Version 1.0

# Beams 3S-GE Coolant Temperature Sensor Analysis

By James Seal (jamesrseal@gmail.com)







Was this white paper helpful? Then help me buy more car parts by clicking here!

# Abstract

The resistance vs temperature profiles of three different 3S-GE BEAMS coolant temperature sensors were measured and plotted in order to describe their characteristics. The sensors included an OEM 2 wire temperature sensor (Toyota Part # 89422-35010), an aftermarket 2 wire temperature sensor and an aftermarket 3 wire temperature sensor. The results showed the temperature responses of the OEM 2 wire temperature sensor and the aftermarket 3 wire temperature sensor were close to identical, while the temperature response of the aftermarket 2 wire sensor deviated from the others. Care should be taken when buying non-OEM coolant temperature sensors to prevent incorrect engine temperature information being read by the ECU which could possibly result in overheating or engine damage. Additionally, if the resistance vs temperature response of a temperature sensor is unknown it can be measured and compared to the OEM part.


# Introduction

Accurate coolant temperature measurement of an engine is vital to the engine's performance and its reliability. The 5th generating BEAMS 3S-GE's ECU uses the input from the coolant temperature sensor to measure load on the engine. In some cases it is necessary to upgrade or replace the OEM BEAMS 3S-GE temperature sensor. In my case the plastic clip on the OEM temperature sensor became damaged and required replacement. Similarly, when performing an engine swap, some people desire a dedicated coolant temperature gauge in the cabin of their car to monitor the engine's temp. Toyota has used several 3 wire coolant temperature sensors which provide two resistance outputs, one to the ECU and one to a secondary gauge.

In order to know what temperature the engine is operating at the ECU passes a current through the coolant temperature sensor and measures a resistance. The ECU uses the measured resistance combined with information in an internal look-up table to determine the engine's current coolant temperature. When selecting a replacement temperature sensor it is important to use one that has a resistance vs temperature profile that closely matches that of the OEM sensor's. If the replacement temperature sensor's resistance vs temperature profile is different than what the ECU expects the ECU will receive a resistance value that does not correctly represent the true temperature of the engine which could result in reduced performance or engine damage.

# Equipment & Methodology

The resistance vs temperature profiles of three different 3S-GE BEAMS coolant temperature sensors were measured. The sensors included an OEM 2 wire temperature sensor (Toyota Part # 89422-35010), an aftermarket 2 wire temperature sensor and an aftermarket 3 wire temperature sensor. Figure 1 shows the three coolant temperature sensors used.

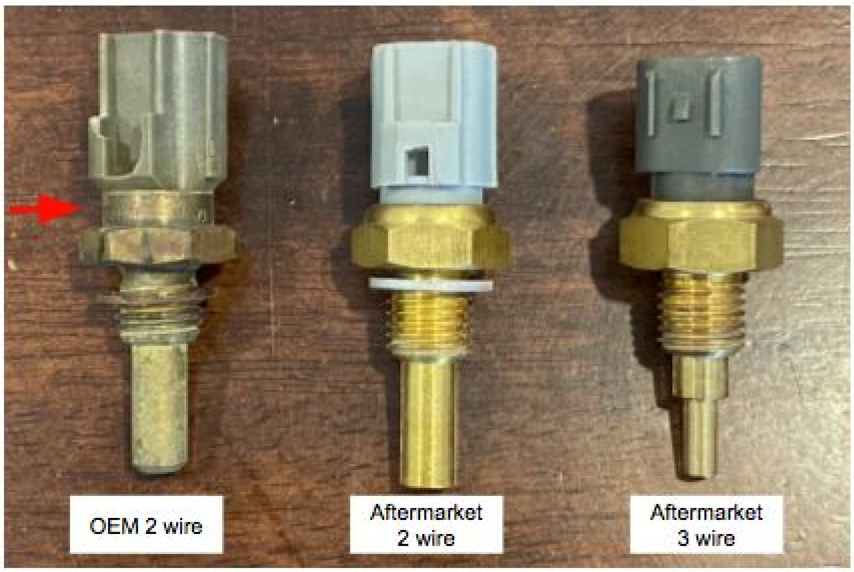


Figure 1. Three different coolant temperature sensors measured. The red arrow indicates the OEM Part number on the OEM 2 wire temperature sensor. This part number is absent on the aftermarket 2 wire temperature sensor, even though it claims to be an OEM part...

