Application Report

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Method of Graphing Safe Operating Area (SOA) Curves in DC-DC Converter

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ABSTRACT

This document describes how to graph the SOA curves with airflow in the DC-DC power supply converter. To reduce the overall cost of a system, the converter solution reduces the printed-circuit-board (PCB) area while maintaining the highest efficiency possible. These requirements limit the electrical and material stresses of a component to operating safety over the wide range of temperature. As a result, the designer must know the safe operating temperature range versus the maximum output loading in the switching power supply converter.

1 Introduction

Any component in the power supply converter, such as a controller or a power conversion MOSFET, has its own safety operating temperature range. The converter will fail if any component operates outside its temperature range. As result, the SOA curves of a converter are serving as a design guideline recommendation at a given operating temperature range.

This document shows how to generate the SOA curves with natural convection and air velocity linear feet per minute (LFM) in the system. Figure 1 shows an example of typical SOA curves of the TPS546C23.

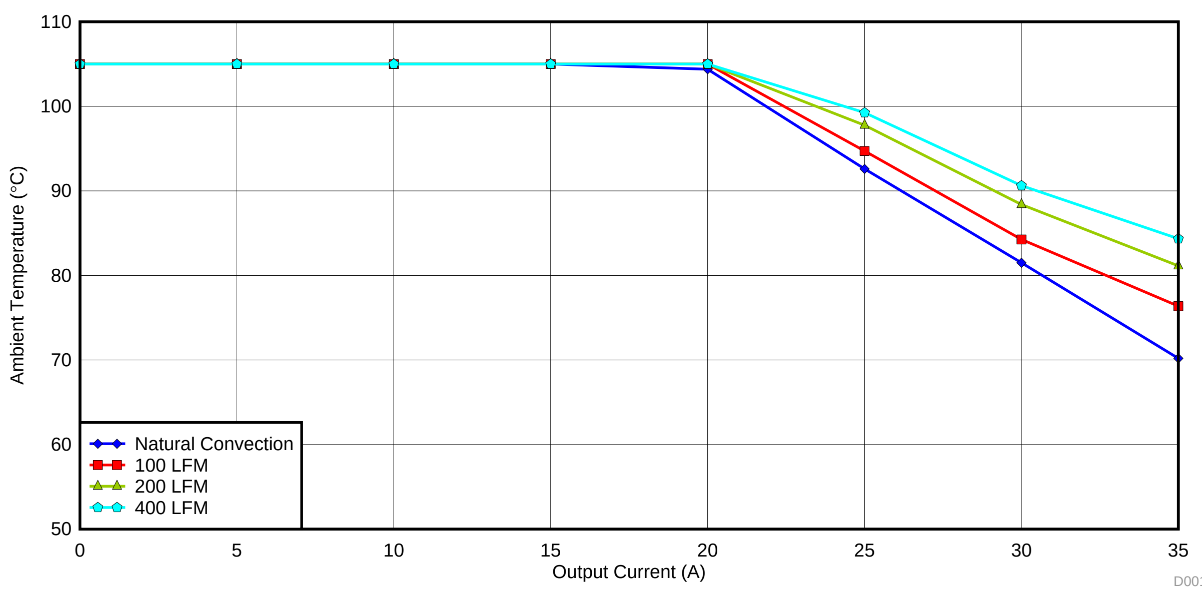

Figure 1. TPS546C23 Typical SOA Curves

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2 Plotting SOA Curve Procedures

2.1 Natural Convection SOA Curve

2.1.1 Oven Temperature Unit Setup

A labview program interface is used to control both the evaluation board and the oven temperature. Figure 2.1 shows the front interface of the oven temperature (TESTEQUITY Model 115) and evaluation board inside the oven. Figure 2.2 shows the upper chamber inside the oven which is used to provide the programmed ambient temperature to the lower chamber. Figure 2.3 shows the thermal wire used to regulate the programmed temperature. Figure 2.4 shows the evaluation board set up at the lower chamber inside the oven and limits the hot air flowing directly on top of the board.

