SiC MOSFET

5 kW High-Efficiency Fan-less Inverter

We employ trans-linked interleaved circuits as inverter circuits that utilize the high frequency switching performance of silicon carbide (SiC) MOSFET\(^\text{\textsuperscript{1}}\), achieving a power conversion efficiency of 99% or more at 5 kW. Since this circuit topology allows a reduction in the inductance of the smoothing reactor, the high efficiency is achieved by reducing the number of windings of the reactor to dramatically reduce the copper loss. This document introduces an example of this novel inverter design.

These novel inverter circuits have been developed jointly with Power Assist Technology Ltd. ([https://www.power-assist-tech.co.jp/](https://www.power-assist-tech.co.jp/))

Comparison with conventional circuit

Figure 1 shows a comparison of the full bridge type with conventional circuit configuration (conventional type) and the trans-linked interleaved type (interleaved type) introduced in this document. The output power of both types is 5 kW.

Although the conventional type is configured with two IGBT (STGW60H65DFB) as switching devices in parallel, its efficiency of 97.4% at 5 kW (total loss 133 W) requires a cooling fan. In contrast, since the interleaved type using SiC MOSFET (SCT3017AL, SCT3030AL) has an efficiency of 99.0% (total loss 51 W), heat generation is reduced, and the circuit can be cooled with downsized heat radiation fins without using a cooling fan. Furthermore, since the apparent switching frequency is doubled for the interleaved type, the smoothing filter is downsized by a factor of 2 in its size and weight.

![Comparison with conventional circuit configuration](image-url)
Circuit configuration

Figure 2 shows a diagram of the circuit configuration for the interleaved type.

This inverter circuit has three half bridges (B1, B2, and B3). Each half bridge contains two transistors (Q_{Hk} and Q_{Lk}, k = 1, 2, and 3). A Schottky barrier diode (SBD) is connected with the transistors in parallel as a free wheeling diode. B2 and B3 are operated in the PWM mode with their phases inverted by 180° relative to each other. B1 is operated as a low frequency switching bridge with Q_{H1} and Q_{L1} alternately switched at 50 Hz. The output lines of B2 and B3 interact with each other via the coupling reactor \((L_c)\), and the currents are added after flowing through \(L_c\). The output lines of B2 and B3 and the middle point of B1 are connected to the output capacitor (C_o).

![Figure 2. Trans-linked interleaved inverter circuit](image)

Figure 3 shows an equivalent circuit to the coupling reactor.

The coupling reactor can be divided into two leakage inductances \((L_1 \text{ and } L_2)\), a magnetizing inductance \((L_m)\), and an ideal reverse polarity transformer. \(V_{L1}, V_{L2}, V_1, \text{ and } V_2\) represent self-induced electromotive forces of the respective inductances shown in Figure 3. \(i_{L1}, i_{L2}, i_1, \text{ and } i_2\) are currents defined in Figure 3. Assume that the PWM part is operated with duty ratio \(d\) when \(Q_{H2}\) is ON. Because of the inverter operation, \(d\) varies with time. For the sake of convenience, assume that \(L_1 \text{ and } L_2\) have the same inductance represented with \(L\). Except for the dead time period, all half bridges in the inverter are operated with synchronous rectification.

![Figure 3. Equivalent circuit to coupling reactor \((L_c)\)](image)
The relationship between $V_{in}$ and $V_{out}$ is represented with Equation (1), similarly to the relationship for normal buck converters.

$$V_{out} = dV_{in} \quad (1)$$

Theoretical analyses of the interleaved buck converters have already been discussed in various publications (*4) to (*6). The same calculations are applied to this trans-linked type as well.

![Figure 4. Timing charts for QH2 and QH3](image)

(a) $d < 0.5$  
(b) $d \geq 0.5$

Figure 4 shows the timing charts for QH2 and QH3. Gate-source voltages $V_{gs(QH2)}$ and $V_{gs(QH3)}$ indicate the ON and OFF states, and $t_j$ ($j = 0$ to 4) indicates the time when the transistor is switched. As shown in Figure 4, QH2 and QH3 can be simultaneously OFF when (a) $d < 0.5$, while they cannot be simultaneously OFF if (b) $d \geq 0.5$. Therefore, it is necessary to analyze the circuit operations separately for (a) $d < 0.5$ and (b) $d \geq 0.5$.

