EVALUATION OF PERFORMANCE OF SOLAR POWERED FLASHING BEACONS AT ROOM TEMPERATURE CONDITIONS

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A report of the findings of
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Evaluation of Performance of Solar Powered Flashing Beacons

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This report presents the results of five tests on JSF flashing beacons and the results of 10 tests on Carmanah flashing beacons under room temperature conditions. Each test determined the time each module flashed in the Manual on Uniform Traffic Control Devices (MUTCD) flashing pattern, the battery voltage over time, and the outputted light intensity over time. The results of the tests showed that for JSF flashing beacons, the voltage drops gradually over time. The red color of JSF flashed in the MUTCD flashing pattern for at least 24 days. The yellow color of JSF beacon flashed in the MUTCD flashing rate for at least 16 days. For both colors of JSF beacons, the outputted light intensity remained at an almost constant level over time at 22-27 foot-candles for the red color and 25-30 foot-candles for the yellow color. In the fall months, the JSF flashing beacons needed around three days to get fully charged. The six uninterrupted tests conducted on Carmanah modules proved the company’s claim that both modules would flash in the MUTCD flashing pattern for one day and then switch to the power saving mode if they do not receive any charge from the solar panel. On the other hand, the results of the four interrupted tests revealed that the red color of Carmanah beacon can flash in the MUTCD flashing pattern for 11.5 to 12.5 days. The yellow color of Carmanah can flash in the MUTCD pattern for 8.6 to 10.1 days. The Carmanah modules produced a high light intensity of approximately 100 ft-candle for red and 160 ft-candle for yellow at the beginning of the discharge period, but the intensity for the red module decreased to 20 ft-candle in 8 to 10 days and to 40 ft-candle for yellow in six to eight days. In the fall, Carmanah flashing beacons need around six days to become fully charged.
ACKNOWLEDGMENT AND DISCLAIMER

This publication is based on the results of ICT-R27-59, Evaluation of Performance of Solar Powered Flashing Beacons. ICT-R27-59 was conducted in cooperation with the Illinois Center for Transportation; the Illinois Department of Transportation; and the U.S. Department of Transportation, Federal Highway Administration.

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The contents of this report reflect the view of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Center for Transportation, the Illinois Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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EXECUTIVE SUMMARY

This study was conducted in the Traffic Operations Lab (TOL) of the University of Illinois at Urbana-Champaign to determine: a) the time the solar powered flashing beacons continue flashing in MUTCD pattern without being recharged, b) their charge time, and c) their outputted light intensity in room temperature conditions. The beacons were provided by: JSF Electronics and Carmanah Technologies Corporation.

The yellow and red-color JSF modules flashed in the MUTCD flashing pattern for at least 16 and 24 days, respectively. For both colors of JSF beacons, the outputted light intensity remained almost constant over time at 22 to 27 foot-candle range for the red color and 25 to 30 foot-candle range for the yellow color. It took almost three days to fully charge the JSF flashing beacons. The red color of Carmanah flashed in MUTCD pattern for at least 11.5 days, and the yellow color flashed for at least 8.6 days. The light intensity for the Carmanah red module started at a high level of around 100 foot-candles and dropped to about 20 foot-candles in 8 to 10 days. For the yellow module, it dropped from 160 to 40 foot-candles in 6 to 8 days. Carmanah flashing beacons needed around six days to become fully charged.
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1. INTRODUCTION

The use of solar powered flashing beacons on the state highway system is increasing. The flashing beacons may be used at rural stop controlled intersections, roadways with restricted geometry, in advance of work zones, and other situations that require more attention from drivers than normal driving conditions. The flashing beacons’ feasibility, reliability, and performance have improved with the advancement in technology including the use of LED modules. However, how long the beacons can function depends on the battery type, operating environment, and the flashing pattern used. Environmental conditions (temperature, cloud, etc.) could affect the battery charge level. The flashing pattern and visibility of the beacon may change as the battery charge level decreases. The beacons could be in locations with a lot or with a limited amount of sunshine. As a result, it is critical to know how long the beacon can flash in Manual on Uniform Traffic Control Devices (MUTCD) pattern if for some reason they are not exposed to sunlight for a short time period. In addition, it is necessary to know how long they continue flashing in the MUTCD flashing pattern before switching to the power saving pattern and how long they continue working in any flashing pattern. The output light intensity of the flashing beacons in each pattern needs to be known since it affects its visibility. Moreover, the user should know how long it would take to fully charge the batteries and what the charging pattern is.