In order to measure the resistance vs temperature responses of the temperature sensors a simple experiment was set-up as shown in Figure 2. The tip of each temperature sensor was suspended in a pot of water and a kitchen stove was used to increase the temperature of the water. As the temperature of the water increased the resistance measured across the temperature sensor was recorded using a digital multimeter. The temperature of the water was measured using a kitchen thermometer. The temperature range for all tests was between ~ 70 - 210℉. The temperature sensor and kitchen thermometer were suspended above the pot using a piece of wood with two holes drilled into it. A large hole was used to securely hold the temperature sensor and a second smaller hole was used to hold the kitchen thermometer. Care was taken to ensure the tip of the kitchen thermometer did not extend past the tip of the temperature sensor in order to ensure both temperature probes experienced similar water temperatures. After each test the pot was emptied, cooled under running water, and refilled with room temperature water.

Was this white paper helpful? Then help me buy more car parts by clicking here!

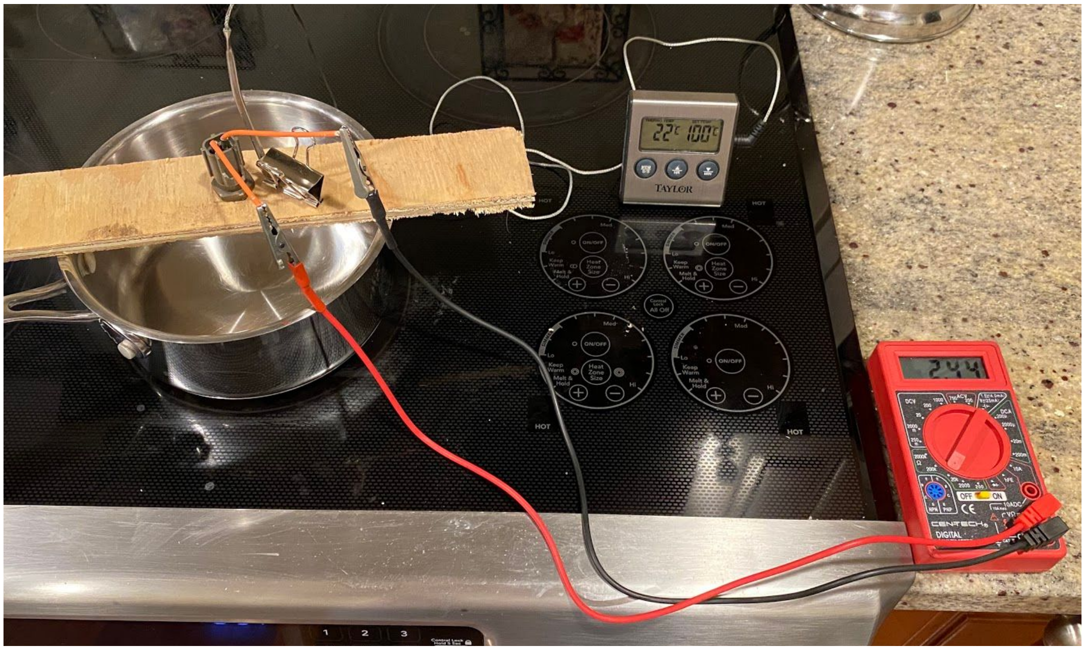

Figure 2. Experimental set-up for measuring resistance vs temperature response.

Temperature and resistance data was recorded using Google Sheets and exported as a CSV file. Python was used to read the CSV file and create the resistance vs temperature plots as well as the line of best fit. The raw data and Python code can be found in the Appendix.

# Results & Analysis

All resistance vs temperature plots are plotted on a semi-log scale. Resistance values in ohms (Ω) on the y-axis are plotted on a log scale while temperature values (℉) on the x-axis are plotted on a linear scale. Curve fitting for resistance vs temperature plots was done using the following equation:

$$y = a * \exp(b*x)$$

Where y is the resistance, x is the temperature and a and b are constants.

## OEM 2 Wire Temperature Sensor

The first temperature sensor measured was the OEM 2 wire temperature sensor. Figure 3 shows the resistance vs temperature response of this sensor. The line of best fit and its corresponding $R^2$ value are shown in the legend.