(a) If $d < 0.5$, the time sequence of terms 1, 2, 3, and 4 are defined as follows.

- Term 1 (from $t_0$ to $t_1$): QH2 is turned ON at $t_0$, and QH3 remains OFF
- Term 2 (from $t_1$ to $t_2$): QH2 is turned OFF at $t_1$, and QH3 remains OFF
- Term 3 (from $t_2$ to $t_3$): QH2 remains OFF, and QH3 is turned ON at $t_2$
- Term 4 (from $t_3$ to $t_4$): QH2 remains OFF, and QH3 is turned OFF at $t_3$

Since one cycle is time $T$, terms 1 and 3 are $d \cdot T$, and terms 2 and 4 are $(0.5 - d) \cdot T$.

(b) If $d \geq 0.5$, the sequence is similarly defined as follows.

- Term 1 (from $t_0$ to $t_3$): QH2 remains ON, and QH3 is turned OFF at $t_3$
- Term 2 (from $t_3$ to $t_4$): QH2 remains ON, and QH3 is turned ON at $t_4$
- Term 3 (from $t_4$ to $t_2$): QH2 is turned OFF at $t_4$, and QH3 remains ON
- Term 4 (from $t_2$ to $t_1$): QH2 is turned ON at $t_2$, and QH3 remains ON

Therefore, terms 1 and 3 are $(1 - d) \cdot T$, and terms 2 and 4 are $(d - 0.5) \cdot T$.

For both cases where (a) $d < 0.5$ or (b) $d \geq 0.5$, QL2 and QL3 are switched mutually with QH2 and QH3, respectively, leading to the following relational expressions.

$$V_1 = -V_2 \quad (2)$$
$$i_{L1} = i_{m} + i_1 \quad (3)$$
$$i_{L2} = i_2 \quad (4)$$
$$i_1 = i_2 \quad (5)$$

From Equations (2) to (5), $i_m$ and its ripple component $\Delta i_m$ are calculated as follows.

$$i_m = i_{L1} - i_{L2} \quad (6)$$
$$\Delta i_m = \Delta i_{L1} - \Delta i_{L2} \quad (7)$$
From the basic formulas for induced electromotive force of \( V = -\frac{L}{d} \), the formulas for \( \Delta i_{L1} \) and \( \Delta i_{L2} \) are derived as shown in Table 1. As shown in Equations (8) to (9), the sum of \( i_{L1} \) and \( i_{L2} \) equals output current \( i_{out} \), and the sum of \( \Delta i_{L1} \) and \( \Delta i_{L2} \) equals output current ripple \( i_{out, pp} \).

\[
\begin{align*}
    i_{out} &= i_{L1} + i_{L2} \quad \text{(8)} \\
    i_{out, pp} &= \Delta i_{L1} + \Delta i_{L2} \quad \text{(9)}
\end{align*}
\]

Table 1. \( \Delta i_{L1} \) and \( \Delta i_{L2} \) for each term (1 to 4)

(a) \( d < 0.5 \)

<table>
<thead>
<tr>
<th>Term</th>
<th>( \Delta i_{L1} )</th>
<th>( \Delta i_{L2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( \frac{dV_{in}}{L} \left( 1 - \frac{L}{L + 2L_m} - d \right) T )</td>
<td>( \frac{dV_{in}}{L} \left( \frac{L}{L + 2L_m} - d \right) T )</td>
</tr>
<tr>
<td>2</td>
<td>(- \frac{(0.5 - d)dV_{in}}{L} T )</td>
<td>(- \frac{(0.5 - d)dV_{in}}{L} T )</td>
</tr>
<tr>
<td>3</td>
<td>( \frac{dV_{in}}{L} \left( \frac{L}{L + 2L_m} - d \right) T )</td>
<td>( \frac{dV_{in}}{L} \left( \frac{1 - L}{L + 2L_m} - d \right) T )</td>
</tr>
<tr>
<td>4</td>
<td>(- \frac{(0.5 - d)dV_{in}}{L} T )</td>
<td>(- \frac{(0.5 - d)dV_{in}}{L} T )</td>
</tr>
</tbody>
</table>

(b) \( d \geq 0.5 \)