The purpose of this study is to determine how long a fully charged flashing beacon module continues flashing in the MUTCD flashing pattern, what the light intensity is and how it changes over time, and what the charging and discharging pattern of the batteries are. Two companies (JSF and Carmanah) provided solar powered flashing beacons to be tested. Each company provided one yellow and one red flashing beacon. The performance of the flashing beacons was tested in three temperature conditions (room, cold, and hot). This report presents the beacons’ performance at room temperature. The performance is evaluated in terms of duration of flashing in MUTCD pattern, light intensity output, and battery charge level. The performance data for cold and hot temperature conditions are being collected and will be presented in separate reports.
2. LITERATURE REVIEW

While there are many studies on effectiveness of various flashing beacons on safety, no study was found that particularly evaluates the performance of the batteries of the solar powered flashing beacons over time at different temperatures. However, there are some studies that determine the battery life of Uninterrupted Power Supply (UPS) systems used at intersections. Chitturi and Benekohal (2005) measured the charge and discharge times of the above-mentioned UPS systems. Chitturi and Benekohal (2003) conducted similar studies to determine the time a UPS system can power an intersection with LED modules when there is a power outage. In this study, a similar approach to determine the discharge time of solar powered flashing beacons is used.
3. TEST DESCRIPTION

Two companies that have sold a substantial number of flashing beacons in Illinois, J S F Electronics (JSF) and Carmanah Technologies Corporation (Carmanah), were asked to provide a sample of their yellow and red flashing beacons for this evaluation. The model numbers of the tested beacons are: FL-12R-1412 for JSF Red and Yellow colors, and 46319 R24730 for Carmanah Red and Yellow colors. The beacons were installed in a support structure in the Traffic Operations Lab (TOL) and were prepared for testing. The research team made sure the devices were working properly and charging and discharging as expected. Data collection equipment (multimeter, computer, monitor, video recorder, software, etc.) were assembled and tested to be sure they were working properly. Test runs checked the measurements and confirmed that testing procedures were working properly. The items monitored were:

a. Voltage level of battery
b. Flashing pattern and duration
c. Light intensity level

Figure 3.1 (a and b) shows the modules mounted in a metallic frame for the room temperature test. In figure 3.1.a both JSF modules are flashing and in figure 3.1.b both Carmanah modules are flashing. As shows in the figure the solar panel compartment of Carmanah modules were dissembled from the lens.
3.1. VOLTAGE LEVEL OF BATTERY

To make sure the battery is fully charged, the voltage level of the battery was monitored over time at 15-minute intervals. When the voltage level stops increasing, the battery is considered fully charged. Figure 3-2 shows voltage level during recharging for the battery used for Carmanah’s red module. A similar plot was obtained for the battery for Carmanah’s yellow module. It should be mentioned that during the charging period the flashing beacons were turned off or disconnected from the battery. Thus, the LEDs did not use any battery power when the charging was in progress.
Figure 3.2. Voltage versus time for the battery of Carmanah’s red flashing beacon.
3.2 FLASHING PATTERN AND DURATION

Once the battery was fully charged according to the manufacturer’s recommendation, it was allowed to remain inside the lab for about an hour so the charge level is “stabilized.” Then, the flashing beacon was connected to the battery and the voltage level was monitored. A multimeter was connected to the battery poles showing the voltage of the battery. This multimeter was also connected to the computer so that it was sending the voltages on 1-minute intervals to the computer. The voltage and its time stamp were recorded in the computer and used to plot voltage versus time. A summary of findings is presented for each module later in this section. In addition, a video recording device capable of time lapsed recording was used to record the flashing pattern to confirm the time the flashing pattern was changed. The recording was done in three-hour time interval for a period of one minute.

