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Office of Transportation and Air Quality
U.S. Environmental Protection Agency
2000 Traverwood
Ann Arbor, MI 48105

RE: Application for Pulse Width Modulated Brushless Motor off-cycle GHG credit

This document represents SUBARU's application for Pulse Width Modulated Brushless Motor off-cycle CO2 credit under the alternative methodology outlined in 40 CFR §86.1869-12 (d).

Pursuant to 40 CFR §86.1869-12, car manufacturers can obtain off-cycle credit for the use of GHG reducing technologies that do not fully benefit from federal test procedures and / or highway fuel economy testing. This application for off-cycle credit is filed in accordance with the regulation subsection (d). This allows manufacturers to earn credit by demonstrating that applicable technologies provide GHG reductions.

SUBARU also states that the Brushless Motor technology covered by this application is not a safety-related technology and is not subject to the exclusions listed in 40 CFR §86.1869-12 (a). 40 CFR §86.1869-12 (a) was established to achieve compliance with collision avoidance technologies, safety-critical systems, technologies designed to reduce the frequency of vehicle collisions, or vehicle safety standards or regulatory sets Specifies that off-cycle credit cannot be earned for technology (described in CFR Title 49).

We would be grateful if you could notify us in writing or by email that EPA has received this off-cycle credit application. If there are any questions or concerns regarding the material, please contact David Barker at 856-488-8500.

Request for Brushless Motor Credits

1. Introduction and overview

Pursuant to 40 CFR § 86.1869 - 12(d), 49 CFR 531.6(b), and 49 CFR 533.6(c) Subaru Corporation (herein referred to as “Subaru”) requests the following Greenhouse Gas (GHG) off - cycle CO2 credits for Pulse Width Modulated (PWM) HVAC Brushless Motor (BLM) Power Controller Technology.

Table 1 PWM BLM Credit Request

	Total credit (g CO2/mi)	A/C On (g CO2/mi)	A/C Off (g CO2/mi)
Manual A/C	0.4	0.2	0.2
Automatic A/C	0.4	0.3	0.1

Blower motor controls which limit wasted electrical energy (e.g. pulse width modulated power controller) are listed in the EPA US Light - Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards credit menu (40 CFR 86.1868 - 12). SAE J3109 is an established SAE methodology for validating the savings provided by pulse width modulated controllers. This standard provides the framework for measuring the efficiency of such controllers and is intended for OEMs to demonstrate compliance to regulatory agencies.

Subaru reviewed Toyota's application for BLM credit "Request for GHG Off - Cycle Credit for Pulse Width Modulated HVAC Brushless Motor Power Controller Technology, FR/Vol. 84, No. 119, 28811-28812" in 2019 and did comparison testing of the PWM brushed motor (PWM BMM) and PWM BLM to obtain the additional power saving of the BLM.

Subaru explained the proposal mentioned above in a technical meeting with EPA in December of 2019. As a result of consultation, EPA agreed to the proposal and SUBARU proceeded with the next steps in technical data acquisition.

2. Description of System

The difference between a BMM and BLM is that the BMM uses mechanical switching while the BLM uses circuit switching. A BMM uses brushes to deliver current to the motor windings on the rotor. The benefit of the BLM is removal of frictional losses by eliminating the consumable brush and physical contact between stator and commutator, which also reduces the amount of power lost to heat.

3. Rationale for Alternative Method Off Cycle Application

The off-cycle system was established to support technologies which reduce real-world greenhouse gas emissions though they cannot be accounted for in 2-cycle testing (City/Highway) alone. Since the air conditioner is not used in the 2-cycle tests it is necessary to use either 5-cycle testing or the alternative procedure application process to quantify the CO2 reduction. Two of the 5-cycle tests utilize the air conditioner (cold FTP and SC03), though these two test conditions cannot sufficiently account for customer air conditioner usage due to the narrowly defined testing conditions required for the tests.

Noting the above restrictions, it is necessary to demonstrate a CO2 reduction by the alternative procedure method.

4. Alternative Demonstration Method

4-1. System Selection

The DENSO HVAC module installed on 19MY ASCENT was used for this testing. Either BMM or BLM can be installed in this HVAC system structure. To remove the impact of additional factors, we selected this HVAC system for demonstration purposes.

4-2. Comparison of the effect

Toyota measured the amount of power lost to heat by comparison of PWM BMM and PWM BLM, because Toyota has chosen to utilize both systems. Subaru's blower motor lineup is only PWM BLM and BM, without PWM control. Therefore, it is needed to calculate the power consumption of PWM BMM under Subaru's current conditions. Power consumption of PWM BMM was calculated using the PWM-BLM power consumption and the motor efficiency of BM and BLM.