<table>
<thead>
<tr>
<th>Term</th>
<th>( \Delta i_{L1} )</th>
<th>( \Delta i_{L2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( \frac{(1 - d)V_{in}}{L} \left( 1 - \frac{L}{L + 2L_m} - d \right) T )</td>
<td>( \frac{(1 - d)V_{in}}{L} \left( \frac{L}{L + 2L_m} - d \right) T )</td>
</tr>
<tr>
<td>2</td>
<td>( \frac{(d - 0.5)(1 - d)V_{in}}{L} T )</td>
<td>( \frac{(d - 0.5)(1 - d)V_{in}}{L} T )</td>
</tr>
<tr>
<td>3</td>
<td>( \frac{(1 - d)V_{in}}{L} \left( \frac{L}{L + 2L_m} - d \right) T )</td>
<td>( \frac{(1 - d)V_{in}}{L} \left( 1 - \frac{L}{L + 2L_m} - d \right) T )</td>
</tr>
<tr>
<td>4</td>
<td>( \frac{(d - 0.5)(1 - d)V_{in}}{L} T )</td>
<td>( \frac{(d - 0.5)(1 - d)V_{in}}{L} T )</td>
</tr>
</tbody>
</table>

**Advantages of trans-linked topology**

The trans-linked topology can significantly reduce the copper loss of the reactor by using the coupling reactor connected with the output lines. The reasons are as follows. (*2)~(*3)

- Since the output current is divided into two phases, the loss due to Joule heating is reduced by 50%.
- The inductance required for smoothing can be reduced.

One cycle of the current ripple in the reactor is reduced by a factor of 2 with the trans-linked part, which is designed to be operated in the reverse phase so that the current is divided into two. In addition, these reverse currents alternately magnetize the coupling reactor and prevent magnetic saturation. Therefore, materials with a high saturation magnetic flux density \( B_S \) are not required and materials with a high magnetic permeability (low \( B_S \)), such as ferrite, can be used. As a result, the number of windings \( N \) of the reactor is reduced, resulting in the reduction of the copper loss.
Design of coupling reactor

As shown in Figure 5, the coupling reactor is composed of two magnetic elements referred to as the “outer leg” and the “center leg”. Since the reactor is a reverse polarity transformer, the magnetic fluxes produced by \( i_{L1} \) and \( i_{L2} \) are canceled out by each other in the outer leg. This means that it is not necessary for the magnetic material of the outer leg to have a high Bₜ.

In contrast, the magnetic fluxes flow in the same direction and are intensified in the center leg. At the same time, since the phases of \( i_{L1} \) and \( i_{L2} \) are shifted relative to each other by 180°, the vibration frequency of the total magnetic flux is doubled. Therefore, it is necessary for the magnetic material used for the center leg to have a high Bₜ and good characteristics for high frequency operation. Accordingly, ferrite MB3 [JFE FERRITE (*8)] is employed for the outer leg material, and Liqualloy™ [ALPS ELECTRIC (*9), (*10): currently ALPS ALPINE] is employed for the center leg.

The most important factors to be considered in designing the coupling reactor are \( L \) and \( L_m \). These two parameters determine the ripple waveform of \( I_{out} \) and the magnetic flux density. As explained in detail below, the maximum value of \( |I_{out,pp}| \) is determined by \( L \). From Table 1 and Equation (9), \( |I_{out,pp}| \) for each term is expressed as Equation (10).

\[
|I_{out,pp}| = \begin{cases} 
\frac{d(1-2d)V_{in}T}{L} & (\text{for } d < 0.5) \\
\frac{(1-d)(2d-1)V_{in}T}{L} & (\text{for } d \geq 0.5) 
\end{cases} 
\]  

(10)

At \( d = 0.25 \) and 0.75, \( |I_{out,pp}| \) reaches its maximum and the value of \( |I_{out,pp}|_{max} \) is expressed as Equation (11).

\[
|I_{out,pp}|_{max} = \frac{V_{in}T}{8L} 
\]  

(11)

From Table 1, \( \Delta l_m \) for terms 1 and 3 is expressed as follows based on Equation (7).

\[
\Delta l_m = \begin{cases} 
\pm \frac{dV_{in}T}{L + 2L_m} & (\text{for } d < 0.5) \\
\pm \frac{(1-d)V_{in}T}{L + 2L_m} & (\text{for } d \geq 0.5) 
\end{cases} 
\]  

(12)