3.3 LIGHT INTENSITY LEVEL

In order to measure the light intensity of the modules, three different methods were attempted. First, the modules were set to work on steady state (solid not flashing) for about two minutes so that repeated light intensity measurements could be taken using the K-Light LED light intensity measuring device. As expected, the voltage level and light intensity level dropped as the time passed. Considering the amount of the voltage drop, this test was draining the battery rapidly and seemed inappropriate.

The second method was to turn on the module to a steady state for 3 seconds so a single measurement of the light intensity could be taken; then turn it off and wait for 30 seconds; and then turn it on again. This method did not drain the battery like the first method, but it required the test be interrupted multiple times to get the light intensities measurements. To solve this problem, a third method was used in which the light intensity was measured while the beacon was flashing. This method of measurement did not interrupt the test; however, the testers needed to make sure that the device is capable of measuring the light intensity when the beacon was flashing. To make sure the device was capable, the light intensity in the steady state and in the flashing mode were measured and compared. This comparison showed that the device could be used to measure the light intensity in the flashing mode.

In each run of the test, the light intensity was measured frequently as soon as the test was started. During the first day, around six measurements were completed. Later on, one measurement was completed every two or three days.
4. RESULTS

This section presents the findings from multiple tests for each module. The findings for red and yellow JSF modules are presented first, followed by the findings for Carmanah modules.

4.1. JSF RED

4.1.1. JSF Red Duration

Presently five tests have been conducted on the JSF red module. Except for the first test, the batteries were fully charged (in Test 1 the batteries were fully charged but, test started 10 days later so they lost some power). Figure 4.1 shows the voltage – time diagram for the red module.

![Figure 4.1. All test results for Red JSF.](image)

A summary of all five tests has been presented in Table 4.1.
Table 4.1. Summary of Tests for Red JSF

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Initial Voltage (V)</th>
<th>How long it lasted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.20 (Fully Charged level = 4.3)</td>
<td>1 Day</td>
</tr>
<tr>
<td>2</td>
<td>4.31 (Fully Charged level = 4.3)</td>
<td>24 Day</td>
</tr>
<tr>
<td>3</td>
<td>4.31 (Fully Charged level = 4.3)</td>
<td>13 Day*</td>
</tr>
<tr>
<td>4</td>
<td>4.28 (Fully Charged level = 4.3)</td>
<td>17 Day**</td>
</tr>
<tr>
<td>6</td>
<td>4.60 (Fully Charged level = 4.3)</td>
<td>24 Day</td>
</tr>
</tbody>
</table>

*: test was interrupted **: Not Fully Charged

In Test 1 after a day, the flashing rate changed from the MUTCD flashing pattern to power saver pattern. An upward shift in the voltage – time diagram of Test 1 corresponds to this change. No such jump was observed in tests 2, 3, or 4, which indicates the flashing pattern did not change during these tests. In the tests with a fully charged battery, the red JSF module flashed in MUTCD pattern for at least 24 days in Test 2 (test was ended at 24 days), at least 13 days in Test 3 (test was ended at 13 days), at least 17 days in Test 4, and 24 days in Test 6, as the upward shift is observed in Figure 4.1. The reason the battery lasted about 13 days in Test 3 was because the lights were turned on in steady mode (not flashing) to measure the light intensity. Test 4 was interrupted after 17 days by an unexpected power outage that lasted longer than the time the UPS device could provide (45 minutes) electricity to our computer. We expect the red module to stay in the MUTCD flashing rate for more than 17 days. Thus, based on the test results it was concluded that JFS red module in room temperature flashes in MUTCD pattern for at least 24 days.

4.1.2. JSF Red Light Intensity

In addition to voltage measurements, for Tests 3, 4, and 6, the outputted light intensity was measured. Intensity–time plots are presented in Figure 4.2. The light intensity did not change a lot over time, and the fluctuation was limited to 1-2 foot candles. This means that the red module of JSF was able to maintain its initial light intensity during 13-24 days that the light output was measured. The fluctuation in the graph could be due to the error in light intensity measurement since the device is very sensitive to its placement on the module. The absolute values of the light intensity measures are not as important as the changes over time. The investigators were looking for a potential trend in light intensity versus the voltage level at the battery poles. However, the plots show that for JSF red module, the intensity did not decrease as the battery voltage level changed.
It should be mentioned that the light intensity was measured by two different light intensity measuring devices: K-Light and Tektronix. The intensity measurements shown in Figure 4.2 were made by the K-Light device. To make sure the measurements are reliable, the Tektronix device was used to measure the intensity. Figure 4.3 shows the measurements done by both devices on different axis. The light intensities measured by the Tektronix device were generally higher than those by K-Light device; however, the difference was in the order of 4-foot candles for the red color. Even though these devices did not result in matching values (that was not expected), these measurements are close enough and support each other.