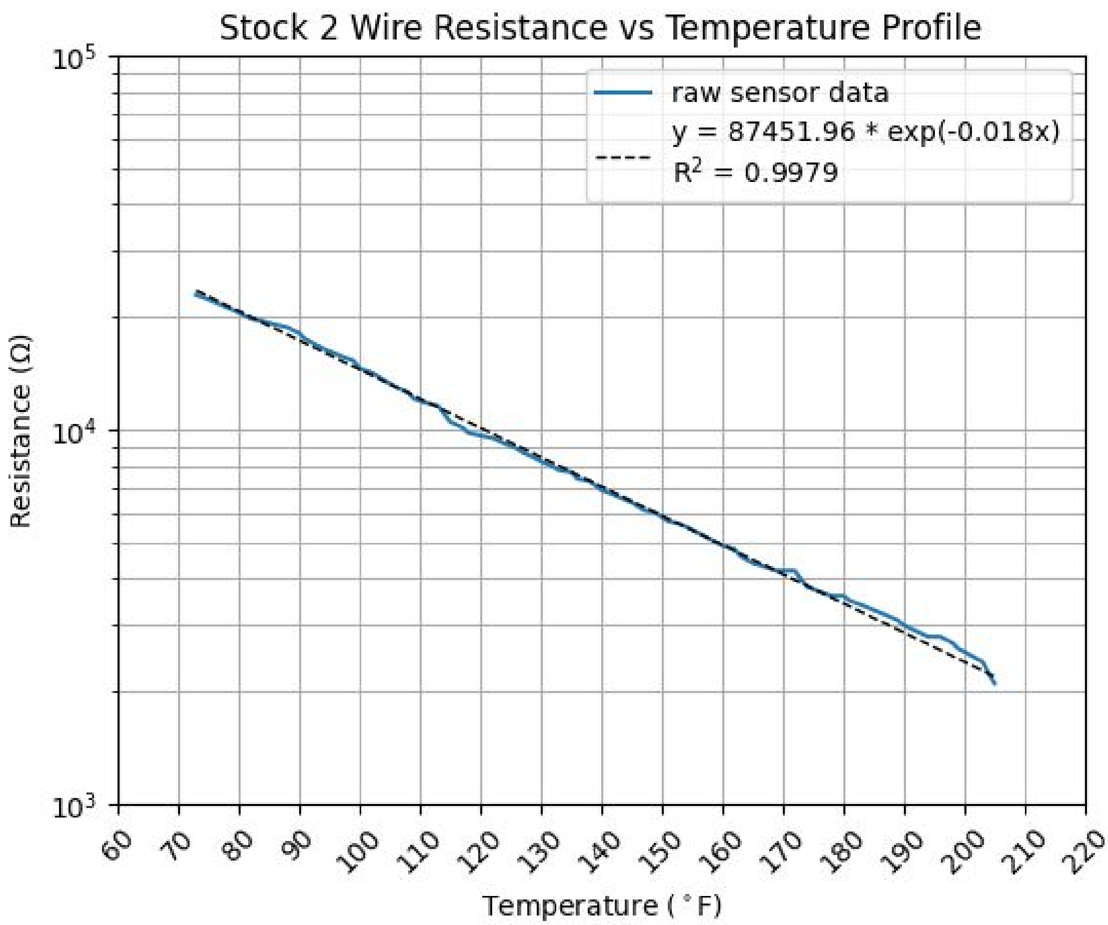


Figure 3. Resistance vs temperature response of the Toyota OEM 2 wire coolant temperature Sensor.

## Aftermarket 2 Wire Temperature Sensor

The second temperature sensor measured was the aftermarket 2 wire temperature sensor. Figure 4 shows the resistance vs temperature response of this sensor. The line of best fit and its corresponding $R^2$ value are shown in the legend.