\( \Delta l_m \) is positive for term 1, negative for term 3, and 0 for terms 2 and 4. Since the circuit configuration is symmetric, the average values of \( i_{L1} \) and \( i_{L2} \) over one cycle \( T \) are \( I_{out}/2 \) as calculated with Equation (8). As a result, the average value of \( l_m \) expressed with
Equation (6) must be zero. This result and Equation (12) lead to the following equation for $d < 0.5$.

$$
\begin{align*}
\begin{cases}
  i_{m1} - i_{m0} &= \frac{dV_{in}T}{L + 2L_m} \\
  i_{m2} - i_{m1} &= 0 \\
  i_{m3} - i_{m2} &= -\frac{dV_{in}T}{L + 2L_m} \\
  i_{m4} - i_{m3} &= 0 \\
  \frac{i_{m5} + i_{m4}}{2}d + i_{m1}(0.5 - d) + \frac{i_{m2} + i_{m3}}{2}d + i_{m3}(0.5 - d) &= 0
\end{cases}
\end{align*}
$$

$i_{mj}$ ($j = 0$ to 4) represents $i_m$ at $t_j$. In the fifth equation in (13), the left term represents the average value of $i_m$.

From Equation (13), $i_{mj}$ can be calculated as follows.

$$
\begin{align*}
\begin{cases}
  i_{m0} &= i_{m3} = i_{m4} = -\frac{dV_{in}T}{2(L + 2L_m)} \\
  i_{m1} &= i_{m2} = \frac{dV_{in}T}{2(L + 2L_m)}
\end{cases}
\end{align*}
$$

The same calculation method shows $i_{mj}$ for $d \geq 0.5$ as well.

$$
\begin{align*}
\begin{cases}
  i_{m0} &= i_{m3} = i_{m4} = -\frac{(1 - d)V_{in}T}{2(L + 2L_m)} \\
  i_{m1} &= i_{m2} = \frac{(1 - d)V_{in}T}{2(L + 2L_m)}
\end{cases}
\end{align*}
$$

Therefore, $|i_{m}|_{max}$, the maximum value of $|i_m|$, is expressed as follows at $d = 0.5$.

$$
|i_{m}|_{max} = \frac{V_{in}T}{4(L + 2L_m)}
$$

In addition, magnetic flux density $B_m$ of the outer leg can be calculated as follows.

$$
B_m = \frac{i_{m}L_m}{NA_e}
$$

$A_e$ represents the effective area of the ferrite core of the outer leg.
Input and output specifications of inverter

The input and output specifications of the inverter designed here are shown below.

- \( V_{\text{in}} = 320 \text{ V} \)
- \( V_{\text{out}} = \text{AC 200 V} \)
- \( I_{\text{out}} = \text{AC 25A} \)
- \( f_{\text{sw}} = 40 \text{ kHz} \)
- \( I_{\text{out \, pp}}/I_{\text{out \, peak}} < 0.2 \)
- \( B_{\text{m \, max}} < 0.15 \text{ T} \)

\( I_{\text{out \, pp}}/I_{\text{out \, peak}} \) is the setting for reducing the \( C_{\text{o}} \) loss. \( B_{\text{m \, max}} \) is the condition for avoiding the risk of magnetic saturation [approximately less than a third of \( B_{\text{S}} \) of MB3 (*8)].

From Equation (11) and the relationship between \( I_{\text{out \, pp}}/I_{\text{out \, peak}} \) and \( L \), it is necessary for \( L \) to exceed \( 100\sqrt{2} \mu\text{H} \). For this core, \( L = 170 \mu\text{H} \) when \( N = 19 \). This design employs \( 2.2 \text{ mH} \) for \( L_{\text{n}} \) and \( 378 \text{ mm}^2 \) for \( A_{\text{e}} \) of the outer leg. From Equations (16) and (17), it can also be seen that these parameters satisfy \( B_{\text{m \, max}} < 0.15 \text{ T} \).

