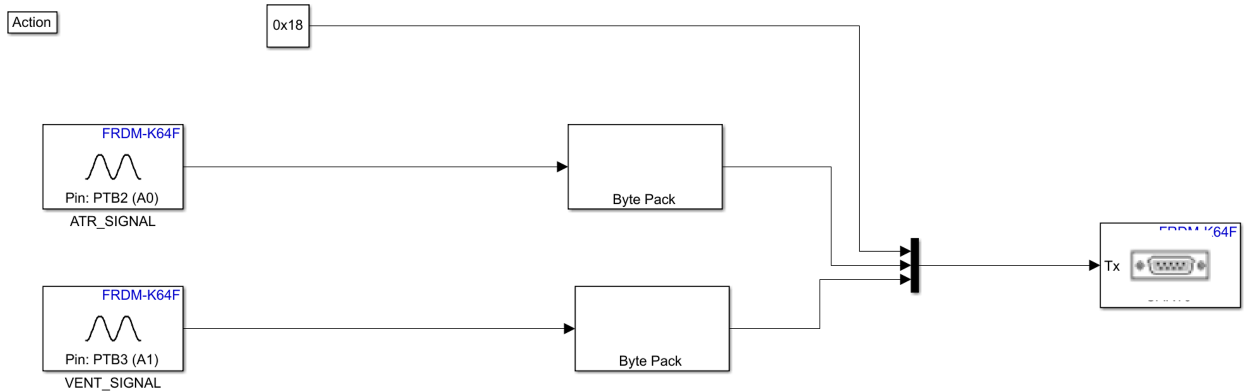
In this section, the implementation of serial communication will be discussed as well as the connections between the hardware and simulink models.

2.2 Serial communication

The serial communication module is an additional subsystem that ensures ease of operation of the pacemaker. Instead of manually restarting the device to enter new pacing modes, the pacemaker now receives data from the DCM which specifies the modes as well as other input parameters.



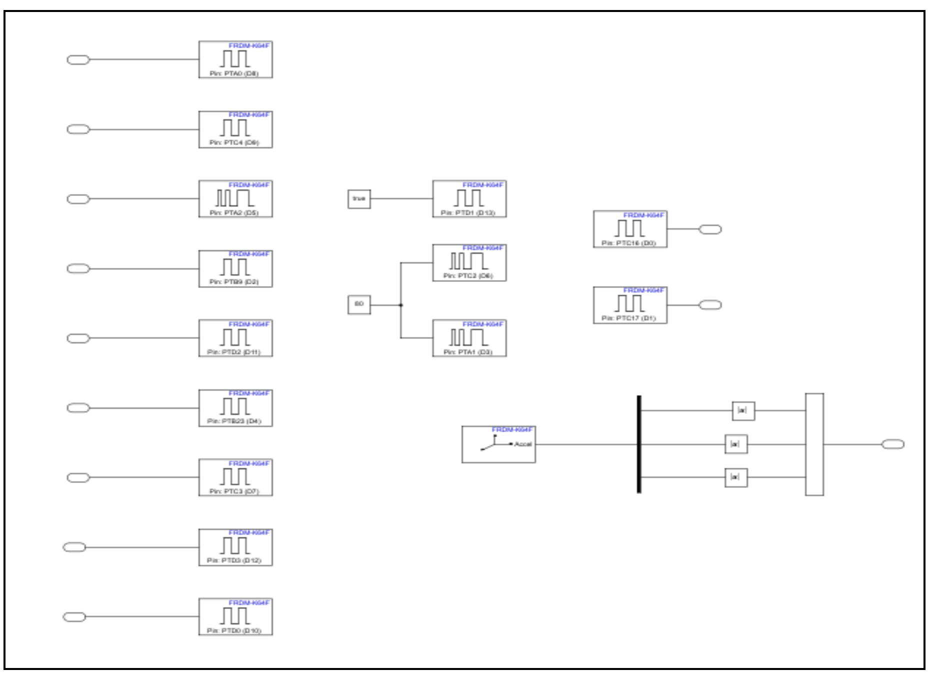
In the ‘start’ state the pacemaker generates default parameters then enters the IDLE state where these parameters are passed to the actual pacing component. While receiving data transferred from the DCM, new values will overwrite the default parameters in the SET_PARAMETER state, and this state transfer happens when a start signal is detected from the DCM side.