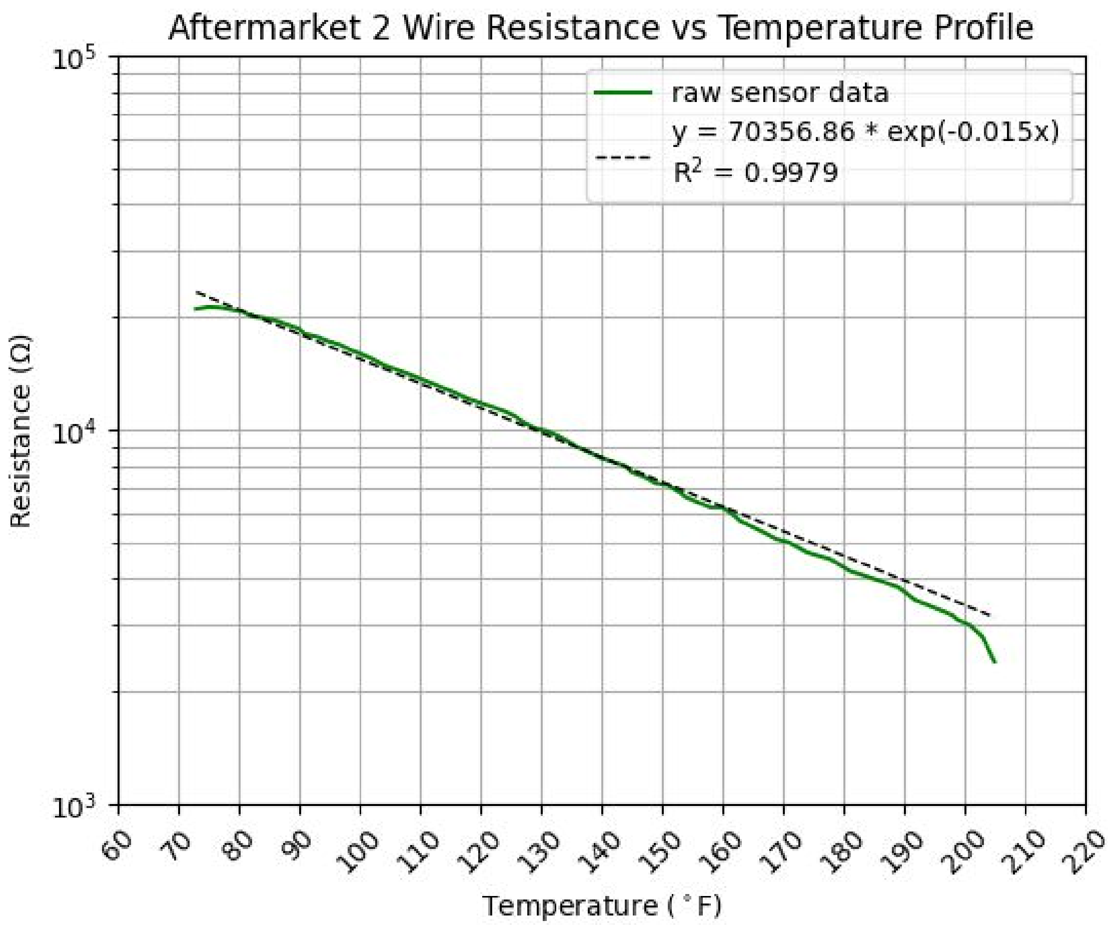


Figure 4. Resistance vs temperature response of the aftermarket 2 wire coolant temperature sensor.

## Aftermarket 3 Wire Temperature Sensor

The third temperature sensor measured was the aftermarket 3 wire temperature sensor. Figure 5 shows the resistance vs temperature response of this sensor. The line of best fit and its corresponding $R^2$ value are shown in the legend.