In this application, the PWM controller, which is an EPA menu credit, uses SAE J3109 as proof of meeting the required efficiency.

4-3. The result of BLM bench test and the calculation of PWM BMM (baseline)

4-3-1. The method and result of BLM bench test

Blower motor controls which limit wasted electrical energy are listed as an EPA menu off-cycle credit technology. SAE J3109 was written as a methodology to show compliance with this menu item and outlines the test procedure and required equipment for determining the weighted power saving of a HVAC blower motor. Toyota used this standard as a basis to confirm the CO2 reduction potential for the BLM using the conditions listed below in Table 2. J3109 section 5 outlines the test set up for the BMM. All the required test equipment outlined in the standard was used for testing. Table 2 shows each of the J3109 test conditions (low through high) and indicates the J3109 fixed values (columns B,D,M). The other columns indicate the values that were collected in the test or the values that were calculated from test results.

Table 2 PWM BLM Test Matrix Showing J3109 Criteria and Calculation Table of PWM BMM

Condition	BLM								BM			L:	M:	N:
	A: Duty cycle[%]	B: Voltage input[V]	C: Current input[A]	D: Power input[W]	E: Power output[W]	F: PWM Efficiency[%]	G: Motor Efficiency[%]	H: RPM	I: RPM	J: Motor Efficiency[%]	K: Power Input[W]	Power saving[W]	Weighting factor[%]	Weighted power saving[W]
Low		13.5		7%×Hi									35	
Medium low		13.5		17%×Hi									22	
Medium	①	13.5	②	36%×Hi	③	E/D	④	⑤	⑥	⑦	D×G/J	K-D	20	L×M
Medium high		13.5		63%×Hi									12	
High		13.5		Hi									10	
													⊿P =	[W]

※Red portion's number is from SAE J3109

The BLM was tested first to capture its power consumption using SAE J3109. The load at the power input is controlled at 13.5V (columns B). To reach the regulated output power (D) the duty cycle was adjusted. The inlet and outlet of the HVAC module was blocked to match the specified output current (C). The definition in J3109 was used to determine the output current for the high condition. The definition states, "Hi is defined as 1A beneath the lower tolerance of the rated current." With that definition, 20A was determined to be high. The input current, rpm, and size of the outlet and inlet blockage were recorded at that condition.

The value of PWM BMM was calculated as follows. The motor efficiency of BLM is different from BM (columns G,J). Using the input power (D) of BLM bench test and the motor efficiency ratio (G,J) of BM and BLM, the input power (K) of BM was calculated. The input value was filled in table 3 as baseline.

After each condition input, the difference of the weighted electric power savings of BM and BLM was calculated. The weighting factor is based on the percent usage of different voltages in the field (J3109). This final power saving was used to calculate the credit amount.

4-3-2. The result of power consumption comparison (BLM and BM)

Table 3 shows the value of BLM bench test and BM calculation. As a result of comparison, the power saving result of BLM was 16.80W.

Table 3 the Result of BLM and BMM

Condition									BM			L:	M:	N:
	A: Duty cycle[%]	B: Voltage input[V]	C: Current input[A]	D: Power input[W]	E: Power output[W]	F: PWM Efficiency[%]	G: Motor Efficiency[%]	H: RPM	I: RPM	J: Motor Efficiency[%]	K: Power Input[W]	Power saving[W]	Weighting factor[%]	Weighted power saving[W]
Low	25.9	13.5	1.4	19.1	14.9	78.1	55.4	1402	1402	44.2	23.9	4.84	35	1.69
Medium low	35.5	13.5	3.5	46.6	39.4	84.5	64.1	1954	1954	51.4	58.1	11.51	22	2.53
Medium	45.7	13.5	7.2	97.1	84.6	87.2	69.7	2526	2526	57.5	117.7	20.60	20	4.12
Medium high	54.7	13.5	12.7	171.9	151.6	88.2	69.6	3032	3032	58.5	204.5	32.61	12	3.91
High	62.5	13.5	20.5	276.0	243.2	88.1	67.9	3470	3470	58.3	321.4	45.44	10	4.54
												Total saving =		16.80

4-4. Benefit Calculation Methodology and Result

4-4-1. Benefit Calculation Methodology

SAEJ3019 provides a method to measure the efficiency of a blower controller but it does not provide a means to estimate the GHG emissions reduction. SAE3174 is the supporting standard that is being written for the calculating the emissions reductions. The calculation accounts for the blower usage, alternator efficiency, engine efficiency, vehicle lifetime mileage, vehicle CO2 emissions, the gasoline heating value, and the calculated power saving from the bench test. Equation 1 shows the final CO2 emission reduction calculation.