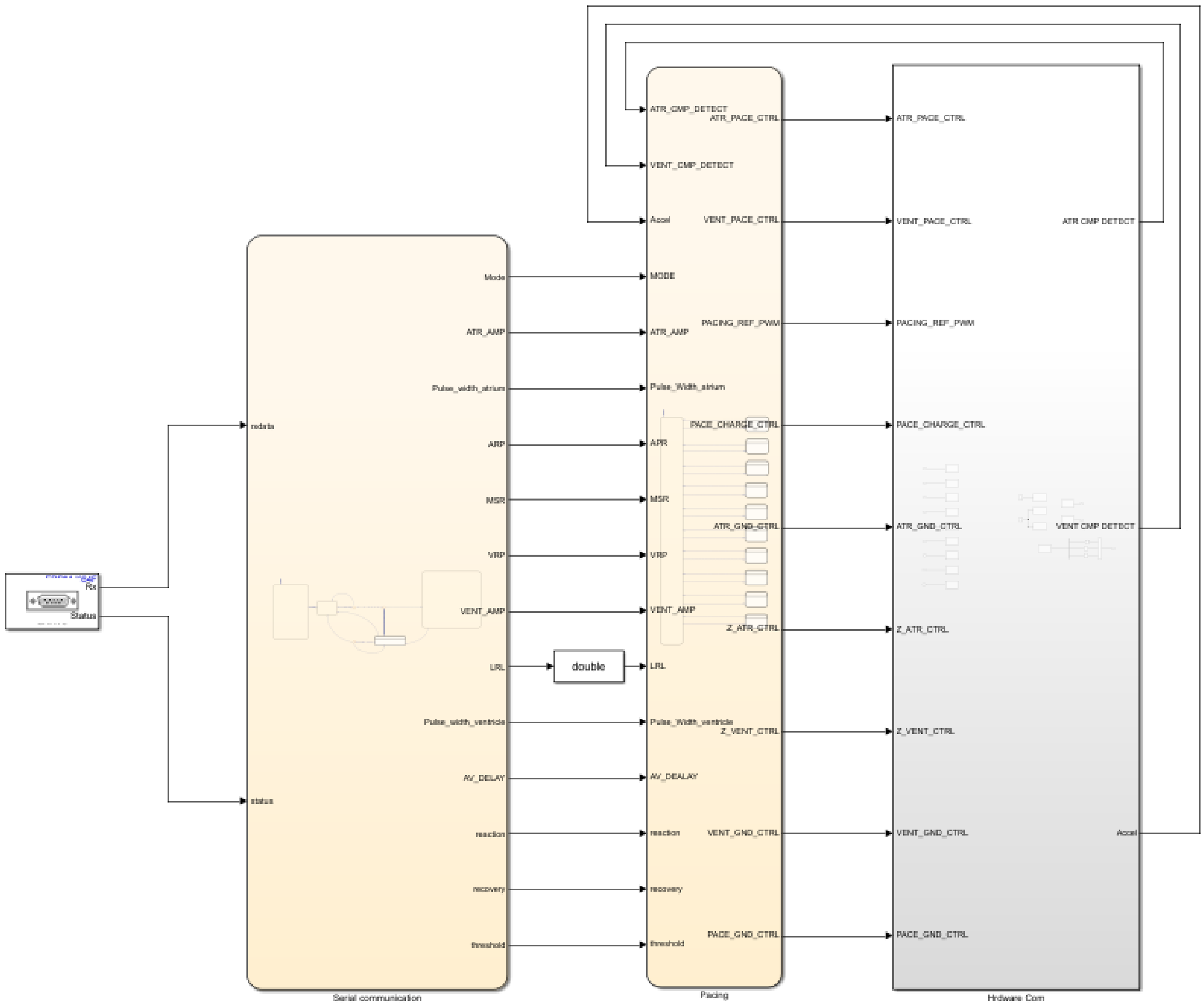
The above diagram allows for transmitting serial data back to the DCM. The byte packs are used to organize the serial transmittion.

2.3 Overall Design

In the overall design of the pacemaker, the main modules include serial communication, rate adaptive calculations, pacing/sensing, and hardware hiding. Parameters are received and transmitted accordingly to and from the DCM and Simulink model.



In the figure above, the hardware hiding portion is put into a simulink subsystem so that the pacemaker may be compatible with different boards.



Above is the overall design of the pacemaker. First there is serial communication which deals with sending and receiving parameters for the pacemaker. Next is the pacing portion which includes normal modes and rate adaptive modes. Inside the calculations for rate adaptive modes are performed.

3 Improvements

Possible improvements to be made are changing the method of connection between the DCM and simulink models. Serial communication can sometimes be difficult to work with when using variable types of ‘single’ and ‘double’. Since these inconveniences can occur, it would be better to find a new form of communication or to make sure that everything within the data sent in the serial communication is of type ‘uint8/int8’, ‘uint16/int16’, ‘uint32/int32’.

The possible future changes will be focusing on strengthening bidirectional transfers between the DCM and the pacemaker in order to send feedback or acknowledge received data. This can be done by updating the existing serial communication module with more functionalities.

The pacemaker can also be improved by including the onboard push button to pace the heart as mentioned in assignment 1, or by maintaining the AC synchrony in specific situations so that DDD and DDDR modes will be supported by the pacemaker. As there are a few onboard LEDs that can be included in the pacemaker design, the state flow will be visible to make debugging procedures easier and to improve the user-friendliness.

Additional modes such as DDIR, DDD, and DDDR may be implemented to improve the pacemaker. These modes will enhance the flexibility of the pacemaker between patients to better suit their requirements for a regular heartbeat.

4 Citations

[1]
G. Meyer, “Pacemaker Microcontroller Shield”, *McMaster University*, November 2020. [Accessed: November 30, 2021]
[2]
“PACEMAKER System Specification”, *Boston Scientific*, January 3, 2007. [Accessed: November 30, 2021