**Test Cases Description**

Strategy: Come up with test cases that show that each timing cycle is satisfied.

Format: Tables, as specified by writeup, followed by justification.

**0. LRI**

| Time (ms) | Action |
|---|---|
| 0 | Vpace (received) |
| between 0 and TIME_LRI | Apace (expected, not enforced) |
| TIME_LRI | Vpace (expected) |
| TIME_LRI + TIME_VRP + 20 | Vsignal (generate) |
| between TIME_LRI + 20 and 2 * TIME_LRI + 20 | Apace (expected, not enforced) |
| 2*TIME_LRI + TIME_VRP + 20 | Vpace (expected) |

20 can be any other small enough number.

**Justification:**
LRI says there must be no more than TIME_LRI between ventricular events. So we test if pacemaker paces ventricle after TIME_LRI after it paces, and after it senses (Vsignal). If it does, then LRI is being enforced correctly.

**1. VRP**

| Time (ms) | Action |
|---|---|
| 0 | Vpace (received) |
| TIME_VRP - 20 | Vsignal (generate) |
| between TIME_VRP - 20 and TIME_LRI | Apace (expected, not enforced) |
| TIME_LRI | Vpace (expected) |

20 can be any other small enough number.

**Justification:**
This tests if we can send a Vsignal within TIME_VRP without “starting a new LRI”. This means Vpace should come after TIME_LRI, not TIME_LRI + TIME_VRP.

**2. AVI (Atrial Ventricular Interval)**

| Time (ms) | Action |
|---|---|
| 0 | Vpace (received) |
| TIME_PVARP + 20 **(> TIME_URI)** | Asignal (generate) |
| TIME_PVARP + 20 + TIME_AVI | Vpace (expected) |

**Justification**:

AVI says that, after a non-ignored atrial event, a ventricular pace should be delivered by pacemaker within TIME_AVI. This tests this behavior by sending an atrial event when it is sure not to be ignored (dependency on PVARP), and expects a Vpace after TIME_AVI.

**3. PVARP (Post Ventricular-Atrial Refractory Period)**

| Time (ms) | Action |
|---|---|
| 0 | Vpace (received) |
| TIME_PVARP - 20 | Asignal (generate) |
| TIME_URI + 20 | Asignal (generate) |
| TIME_URI + TIME_AVI + 20 | Vpace (expected) |

**Justification**:

After a ventricular event, the pacemaker should “ignore” atrial events until TIME_PVARP elapses (i.e. it won’t “start an AVI”). This tests that by generating an Asignal within TIME_PVARP and checking that a Vpace is not generated after TIME_AVI. Then, it generates an Asignal after TIME_PVARP (from the beginning of test) has elapsed, and waits for a Vpace after TIME_AVI.

**4. URI (Upper Rate Interval)**

| Time (ms) | Action |
|---|---|
| 0 | Vpace (received) |
| TIME_PVARP + 20 **(< TIME_URI - TIME_AVI)** | Asignal (generate) |
| TIME_URI | Vpace (expected) |
| TIME_URI + TIME_URI + 20 | Asignal (generate) |
| TIME_URI + TIME_URI + 20 + TIME_AVI | Vpace (expected) |

**Justification:**

After a ventricular event, the pacemaker shouldn't pace before TIME_URI elapses. This means TIME_URI can delay a Vpace if needed ("extends AVI"). This is tested by sending an Asignal some time before TIME_URI - TIME_AVI. If we get a Vpace before TIME_URI, then URI is not being enforced correctly, otherwise it is. Then, if we do get a Vpace at the correct time, we wait for TIME_URI after the Vpace, then send Asignal. We then expect a Vpace after TIME_AVI, which shows TIME_URI correctly didn't inhibit Vpace in this case.

**5. Normal atrium and normal ventricle (NANV)**

| Time (ms) | Action |
|---|---|
| 0 | Vpace (received) |
| TIME_URI | Asignal (generate) |
| TIME_URI + TIME_AVI - 20 | Vsignal (generate) |
| 2 * TIME_URI + TIME_AVI - 20 | Asignal (generate) |
| 2 * TIME_URI + 2 * TIME_AVI - 2 * 20 | Vsignal (generate) |

**Justification**:
This is a "normal" heartbeat. We shouldn't receive any pacing at all for this test case. We test for 2 cycles.

**6. Normal atrium and fast ventricle (NAFV)**

| Time (ms) | Action |
|---|---|
| 0 | Vpace (received) |
| TIME_URI | Asignal (generate) |
| TIME_URI + TIME_AVI / 2 | Vsignal (generate) |
| 2 * TIME_URI + TIME_AVI / 2 | Asignal (generate) |
| 2 * TIME_URI + TIME_AVI | Vsignal (generate) |

**Justification**:
This is a heart in which the atrium behaves normally (waits TIME_URI after ventricular events), but the ventricle is too fast (only waits TIME_AVI / 2). Note this is similar to the normal-A, normal-V case. We shouldn't receive any pacing at all for this test case. We test for 2 cycles.

**7. Normal atrium and slow ventricle (NASV)**

| Time (ms) | Action |
|---|---|
| 0 | Vpace (received) |
| TIME_URI | Asignal (generate) |
| TIME_URI + TIME_AVI | Vpace (expected) |
| 2 * TIME_URI + TIME_AVI | Asignal (generate) |
| 2 * TIME_URI + 2 * TIME_AVI | Vpace (expected) |

**Justification**:
This is a heart in which the atrium behaves normally (waits TIME_URI after ventricular events), but the ventricle is too slow. Only the ventricle should be paced, TIME_AVI after Asignal. We test for 2 cycles.