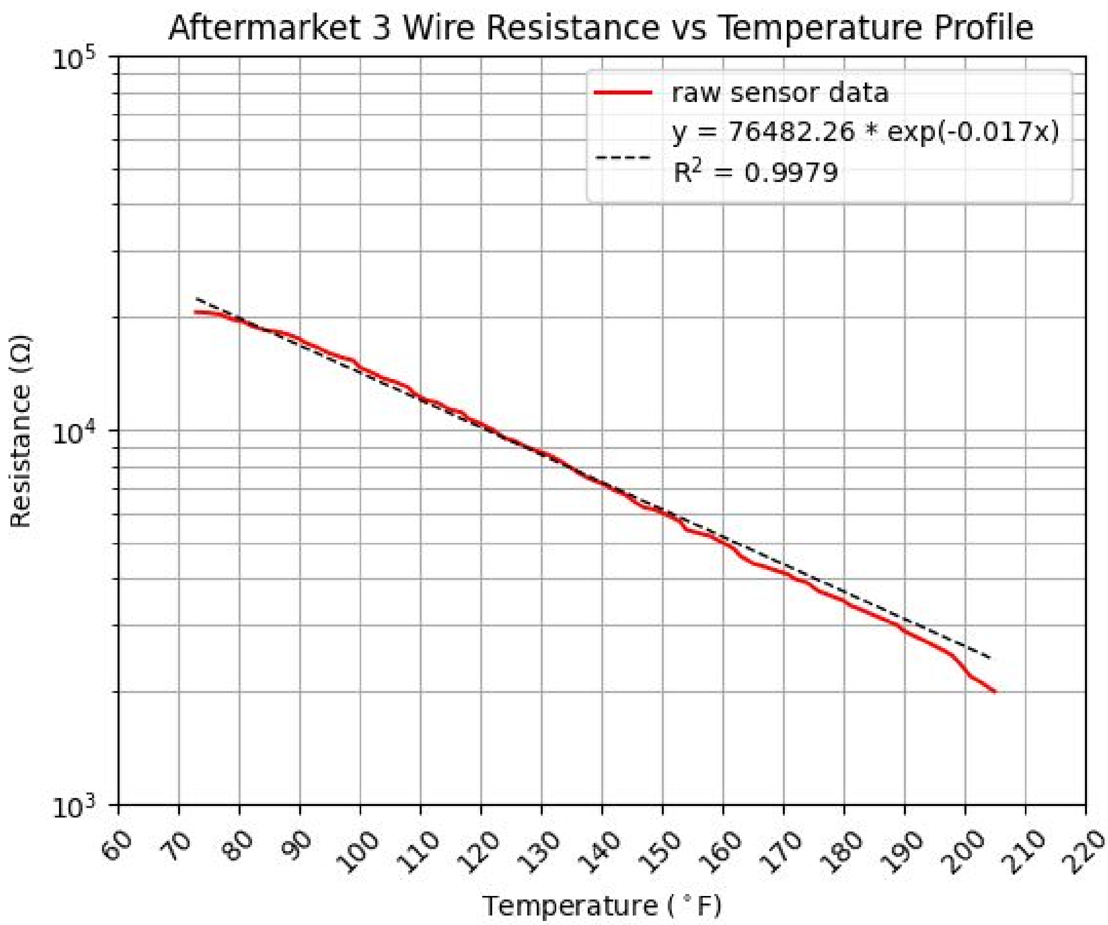


Figure 5. Resistance vs temperature response of the aftermarket 3 wire coolant temperature sensor.

## Temperature Sensor Comparison

The resistance vs temperature responses of all three coolant temperature sensors are plotted together in Figure 6. This figure shows that the resistance vs temperature response of the OEM 2 wire sensor and the aftermarket 3 wire sensor are close to identical, while the temperature response of the aftermarket 2 wire sensor begins to deviate from the other two beyond 90℉.