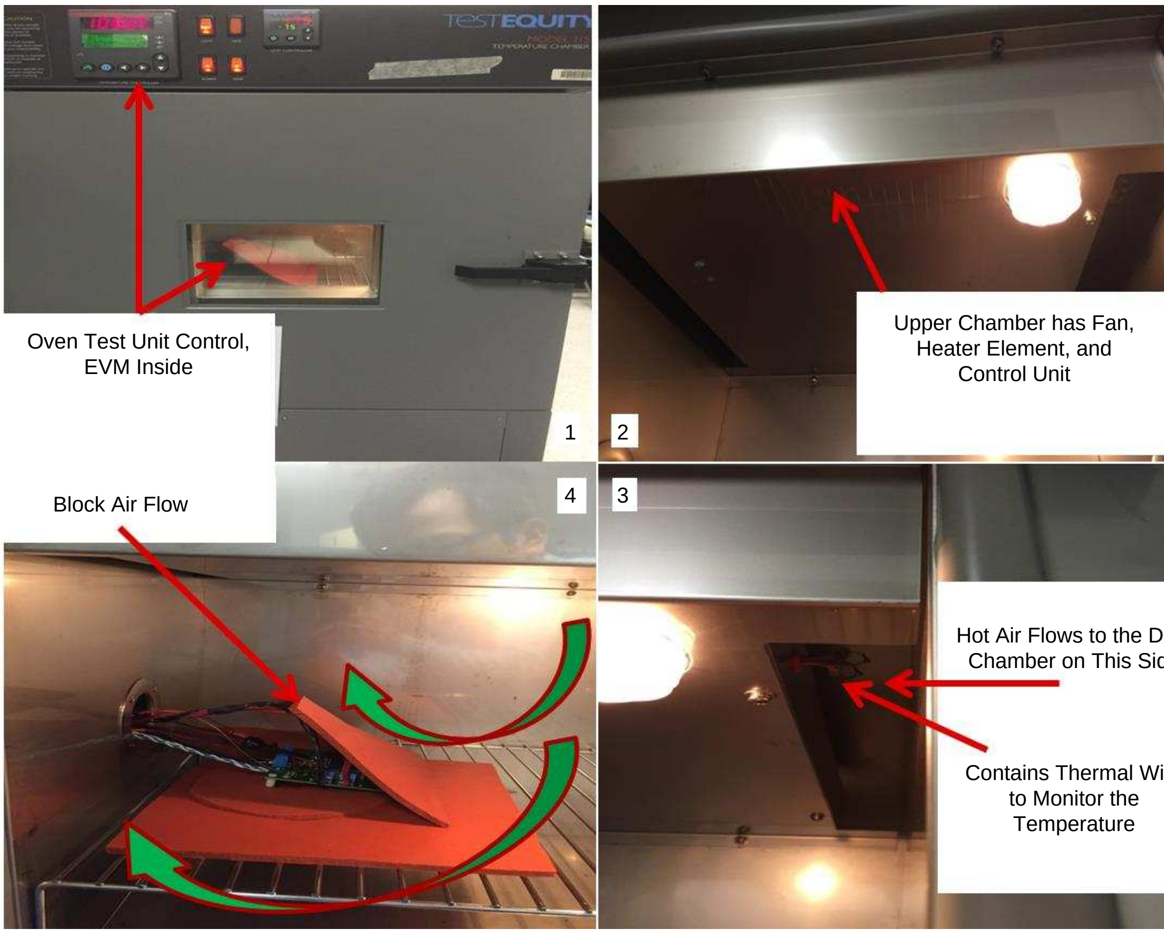

Figure 2. Evaluation Board Inside Oven Temperature Set Up

2.1.2 Junction Temperature Measurement:

An integrated circuit (IC) controller in the DC-DC converter is considered to be the heart of the switching power supply. The junction temperature of this IC controller is normally designed to operate safety in the –40°C to 125°C range. Therefore, it is necessary to have the SOA curves at the maximum junction temperature at 125°C. Depending on the complexity of the controller, one method to measure the junction temperature is through the body diode of the MOSFET at the power good pin. This method gives the reference diode voltage at the junction, 125°C. Table 1 shows an example of the baseline of the diode voltage versus the junction temperature. This junction temperature measures at the condition of no power applied to the evaluation board and 10 minutes settling time for each temperature.