**8. Fast atrium and normal ventricle (FANV)**

| Time (ms) | Action |
|---|---|
| 0 | Vpace (received) |
| TIME_PVARP + 20 | Asignal (generate) |
| TIME_PVARP + TIME_AVI | Vsignal (generate) |
| 2 * TIME_PVARP + TIME_AVI + 20 | Asignal (generate) |
| 2 * TIME_PVARP + 2 * TIME_AVI | Vsignal (generate) |

**Justification**:
This is a heart in which the atrium is too fast (only waits TIME_PVARP + 20), but the ventricle behaves normally (waits TIME_AVI - 20). We shouldn't receive any pacing at all for this test case. We test for 2 cycles.

**9. Fast atrium and fast ventricle (FAFV)**

| Time (ms) | Action |
|---|---|
| 0 | Vpace (received) |
| TIME_URI - 20 | Asignal (generate) |
| TIME_URI + TIME_AVI / 2 - 20 | Vsignal (generate) |
| 2 * TIME_URI + TIME_AVI / 2  - 2 * 20 | Asignal (generate) |
| 2 * TIME_URI + TIME_AVI - 2 * 20 | Vsignal (generate) |

**Justification**:
This is a heart that's beating too fast (violating URI). We also shouldn't receive any pacing for this. We test for 2 cycles.

**10. Fast atrium and slow ventricle (FAFV)**

| Time (ms) | Action |
|---|---|
| 0 | Vpace (received) |
| TIME_PVARP + 20 | Asignal (generate) |
| TIME_PVARP + 20 + TIME_AVI | Vpace (expected) |
| 2 * TIME_PVARP + 2 * 20 + TIME_AVI | Asignal (generate) |
| 2 * TIME_PVARP + 2 * 20 + 2 * TIME_AVI | Vpace (expected) |

**Justification**:
This is a heart in which the atrium is too fast (only waits TIME_PVARP + 20), but the ventricle is too slow. The ventricle should be paced in this case. We test for 2 cycles.

**11. Slow atrium and normal ventricle (SANV)**

| Time (ms) | Action |
|---|---|
| 0 | Vpace (received) |
| TIME_LRI - TIME_AVI | Apace (expected) |
| TIME_LRI - 20 | Vsignal (generate) |
| 2 * TIME_LRI - TIME_AVI - 20 | Apace (expected) |
| 2 * TIME_LRI - 2 * 20 | Vsignal (generate) |

**Justification**:
This is a heart in which the atrium is too slow, but the ventricle behaves normally (waits TIME_AVI - 20). We should receive pacing only for the atrium. We test for 2 cycles.

**12. Slow atrium and fast ventricle (SAFV)**

| Time (ms) | Action |
|---|---|
| 0 | Vpace (received) |
| TIME_LRI - TIME_AVI | Apace (expected) |
| TIME_LRI - TIME_AVI / 2 | Vsignal (generate) |
| 2 * TIME_LRI - TIME_AVI * 3 / 2 | Apace (expected) |
| 2 * TIME_LRI - TIME_AVI / 2 | Vsignal (generate) |

**Justification**:
This is a heart in which the atrium is too slow, but the ventricle is too fast (only waits TIME_AVI / 2). We should receive pacing only for the atrium. We test for 2 cycles.

**13. Slow atrium and slow ventricle (SASV)**

| Time (ms) | Action |
|---|---|
| 0 | Vpace (received) |
| TIME_LRI - TIME_AVI | Apace (expected) |
| TIME_LRI | Vpace (expected) |
| 2 * TIME_LRI - TIME_AVI | Apace (expected) |
| 2 * TIME_LRI | Vpace (expected) |

**Justification**:
This is a heart that's beating too slow. It's not sending signals after being paced because it's supposed to be slow, and I assume the heart won't want to beat on its own after being paced. We test for 2 cycles.

The test log can be found in the next page. We believe most of our model is working correctly (from examining LED activity and scope captures), but the tests mostly fail. We believe this has to do with the test implementation details.

**Test Log**

Test: VRP
Test: VRP fail (paced before Vsense)
Test: AVI
Test: AVI APACE 1 too early
Test: PVARP
Test: PVARP VPACE failed to arrive
Test: URI
Test: URI VPACE 1 failed to arrive
Test: NANV
Test: NANV fail (Apaced before 1st Asignal)
Test: NAFV
Test: NAFV fail (Apaced before 1st Asignal)
Test: Normal atrium and slow ventricle (NASV)
Test: NASV VPACE 1 failed to arrive
Test: Fast atrium and normal ventricle (FANV)
Test passed: FANV
Test: FAFV
Test: FAFV fail (Apaced before 1st Asignal)
Test: LRI
Test: LRI VPACE 1 failed to arrive
Test: FASV
Test: FASV fail (Apaced before 1st Asignal)
Test: slow atrium and normal ventricle (SANV)
Test: SANV APACE 1 too early
Test: slow atrium and fast ventricle (SAFV)
Test: SAFV APACE 1 too early
Test: SASV
Test: SASV fail (Apaced before 1st Apace)