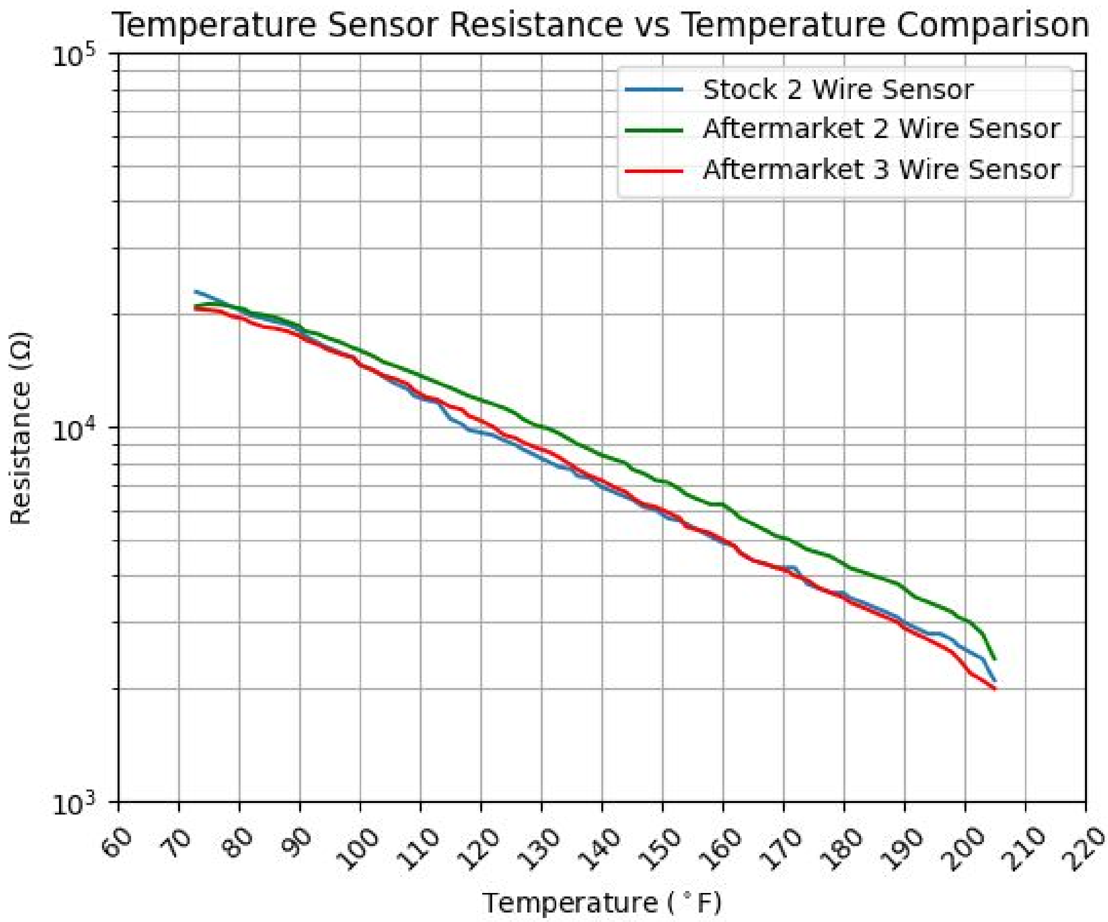


Figure 6. Comparing the resistance vs temperature responses of the three coolant temperature sensors.

The OEM 2 wire and the aftermarket 3 wire sensors show minor inflection points below 75℉ and all three sensor show inflection points beginning around 200℉, suggesting that beyond these temperatures the sensor's response may no longer follow the relationship expressed by the equation:

$$y = a * \exp(b*x)$$

As stated previously, the temperature response of the aftermarket 2 wire sensor begins to deviate from the OEM 2 wire and aftermarket 3 wire sensors beyond 90℉. This deviation in resistance response could be dangerous if this coolant temperature sensor was installed because it would result in the ECU receiving resistance values indicating that the engine is operating cooler than it actually is. When the OEM 2 wire and aftermarket 3 wire sensors are reading 3000 ohms at 190℉ the aftermarket 2 wire sensor is reading close to 4000 ohms which would indicate to the ECU that the engine temperature is only about 170℉. A difference in 20 degrees at the limit could be the difference between a hurt but salvageable engine and a boat anchor.

# Conclusions

The resistance vs temperature responses of three coolant temperature sensors were measured, plotted and analyzed demonstrating a straightforward methodology that anyone can perform at home using simple tools. This methodology could be useful to confirm the operation of a new or replacement temperature sensor or it could be used to map the resistance vs temperature response of an unknown sensor.

The resistance vs temperature responses of the OEM 2 wire sensor and the aftermarket 3 wire sensor were nearly identical. The resistance vs temperature response of the aftermarket 2 wire temperature sensor deviated from the other two sensors and as a result the aftermarket 2 wire temperature sensor has the potential to under-report engine coolant temperatures which could result in engine damage or failure.

The temperature range for all tests was between ~ 70 - 210℉ however it is possible for the coolant temperature of an engine to begin at temperatures much lower than 70℉ and to extend past 210℉. Future tests could be done using cold or ice water to chart the resistance vs temperature responses at low temperature. Creative methods with pressurized fluids or alternative heat sources could be employed to chart the resistance vs temperature responses at higher temperatures.

# Appendix

## Raw Data

```
Temperature (C),Temperature (F),Stock 2 Wire,Aftermarket 2 Wire,Aftermarket 3 Wire
21,70,23600,,
22,72,23200,,
23,73,22900,21000,20600
24,75,22300,21300,20500
25,77,21600,21200,20300
26,79,20900,20900,19700
27,81,20200,20600,19400
28,82,19800,20100,19000
29,84,19500,19900,18500
30,86,19100,19600,18300
31,88,18800,19100,18000
32,90,18100,18600,17500
33,91,17500,18000,17100
34,93,16800,17700,16600
35,95,16200,17200,16000
36,97,15700,16800,15600
37,99,15300,16200,15300
38,100,14600,16000,14700
39,102,14200,15500,14200
40,104,13600,14900,13700
41,106,13000,14500,13400
42,108,12600,14100,13000
43,109,12100,13900,12500
44,111,11800,13500,12000
45,113,11600,13100,11800
46,115,10500,12700,11300
47,117,10150,12300,11100
48,118,9800,12100,10700
49,120,9650,11800,10400
50,122,9500,11500,10000
51,124,9200,11200,9500
52,126,8900,10800,9300
53,127,8700,10500,9100
54,129,8400,10100,8800
55,131,8100,9900,8600
56,133,7800,9600,8300
57,135,7700,9200,7900
58,136,7400,9000,7700
59,138,7300,8700,7400
60,140,6900,8400,7200
61,142,6700,8200,6900
62,144,6500,8000,6700
63,145,6400,7700,6500
64,147,6100,7500,6200
65,149,6000,7200,6100
66,151,5700,7100,5900
67,153,5600,6800,5700
68,154,5500,6600,5400
69,156,5300,6400,5300
70,158,5100,6200,5200
71,160,4900,6200,5000
72,162,4800,5900,4800
73,163,4600,5700,4600
74,165,4400,5500,4400
75,167,4300,5300,4300
76,169,4200,5100,4200
77,171,4200,5000,4100
78,172,4200,4900,4000
79,174,3800,4700,3900
80,176,3700,4600,3700
81,178,3600,4500,3600
82,180,3600,4300,3500
83,181,3500,4200,3400
84,183,3400,4100,3300
85,185,3300,4000,3200
86,187,3200,3900,3100
87,189,3100,3800,3000
88,190,3000,3700,2900
89,192,2900,3500,2800
90,194,2800,3400,2700
91,196,2800,3300,2600
92,198,2700,3200,2500
93,199,2600,3100,2400
94,201,2500,3000,2200
95,203,2400,2800,2100
96,205,2100,2400,2000
97,207,,,
98,208,,,
99,210,,,
100,212,,,
```