Table 1. Reference Junction Temperature

Junction Temperature (0°C)	Measured Diode (V)
25	0.57347
50	0.55329
85	0.51591
100	0.49423
125	0.45831
150	0.42045

2.1.3 Data Collection Setup

A labview program interface is used to collect the data as shown in Table 2. The procedures to collect the data follow:

1. Set the ambient temperature (T_a): eq. at 25°C
2. Wait for 10 minutes for the temperature inside of the oven to reach the programmed temperature in step 1.
3. Change the load current (I_{OUT}): eq. start at 0 A
4. Wait for 10 minutes for thermal equilibrium, then record the data
5. Change the load current to another value: eq. at 5 A
6. Wait for 10 minutes for thermal equilibrium then record the data.
7. Repeat step 3 to 6 until at full load.
8. Repeat step 1 to 7 at each temperature.

Table 2. Natural Convection Data Collection Example

V_{IN} (V)	V_{OUT} (V)	I_{OUT} (A)	F_S (kHz)	T_a (°C)	Thermal Couple (°C)	V_{Diode} (V)	T_{PMBus} (°C)
12	1.0026253	20	500	25		0.55469582	46.9
12	1.0026383	20	500	50		0.52804621	71.9
12	1.0024828	20	500	70		0.50639045	91.9
12	1.0023922	20	500	80		0.49322489	101
12	1.0022756	20	500	85		0.48643681	106.6
12	1.0020165	20	500	100		0.46480054	122
12	1.001887	20	500	105		0.45720211	127.1
12	1.0017575	20	500	110		0.44938101	133.1
12	1.0015373	20	500	120		0.43356414	143.1
12	1.0014207	20	500	125		0.42541352	148.9

V_{IN} and V_{OUT} are the input and output voltage to the evaluation board, respectively. I_{OUT} is the output loading of the converter. F_S is the switching frequency for the converter. T_a is the ambient temperature inside the oven. T_{PMBus} is the junction temperature which measures using the digital method through PMBus™ data lines. In the case of a controller without the PMBus capability, the junction temperature can be measured through the thermal coupling wire placed on the top surface of controller device.

2.1.4 SOA Curve Graphing Method

The first step must graph the relationship between V_{Diode} and T_{PMBus} columns as shown in Figure 3. With the trend line of this graph, solve the V_{Diode} at 125°C junction temperature. This calculated diode voltage should be close to the measured diode voltage in Table 1 . The next step must graph the relationship between V_{Diode} and T_a columns as shown in Figure 4. Again, with the trend line of this graph, solve the ambient temperature at 125°C junction temperature through the V_{Diode} in the previous step. These two graphing methods must repeat for all the output load ranges. At the end, one can graph the natural convection SOA curve as shown in Figure 2. This SOA curve is considered as the worst case of the SOA graph.