4.1.3. JSF Red Charging Time
When recharging the battery for Tests 3 and 4 (after the second test charging graphs were recorded and for Test 6 it was not recorded), voltage level versus time was recorded to ascertain the time needed for fully charging the battery from an "empty"
state. Figure 4.4 presents this time for Test 3, and similar results were obtained for other tests.

The module was left outside (for more than 11 days) in the evening and as Figure 4.4 shows, the voltage did not change for the first few hours; however, when the sun came up the voltage level increased. After the sunset, the voltage decreased gradually to a point, which was less than the fully charged threshold. This means that the module did not get fully charged after one day. The voltage level increased in the second day but kept fluctuating for two days because these two days were cloudy. After the sunset in the third day, the voltage level decreased gradually. However, at this point, the voltage was more than the fully charged level. This means that in the fall season, JSF red module receives enough power to be fully charged in three days. After three days, the battery was left outside to get the charging graph for beyond the fully charged state. As it is shown, the voltage level increased in the daytime to 5.8 volts; however, in the nighttime it decreased to around 4.3 V, which is the fully charged threshold. This indicates that leaving the batteries outside for a very long time does not result in a higher voltage level than the fully charged level. The charging plots for all tests are presented in Appendix A.

4.2. JSF YELLOW

4.2.1. JSF Yellow Duration

As mentioned before, except for in Test 1, the batteries were fully charged. Figure 4.5 shows the voltage-time diagram for the battery for the yellow module. In Test 1 after a day, the flashing rate changed from MUTCD flashing pattern to power saver mode. An upward shift in the voltage-time diagram of Test 1 corresponds to this change. This jump was observed in Test 2 after 22 days indicating that the MUTCD flashing pattern continued for 22 days and then switched to the power saver mode. This point was not observed in Test 3 because the module was intermittently set to work in steady state mode to measure the light intensity, so we decided to end the test after 13 days. In Test 4, the jump in voltage level was observed in 16 days. This means that the yellow color of the JSF module kept flashing for 16 days in MUTCD pattern and then switched to a power saving pattern. The results of Test 6 showed that the JSF yellow module...
continued flashing in the MUTCD flashing rate for 18 days, and then switched to power saver mode. Thus, based on the test results it was concluded that JFS yellow module in room temperature could flash in MUTCD pattern for at least 16 days.

As Figure 4.5 shows for Tests 2, 4, and 6, the flashing pattern was changed when the voltage reached a value around 4.21 V. This could be a potential threshold used by JSF to change the flashing pattern. We asked JSF about this, but they refused to provide any response to our questions because they considered them private information.

A summary of all five tests has been presented in Table 4.2.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Initial Voltage (V)</th>
<th>How long it lasted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.21 (Fully Charged level = 4.3)</td>
<td>1 Day</td>
</tr>
<tr>
<td>2</td>
<td>4.31 (Fully Charged level = 4.3)</td>
<td>22 Day</td>
</tr>
<tr>
<td>3</td>
<td>4.31 (Fully Charged level = 4.3)</td>
<td>13 Day</td>
</tr>
<tr>
<td>4</td>
<td>4.30 (Fully Charged level = 4.3)</td>
<td>16 Day</td>
</tr>
<tr>
<td>6*</td>
<td>4.60 (Fully Charged level = 4.3)</td>
<td>18 Day</td>
</tr>
</tbody>
</table>

*: test five does not contain data for JSF beacons.