## Python Code

```
import matplotlib.pyplot as plt
import numpy as np
import scipy.optimize as opt

# curve fitting function for scipy.optimize.curve_fit
def func(x, a, b):
    return a * np.exp(b * x)

# get the data from the csv file
temp_data = np.genfromtxt('Toyota Temp Sensor Analysis - Combined Data.csv', delimiter=',', skip_header=1)

# put the delimited data into [1,1] arrays to prep for plotting ignore the first two rows
# and last 4 rows of data because there are no data points at these temps and curve fitting will throw and error
stock_2_wire = temp_data[2:76, 2]
aftermarket_2_wire = temp_data[2:76,3]
aftermarket_3_wire = temp_data[2:76,4]

# reference column 0 to plot data in Celsius e.g. temp = temp_data[2:76, 0]
# plt.xticks(np.arange(20, 100, 10.0)) should also be adjusted
temp = temp_data[2:76, 1]

# curve fit the stock 2 wire temp sensor data
optimizedParameters, pcov = opt.curve_fit(func, temp, stock_2_wire, p0=[20000, 0], bounds=(-np.inf, np.inf))
residuals = stock_2_wire - func(temp, *optimizedParameters)
ss_res = np.sum(residuals**2)
ss_tot = np.sum((stock_2_wire-np.mean(stock_2_wire))**2)
stdevs = np.sqrt(np.diag(pcov))
r_squared = 1 - (ss_res / ss_tot)
r_squared_text = 'R$^2$ = ' + str(round(r_squared,4))
fit_equation = 'y = ' + str(round(optimizedParameters[0],2)) + ' * exp(' + str(round(optimizedParameters[1],3)) + 'x)\n' +
r_squared_text


# curve fit the aftermarket 2 wire temp sensor data
optimizedParameters1, pcov1 = opt.curve_fit(func, temp, aftermarket_2_wire, p0=[20000, 0], bounds=(-np.inf, np.inf))
residuals1 = aftermarket_2_wire - func(temp, *optimizedParameters1)
ss_res1 = np.sum(residuals1**2)
ss_tot1 = np.sum((aftermarket_2_wire-np.mean(aftermarket_2_wire))**2)
stdevs1 = np.sqrt(np.diag(pcov1))
r_squared1 = 1 - (ss_res1 / ss_tot1)
r_squared_text1 = 'R$^2$ = ' + str(round(r_squared,4))
fit_equation1 = 'y = ' + str(round(optimizedParameters1[0],2)) + ' * exp(' + str(round(optimizedParameters1[1],3)) +
'x)\n' + r_squared_text1
```

```
# curve fit the aftermarket 3 wire temp sensor data
optimizedParameters2, pcov2 = opt.curve_fit(func, temp, aftermarket_3_wire, p0=[20000, 0], bounds=(-np.inf, np.inf))
residuals2 = aftermarket_3_wire - func(temp, *optimizedParameters2)
ss_res2 = np.sum(residuals2**2)
ss_tot2 = np.sum((aftermarket_3_wire-np.mean(aftermarket_3_wire))**2)
stdevs2 = np.sqrt(np.diag(pcov2))
r_squared2 = 1 - (ss_res2 / ss_tot2)
r_squared_text2 = 'R$^2$ = ' + str(round(r_squared,4))
fit_equation2 = 'y = ' + str(round(optimizedParameters2[0],2)) + ' * exp(' + str(round(optimizedParameters2[1],3)) +
'x)\n' + r_squared_text2

# plot the stock 2 wire sensor data
fig1, ax1 = plt.subplots()
ax1.plot(temp, stock_2_wire, label='raw sensor data')
ax1.plot(temp, func(temp, *optimizedParameters), label=fit_equation, linestyle='--', linewidth=1, color='black')
ax1.legend()
plt.xlabel('Temperature ($^\circ$F)')
plt.ylabel('Resistance ($\Omega$)')
plt.title('Stock 2 Wire Resistance vs Temperature Profile')
plt.grid(True, which = 'both')
plt.xticks(np.arange(60, 225, 10.0))
plt.xticks(rotation = 45)
plt.yscale("log")
plt.yticks([1000, 10000, 100000])
plt.subplots_adjust(top = .95, bottom = 0.15)
plt.show()

# plot the aftermarket 2 wire sensor data
fig2, ax2 = plt.subplots()
ax2.plot(temp, aftermarket_2_wire, label='raw sensor data', color = 'g')
ax2.plot(temp, func(temp, *optimizedParameters1), label=fit_equation1, linestyle='--', linewidth=1, color='black')
ax2.legend()
plt.xlabel('Temperature ($^\circ$F)')
plt.ylabel('Resistance ($\Omega$)')
plt.title('Aftermarket 2 Wire Resistance vs Temperature Profile')
plt.grid(True, which = 'both')
plt.xticks(np.arange(60, 225, 10.0))
plt.xticks(rotation = 45)
plt.yscale("log")
plt.yticks([1000, 10000, 100000])
plt.subplots_adjust(top = .95, bottom = 0.15)
plt.show()

# plot the afermarket 3 wire sensor data
fig3, ax3 = plt.subplots()
ax3.plot(temp, aftermarket_3_wire, label='raw sensor data', color = 'r')
ax3.plot(temp, func(temp, *optimizedParameters2), label=fit_equation2, linestyle='--', linewidth=1, color='black')
```

```
ax3.legend()
plt.xlabel('Temperature ($^\circ$F)')
plt.ylabel('Resistance ($\Omega$)')
plt.title('Aftermarket 3 Wire Resistance vs Temperature Profile')
plt.grid(True, which = 'both')
plt.xticks(np.arange(60, 225, 10.0))
plt.xticks(rotation = 45)
plt.yscale("log")
plt.yticks([1000, 10000, 100000])
plt.subplots_adjust(top = .95, bottom = 0.15)
plt.show()

fig4, ax4 = plt.subplots()
ax4.plot(temp, stock_2_wire, label='Stock 2 Wire Sensor')
ax4.plot(temp, aftermarket_2_wire, label='Aftermarket 2 Wire Sensor', color = 'g')
ax4.plot(temp, aftermarket_3_wire, label='Aftermarket 3 Wire Sensor', color = 'r')
ax4.legend()
plt.xlabel('Temperature ($^\circ$F)')
plt.ylabel('Resistance ($\Omega$)')
plt.title('Temperature Sensor Resistance vs Temperature Comparison')
plt.grid(True, which = 'both')
plt.xticks(np.arange(60, 225, 10.0))
plt.xticks(rotation = 45)
plt.yscale("log")
plt.yticks([1000, 10000, 100000])
plt.subplots_adjust(top = .95, bottom = 0.15)
plt.show()
```