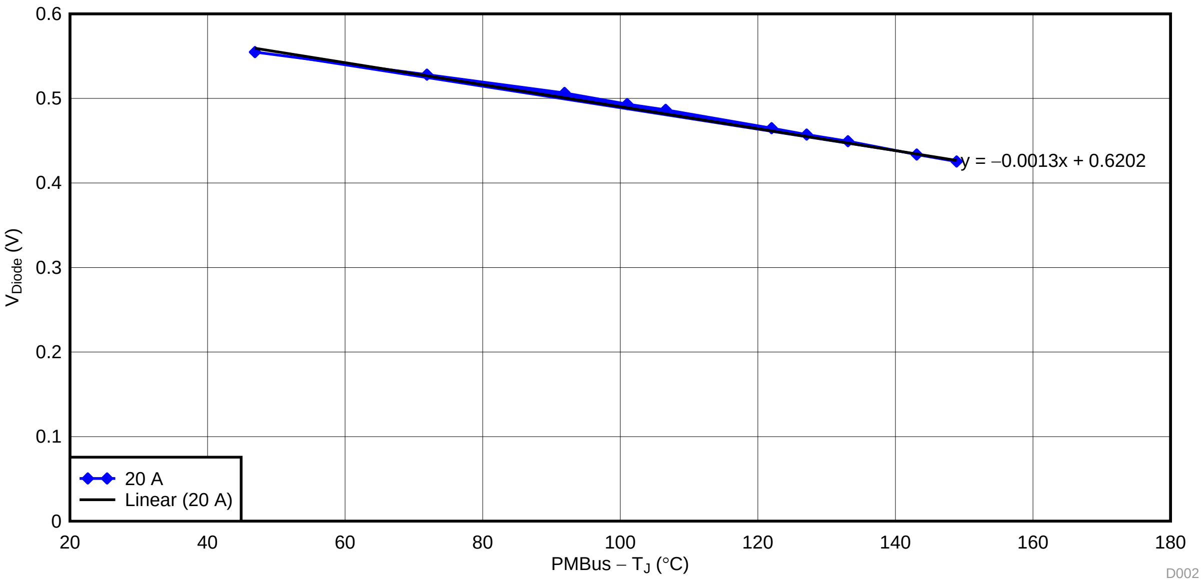

Figure 3. Junction Temperature vs Diode Voltage

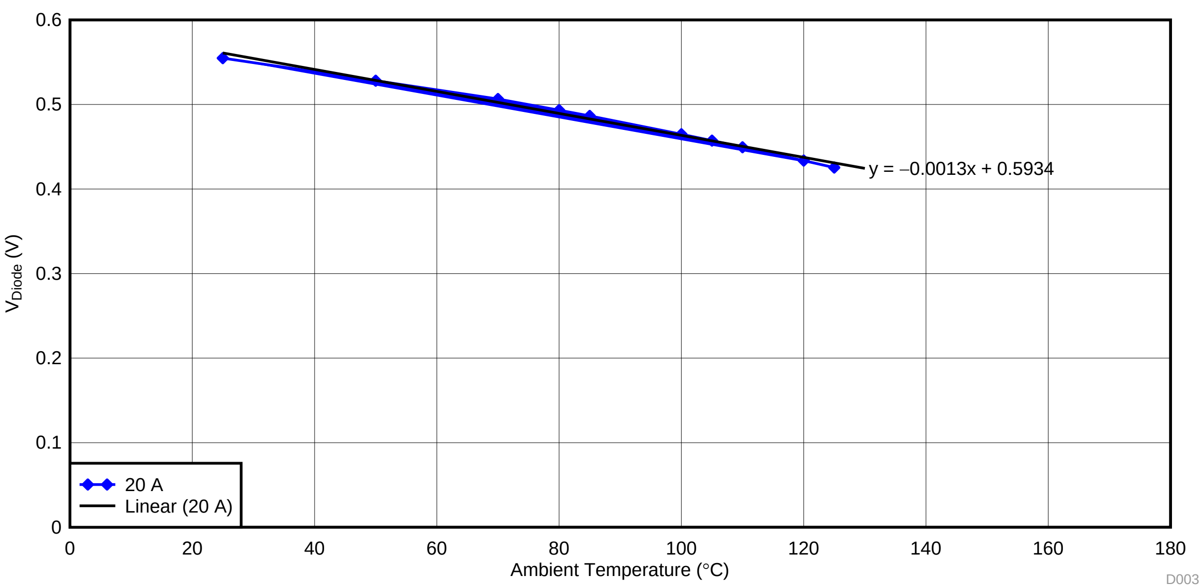

Figure 4. Ambient Temperature vs Diode Voltage

2.2 Airflow SOA Curves

2.2.1 Airflow Unit Setup

Figure 5 shows the airflow tunnel setup. Figure 5.1 shows the setup which includes the fan controller, thermal image window (if needed to get access to the evaluation board), airflow meter, airflow sensor, and output airflow direction. Figure 5.2 shows how the evaluation board is mounted for the airflow directional. This airflow unit regulates the DC fan to produce the air velocity in terms of LFM.