4.2.2. JSF Yellow Light Intensity

As mentioned before, for Tests 3, 4, and 6, the light intensity level was also measured. Intensity – time plots are presented in Figure 4.6 and show that the light intensity did not change significantly as the battery voltage level decreased. The change was only limited to 1-2 ft-candles and a decreasing pattern was not observed. This means that the yellow module of JSF was able to maintain its initial light intensity level
for 16 days. The fluctuation in the graph could be due to the error in light intensity measurement since the device is very sensitive to its placement on the module.

Figure 4.6. Flashing light intensity for yellow JSF.

Figure 4.7 shows the measurements done by K-Light and Tektronix devices on different axis. The light intensities measured by the Tektronix device were generally higher than those by K-Light device; however, the difference was in the order of 4-foot candles for the yellow color. This means that, although these devices did not result in matching values, these measurements are close enough and support each other.

Figure 4.7. Light intensity measurements by K-Light and Tektronix Device for yellow JSF.
4.2.3. JSF Yellow Charging Time

Figure 4.8 presents voltage – time graph during the charge period for Test 3.

![Voltage-Time Graph for Test 3](image)

This shows the JSF yellow module got fully charged in three days. After three days, the modules were left under the sunshine to observe the charging graph for a longer time. As it is shown, the voltage level increased in the daytime to more than 5.8 volts; however, in the nighttime it decreased to around 4.3 V, which is the fully charged threshold. This means that leaving the batteries outside for a very long time does not result in a higher voltage than the fully charged level. The charging plots for all tests (if available) are presented in Appendix A.

4.3. CARMANAH RED

4.3.1. Carmanah Red Duration

Ten tests were conducted on the Red Carmanah modules. The first six tests were uninterrupted tests, and the next four tests were interrupted tests. In the uninterrupted tests, after charging the module, the solar panel was disconnected, the modules were turned on, and the time the flashing rate changed was recorded. The results of these tests supported the Carmanah's claim that the modules work in MUTCD flashing rate for a day and if they do not receive any power from the solar panel in the past 24 hours, they switch the flashing rate from MUTCD to non-MUTCD pattern.

To determine how long they stay in the MUTCD flashing rate if the solar panel is disconnected, the research team decided to reconnect the solar panel for 5 minutes just before the end of the period of 24 hours. This was done in Test 7, and it was found that the red Carmanah module flashed in the MUTCD flashing rate for three days. However, it switched the flashing rate during the third day because connecting the solar panel to the battery for 5 minutes was not enough. As a result, for Tests 8, 9, and 10, the module was reset a few minutes before the end of 24 hours. As Figure 4.9 presents, the red module flashed in the MUTCD flashing pattern for 11.5 to 12.5 days. The voltage-time graph for Tests 1 to 6 is available in the Appendix B.
In Tests 8, 9, and 10, as Figure 4.9 shows Carmanah’s red module continued flashing in MUTCD flashing pattern as long as the voltage at the battery pole was more than 11.8 V. This voltage could be as a potential threshold that Carmanah uses to change the flashing pattern. The number of days that Carmanah red module flashed in MUTCD flashing rate depended on the voltage level of battery at the start of the test. The initial voltage and total time the red Carmanah module flashed in MUTCD flashing pattern for different tests are presented in Table 4.3. It shows that a higher initial voltage results in longer time in MUTCD flashing pattern.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Initial Voltage (V)</th>
<th>How long it lasted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.58 (Fully Charged level = 12.8)</td>
<td>1 Day</td>
</tr>
<tr>
<td>2</td>
<td>12.96 (Fully Charged level = 12.8)</td>
<td>1 Day</td>
</tr>
<tr>
<td>3</td>
<td>12.92 (Fully Charged level = 12.8)</td>
<td>1 Day</td>
</tr>
<tr>
<td>4</td>
<td>12.82 (Fully Charged level = 12.8)</td>
<td>1 Day</td>
</tr>
<tr>
<td>5</td>
<td>12.64 (Fully Charged level = 12.8)</td>
<td>1 Day</td>
</tr>
<tr>
<td>6</td>
<td>12.80 (Fully Charged level = 12.8)</td>
<td>1 Day</td>
</tr>
<tr>
<td>7</td>
<td>12.85 (Fully Charged level = 12.8)</td>
<td>10 Day</td>
</tr>
<tr>
<td>8</td>
<td>13.15 (Fully Charged level = 12.8)</td>
<td>11.5 Day</td>
</tr>
<tr>
<td>9</td>
<td>13.14 (Fully Charged level = 12.8)</td>
<td>11.5 Day</td>
</tr>
<tr>
<td>10</td>
<td>13.34 (Fully Charged level = 12.8)</td>
<td>12.25 Day</td>
</tr>
</tbody>
</table>