# Disclaimer

NO WARRANTIES: All of the information provided in this white paper is provided "AS-IS" and with NO WARRANTIES. No express or implied warranties of any type, including for example implied warranties of merchantability or fitness for a particular purpose, are made with respect to the information, or any use of the information, in this white paper. James Seal ("JS") makes no representations and extends no warranties of any type as to the accuracy or completeness of any information or content of this white paper.

DISCLAIMER OF LIABILITY: JS specifically DISCLAIMS LIABILITY FOR INCIDENTAL OR CONSEQUENTIAL DAMAGES and assumes no responsibility or liability for any loss or damage suffered by any person as a result of the use or misuse of any of the information or content in this white paper. JS recommends safe practices when working with power tools, automotive lifts, lifting tools, jack stands, electrical equipment, blunt instruments, chemicals, lubricants, or any other tools or equipment seen or implied in this white paper. JS assumes or undertakes NO LIABILITY for any loss or damage suffered as a result of the use, misuse or reliance on the information and content of this white paper.

USE AT YOUR OWN RISK: This white paper is for informational purposes only. It is your responsibility to evaluate your own safety and physical condition, or that of your clients, and to independently determine whether to perform, use or adapt any of the information or content in this white paper. Any automotive repair and/or modification may result in injury. By voluntarily undertaking any task displayed in this white paper, you assume the risk of any resulting injury; your safety is the sole responsibility of the user and not JS.

# Changelog

Version 1.0 - 10/06/2020

- Original white paper published