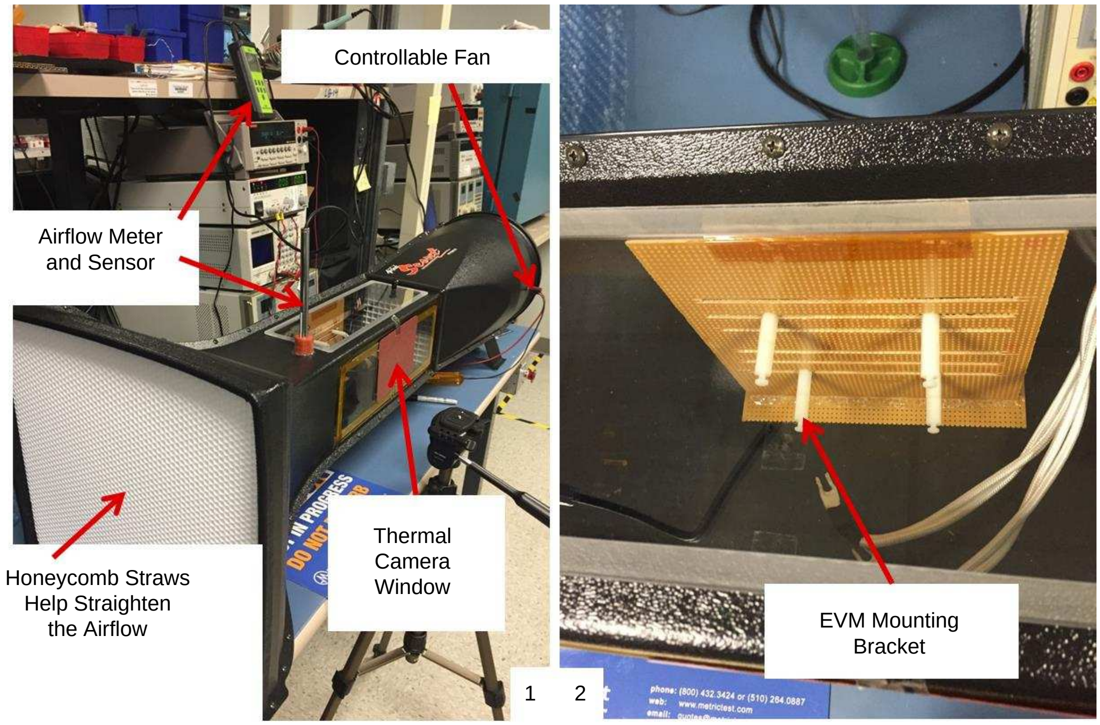

Figure 5. Airflow Tunnel Setup

2.2.2 Data Collection Steps

A labview program interface is used to collect the data as shown in Table 3. The procedures to collect the data follow:

1. Set airflow at highest LFM first: eq. 400 LFM
2. Change the load current: eq. at 0A
3. Wait for 10 minutes for thermal equilibrium, then record the data
4. Change the load current to another value: eq. 5A
5. Wait for 10 minutes for thermal equilibrium then record the data.
6. Repeat step 2 to 5 until at full load.
7. Repeat step 1 to 6 at the next lower LFM.

Table 3. Airflow Data Collection Example

Nat Conv				100 LFM		
I_{OUT} (A)	T_{PMBus} (°C)	V_{DIODE}		I_{OUT} (A)	T_{PMBus} (°C)	V_{DIODE}
0	29.3	0.572431		0	28.9	0.57259
5	32.1	0.570947		5	31.4	0.57141
10	35.8	0.567997		10	34.6	0.56871
15	40.1	0.56353		15	38.8	0.5647
20	44.8	0.556845		20	43.5	0.5587
25	54.6	0.547753		25	50.5	0.55067
30	67.6	0.535576		30	62.7	0.53976
35	80	0.516387		35	72.2	0.52617

2.2.3 LFM SOA Curves Graphing Method

The airflow unit is too big to be inside the oven and has difficulty controlling the uniform air velocity flow across the evaluation board if the unit is in the oven. At result, the airflow unit is located in the typical room temperature and is not in the regulated ambient temperature environment as in the natural convection case. To calculate the ambient temperature of the SOA curve with airflow, it is necessary to calculate the relative difference of diode voltage in Table 3 to the line equations in Figure 3 and Figure 4. The procedures follow:

1. Calculate the V_{Diode} difference between natural convection and 100 LFM in Table 3.
2. Subtract the result, in step 1, from the calculated V_{Diode} of Figure 3 at 125°C junction temperature.
3. Use the result of V_{Diode}, in step 2, to calculate the ambient temperature by using the trend line equation of graph 4.
4. Repeat steps 1 to 3 for each load and each LFM curve.

Finally, graph all of the SOA curves as shown in Figure 2. For the device without the ability to read the junction temperature through the PMBus data lines, the calculation procedures are the same by using the thermal coupling wire data column. For more accurate calculations with this type device, there is a temperature difference between the junction temperature and the top surface of device. At result, the calculation V_{Diode} of Figure 3 should have included this difference.

3 Conclusion

The SOA curves of any DC-DC power supply converter are generated by following the procedures described in Section 2. The purpose of SOA curves is to serve as a design guideline of the thermal performance to a system designer. In the actual implementation of a real system, the SOA curves will vary depending on many other factors such as (PCB) area, heat source, inconsistent airflow velocity, and so forth. As a result, the natural convection SOA curve serves as the worst-case guideline for the system designer.