Thus, based on the test results, it was concluded that the Carmanah red module in room temperature could flash in MUTCD pattern for at least 11.5 days.
4.3.2. Carmanah Red Light Intensity

As mentioned before, in addition to voltage measurements, for Tests 3 thru 10, the intensity was measured. Intensity–time plots are presented in Figure 4.10. Unlike the JSF modules, the light intensity of the red Carmanah module decreased rapidly over time.

As Figure 4.10 shows, for all tests, the light intensity dropped from around 100 ft-candles to around 20 ft-candles in 8-10 days. This shows that the outputted light intensity for the red color of Carmanah module drops as the voltage drops.

Figure 4.11 shows the measurements made by K-Light and Tektronix devices on different axis. The light intensities measured by Tektronix device were generally higher than those by K-Light device; however, the difference was in the order of 10-15 ft-Candles for the red color. This means that, although these devices did not result in matching values, these measurements are close enough and support each other.

As Figure 4.10 shows, for all tests, the light intensity dropped from around 100 ft-candles to around 20 ft-candles in 8-10 days. This shows that the outputted light intensity for the red color of Carmanah module drops as the voltage drops.
4.3.3. Carmanah Red Charging Time

Figure 4.12 presents the charging voltage level versus time for the Carmanah red module. It shows that after six days this module was fully charged, as the voltage did not drop below the fully charged level (12.8 V). This means that in the fall, Carmanah red module receives enough power to get fully charged in six days. After being fully charged, the voltage level increased in the daytime to more than 15.0 volts however, in the nighttime it decreased to around 12.8 V, which is the fully charged threshold. This means that leaving the batteries outside for a very long time does not result in a higher voltage than the fully charged level.

![Figure 4.12. Charging pattern for red Carmanah (Test 3).](image)

4.4. CARMANAH YELLOW

4.4.1. Carmanah Yellow Duration

Ten tests were conducted on the yellow module. Similar to the red color, six of these tests were uninterrupted where the module was left to flash until it changed the flashing rate. However, in the four interrupted tests, the modules were reset just before the 24 hours to find out how long the yellow module flashed in MUTCD flashing rate. Voltage at the battery pole versus time for the yellow Carmanah flashing beacon is presented in Figure 4.13. In Test 7, the solar panel was connected to the battery for five minutes just before the period of 24 hours when the inbuilt clock of Carmanah module changes the flashing rate to power saver if does not receive any power from the module in the past 24 hours. Connecting the solar panel to battery helped prevent this change in the flashing rate. In this Test (Test 7), the yellow Carmanah module kept flashing in MUTCD flashing rate for 8.1 days. In tests 8, 9, and 10, instead of connecting the solar panel to the battery, we reset the module just before the end of the 24-hour period to keep the module flash in MUTCD. In Test 8, the yellow Carmanah module flashed in MUTCD rate for 8.6 days before it switched to the power saver mode. In Test 9, it flashed in MUTCD rate for 9.5 days and in Test 10, it flashed in the MUTCD flashing rate for 10.1 days. The yellow module flashed in the MUTCD flashing pattern for approximately 1.5-2 days less than the red module of Carmanah. This is expected as the yellow module has a higher wattage and thus consumes a higher amount of electricity.
As Figure 4.13 shows, in Tests 7, 8, 9, and 10, the yellow module kept flashing in the MUTCD flashing rate as long as the voltage at the battery pole was more than 11.8 V. This voltage could be a potential threshold that Carmanah uses to change the flashing pattern for the yellow module. The number of days the Carmanah yellow module flashed in MUTCD flashing pattern depended on the voltage level of battery when the test started.