Equation.Credit calculation method

$$BlowerUsage(LDV) = 6151.6hour$$
$$WeightedPowerSaving = 16.80W$$
$$GasolineHeatingValue = 33410\ {}^{W}/_{gal}$$
$$CO_2emissionpergallongasoline = 8887\ {}^{gCO_2}/_{gal}$$
$$AlternatorEfficiency = 80\%$$
$$EngineEfficiency = 42\%$$
$$VehicleLifetimeMileage(LDV) = 195{,}264$$

$$CO_2missionrreduction\ {}^{g}/_{mile} = \frac{\frac{6151.6hour \times \Delta PW}{80\% \times 42\% \times 33410\ {}^{W}/_{gal}} \times 8887\ \frac{gCO_2}{gal}}{195{,}264\ {}^{mile}/_{life}}$$

$$= 0.025 \times \Delta P\ {}^{g}/_{mile} \cdots (1)$$

$$CO_2missionrreduction\ {}^{g}/_{mile} = 0.025 \times 16.80\ {}^{g}/_{mile} = 0.42\ {}^{g}/_{mile} \cdots (2)$$

From equation 2, a CO2 reduction of 0.6g CO2/mile was obtained. However, the power consumption of the PWM BM (baseline) was calculated value, so it is considered to be an ideal value. Therefore, it was judged appropriate to comply using the Toyota value of 0.4g CO2/mile as the application value.

4-4-2. Benefit Calculation Result

This HVAC system yielded a CO2 reduction of 0.4 g CO2/mile total (4-4-1).
EPA advised Toyota to separate the credit between time when the blower is used with the AC "ON" and time with the AC "OFF". According to this, total credit was separated. The calculation used rate (table 4) same as Toyota. For time when the AC is "ON" the AC cap should be applied to the AC usage portion of the total saving. The CO2 reduction outside of AC usage (i.e heater) is not limited by the AC cap.

Table 4 Air Conditioning Usage rate

	Ignition On Time[hrs]	A/C On Time [hrs, %]	A/C Off Time [hrs, %]	Driving Distance Per Year[mi]	Fleet Composition[%]
Manual A/C	393.8	175.6 (44.6%)	218.2 (55.4%)	12500	65
Automatic A/C	393.8	276.8 (70.3%)	117 (29.7%)	12500	35

Using above usage rate, the A/C On and A/C Off credit application can be determined (table 5)

Table 5 PWM BLM Credit Breakdown

	A/C On Time [hrs, %]	A/C Off Time [hrs, %]	Total credit (g CO2/mi)	A/C On (g CO2/mi)	A/C Off (g CO2/mi)
Manual A/C	175.6 (44.6%)	218.2 (55.4%)	0.4	0.18 (44.6%)	0.22 (55.4%)
Automatic A/C	276.8 (70.3%)	117 (29.7%)	0.4	0.28 (70.3%)	0.12 (29.7%)

4-5. Credit Grouping Application Strategy

Table 6 shows the respective credit amount per each HVAC type that utilizes PWM BLMs.

Table 6 PWM BLM Vehicles

	Total credit (g CO2/mi)	A/C On (g CO2/mi)	A/C Off (g CO2/mi)
Manual A/C	0.4	0.2	0.2
Automatic A/C	0.4	0.3	0.1

5. Durability Assessment

Air-conditioning system components are required to adhere to a stringent durability spec to ensure functionality through full useful life. Additionally, the manufacturer of these motors (DENSO) supplies this motor to many OEMs. Therefore, Subaru believes that this HVAC PWM BLM can meet the requirements for vehicle lifetime durability with no degradation in the CO2 reduction benefit. Even if a failure occurs, it is expected that a cease in functionality would be unacceptable to the user and they would seek repair, maintaining the certified performance.

6. Conclusion

From the result of bench test and calculation, SUBARU requests the following off cycle greenhouse gas credit for the following BLM configurations for all vehicles equipped with this technology:

Table 7 HVAC PWM BLM Credit Request

	Total credit (g CO2/mi)	A/C On (g CO2/mi)	A/C Off (g CO2/mi)
Manual A/C	0.4	0.2	0.2
Automatic A/C	0.4	0.3	0.1

Appendix A: Technical introduction plan (CONFIDENTIAL)