![Figure 4.13. All results for yellow Carmanah.](image)

The initial voltage and total time the yellow Carmanah module flashed in MUTCD flashing rate for each test is presented in Table 4.4. It shows that a higher initial voltage results in longer time of flashing in MUTCD flashing rate.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Initial Voltage (V)</th>
<th>How long it lasted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.49 (Fully Charged level = 12.8)</td>
<td>1 Day</td>
</tr>
<tr>
<td>2</td>
<td>13.02 (Fully Charged level = 12.8)</td>
<td>1 Day</td>
</tr>
<tr>
<td>3</td>
<td>12.89 (Fully Charged level = 12.8)</td>
<td>1 Day</td>
</tr>
<tr>
<td>4</td>
<td>12.90 (Fully Charged level = 12.8)</td>
<td>1 Day</td>
</tr>
<tr>
<td>5</td>
<td>12.64 (Fully Charged level = 12.8)</td>
<td>1 Day</td>
</tr>
<tr>
<td>6</td>
<td>13.08 (Fully Charged level = 12.8)</td>
<td>1 Day</td>
</tr>
<tr>
<td>7</td>
<td>12.84 (Fully Charged level = 12.8)</td>
<td>8.1 Day</td>
</tr>
<tr>
<td>8</td>
<td>13.16 (Fully Charged level = 12.8)</td>
<td>8.6 Day</td>
</tr>
<tr>
<td>9</td>
<td>13.16 (Fully Charged level = 12.8)</td>
<td>9.5 Day</td>
</tr>
<tr>
<td>10</td>
<td>13.41 (Fully Charged level = 12.8)</td>
<td>10.1 Day</td>
</tr>
</tbody>
</table>
Thus, based on the test results it was concluded that Carmanah yellow module in room temperature could flash in MUTCD pattern for at least 8.6 days.

4.4.2. Carmanah Yellow Light Intensity

As mentioned before, in addition to voltage measurements, for Tests 3 thru 10, the intensity was measured. Intensity–time plots are presented in Figure 4.14. The light intensity of the yellow Carmanah module rapidly decreased over time. As it was shown in Figure 4.14, in all tests except for Test 6, the light intensity dropped from around 160 ft-candles to around 40 ft-candles in only 6-8 days. In Test 6, it dropped from more than 200 ft-candle to 40 ft-candles in 7 days. These observations show that the outputted light intensity for the yellow color of Carmanah module drops as the voltage drops.

Figure 4.14. Flashing light intensity for yellow Carmanah (in test four, intensity was not measured from day 2 to day 9).

Figure 4.15 shows the measurements done by K-Light and Tektronix devices on different axis. The light intensities measured by Tektronix device were almost similar to those by K-Light device. This means that these measurements supported each other.

Figure 4.15. Light intensity measurements by K-Light and Tektronix Devices for yellow Carmanah.
4.4.3. Carmanah Yellow Charging Time

The charging voltage level versus time, see Figure 4.16, indicated that the Carmanah yellow module got fully charged in 6 days as in the night the voltage level did not drop below a fully charged level. After six days, the modules were left outside in the sunshine so the research team could observe the charging graph for a longer time. As it is shown, the voltage level increased in the daytime to more than 15.0 volts; however, in the nighttime it decreased to around 12.8 V, which is the fully charged threshold. This means that leaving the batteries outside for a very long time does not result in a higher voltage than the fully charged level.

Figure 4.16. Charging pattern for yellow Carmanah (Test 3).
5. CONCLUSIONS

This report contains the results of ten tests for JSF and 20 tests for Carmanah solar powered flashing beacons operating in room temperature conditions. The test results showed that with a fully charged battery, the JSF red module can flash at least 24 days in the MUTCD flashing pattern, while the yellow module can flash at least 16 days in the MUTCD flashing pattern. Then they switch to the power saving mode and continue flashing in non-MUTCD patterns. The light intensity for JSF modules remained about 22-30 ft-candle throughout the test periods even though the battery voltage level decreased. The JSF modules need three days of exposure to sun (during the fall season in Illinois) to get fully charged.

The result of the 12 uninterrupted tests on Carmanah modules (red and yellow) showed that if the battery does not receive any charge from the solar panels within 24 hours, the flashing rate would switch from MUTCD to non-MUTCD. On the other hand, the results of the eight interrupted tests showed that with a fully charged battery, the Carmanah red module can flash at least 11.5 days in the MUTCD pattern, and the Carmanah yellow module can flash for 8.6 days in the MUTCD pattern. Then they switch to the power saving mode with a non-MUTCD flashing pattern.

The red and yellow Carmanah modules did not change from the MUTCD flashing pattern to the power saver mode as long as the voltage at the battery pole was more than 11.8 V. For both colors, the voltage dropped rapidly over time and so did the outputted light intensity. Carmanah produced a good amount of light intensity: about 100 ft-candle for red and 160 ft-candle for yellow at the beginning. However, the intensities decreased over time to 20 ft-candle for red and 40 ft-candle for yellow. The Carmanah modules need six days of exposure to sun (in the fall season in Illinois) to get fully charged.
6. APPENDICES
APPENDIX A

For some of the test the charging graph was recorded. In this section, the charging graphs of those tests are presented.
A.1. Test 3

Red Carmanah

Yellow Carmanah

Red JSF

Yellow JSF
A.2. Test 4

Red Carmanah

Yellow Carmanah

Red JSF

Yellow JSF
A.3. Test 5

Red Carmanah

Yellow Carmanah
A.4. Test 7

Charging Data Was not Recorded

Red Carmanah

Yellow Carmanah
A.5. Test 8

Red Carmanah

Yellow Carmanah
A.6. Test 9

Red Carmanah

Yellow Carmanah
A.7. Test 10

Red Carmanah

Yellow Carmanah
APPENDIX B

This section contains the uninterrupted tests results conducted on Carmanah flashing beacons.

B.1. Carmanah Red

The results of the first six continuous tests are presented in this section. Except for the first test, the batteries were fully charged (in Test 1 the batteries were fully charged but the test did not start right after they were charged, and as a result, the batteries lost some power). In Tests 1 and 2, the module was turned on and the voltage was recorded without any interruption. However, in Tests 3 and 4, some time after the flashing pattern changed from MUTCD to the power saver mode, the test was interrupted; the module was reset, and again turned on. This resetting procedure sent the flashing pattern back to MUTCD. Again, the voltages were recorded. This method of conducting Tests 3 and 4 is equivalent to running independent tests with different initial voltages that may or may not be as much as the fully charged level. The voltage - time diagrams are shown in Figures B.1 and B.2. Figure B.1 shows this diagram as the tests were conducted; however, in Figure B.2 at the point the test was reset, the graphs were separated.

Figure B.1. All results for red Carmanah.
In both graphs, a vertical line is drawn showing exactly one after the test was started. As it is shown in both graphs, a day after starting the tests, the flashing rate was changed from MUTCD to the power saver mode. This means that no matter what the initial voltage is (obviously higher than a minimum) the red Carmanah module flashes in the MUTCD flashing pattern for a day, and then changes the flashing pattern to the power saver pattern. This flashing change was observed in all the tests and looked like a built in function that forces the module to change the flashing pattern.

B.2. Carmanah Yellow

The results of the first six continuous tests are presented in this section. Except for the first test, the batteries were fully charged. Similar to the red color, in Tests 1 and 2 the module was turned on and the voltage was recorded without any interruption. However, in Tests 3 and 4, after the flashing pattern changed from MUTCD to the power saver mode, the test was interrupted; the module was reset, and again turned on. This resetting procedure sent the flashing pattern back to MUTCD. Again, the voltages were recorded. The voltage - time diagrams are shown in Figures B.3 and B.4. Figure B.3 shows this diagram as the tests were conducted however, in Figure B.4 at the point the test was reset, the graphs were separated.
In both graphs, a vertical line is drawn showing exactly one day after the test was started. As it is shown in both graphs, a day after starting the tests the flashing rate was changed from MUTCD to power saver mode. This means that no matter what the initial voltage is (obviously higher than a minimum) the yellow Carmanah module flashes in MUTCD flashing pattern for a day, and then changes the flashing pattern to the power
saver pattern. This flashing change was observed in all the tests and looked like a built-in function that forces the module to change the flashing pattern.