Figure 6 shows the appearance of the coupling reactor containing a copper winding made with 40 litz wires of 0.35 mm in diameter. The measured resistance of the copper wire was 18m\(\Omega \). A ferrite core with magnetic flux density \( B_{\text{S}} \) of 0.45 T and permeability of 2,500 is employed (*8) to reduce the copper wire resistance by reducing the number of windings \( N \). A material with a high \( B_{\text{S}} \) is essential for the center leg. Liqualloy™ (*9) is suitable for the center leg material, achieving a gapless configuration thanks to its high \( B_{\text{S}} \) value of 1.3 T.

| Table 2 \( \Delta i_{L1} \) and \( \Delta i_{L2} \) for each term (1 to 4) |
|-----------------|-----------------|-----------------|
| Dimensions      | Trans-linked interleaved type | Full bridge type |
| Volume          | 6.5 cm x 4.8 cm x 6.2 cm | \( \varnothing 8 \text{ cm } \times 4 \text{ cm } \times 4 \text{ in series} \) |
| Volume ratio    | 1                | 4.68            |

Figure 6. Developed coupling reactor and conventional reactor
Efficiency evaluation

The performance is compared for a trans-linked interleaved inverter using SiC MOSFET (inverter A), conventional full bridge inverter using Si IGBT (inverter B), and conventional full bridge inverter using Si MOSFET (inverter C).

Figure 7 shows the circuit diagram of inverters B and C. Table 3 shows the circuit constants of these two types of inverters.

![Figure 7. Block diagram of conventional inverter circuit (inverters B, C)](image)

In this figure, \( i_L \) represents the current flowing through the smoothing reactor in inverters B and C. As shown in Table 3, the trans-linked type can reduce the necessary capacitance value by reducing the current passing through the MOSFET by a factor of 2 and increasing the frequency of the current ripple. As a result, the number of transistors and capacitors can be reduced.

<table>
<thead>
<tr>
<th>Table 3 Constants of parts used for inverter circuits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input voltage</strong> (( V_{in} ))</td>
</tr>
<tr>
<td>----------------------------------</td>
</tr>
<tr>
<td><strong>Input capacitance</strong> (( C_i ))</td>
</tr>
<tr>
<td><strong>Low frequency switches</strong></td>
</tr>
<tr>
<td><strong>High frequency switches</strong></td>
</tr>
<tr>
<td><strong>Switching frequency</strong> (( f_{sw} ))</td>
</tr>
<tr>
<td><strong>Free wheeling diode</strong> (( D ))</td>
</tr>
<tr>
<td><strong>Magnetizing inductance</strong> (( L_m ))</td>
</tr>
<tr>
<td><strong>Leakage / Smoothing inductance</strong> (( L ))</td>
</tr>
<tr>
<td><strong>Copper wire resistance of the reactor</strong></td>
</tr>
<tr>
<td><strong>Output capacitance</strong> (( C_o ))</td>
</tr>
<tr>
<td><strong>Output voltage</strong> (( V_{out} ))</td>
</tr>
</tbody>
</table>

© 2021 ROHM Co., Ltd.
Figure 8 shows efficiency $\eta$ of inverters A, B, and C taking output power $P_{out}$ as the horizontal axis. In this figure, efficiency $\eta$ is calculated as a ratio of $P_{out}$ against input power $P_{in}$. However, the total power loss ($P_{total} = P_{in} - P_{out}$) does not include the gate drive loss in the MOSFET.

If the Si IGBT is replaced with a SiC MOSFET (from inverter B to inverter C), efficiency $\eta$ is improved over the entire range of $P_{out}$. However, efficiency $\eta$ is monotonically decreased in the $P_{out}$ range above 1 kW, and falls below 99% in the $P_{out}$ range above 3 kW mainly due to increase in the conduction loss in the transistor and the copper loss in the wiring. In contrast, efficiency $\eta$ of inverter A exceeds 99% in the entire $P_{out}$ range from 1 kW to 5 kW, reaching a high efficiency of 99.4% at 2 kW.

**Analysis of Total Loss Power ($P_{total}$)**

The pie chart in Figure 9 shows a breakdown of the total loss power ($P_{total}$) of inverter A (trans-linked type) when the inverter is operated at $P_{out} = 5$ kW. This loss analysis calculation is based on the on-resistance ($R_{ON}$) at 125°C. The details are explained below.

<table>
<thead>
<tr>
<th>Loss Type</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduction loss in the low-frequency MOSFET</td>
<td>0.6 W</td>
</tr>
<tr>
<td>Conduction loss in the high-frequency MOSFET</td>
<td>13.8 W</td>
</tr>
<tr>
<td>Switching loss of high-frequency MOSFET</td>
<td>5.1 W</td>
</tr>
<tr>
<td>Loss during dead time</td>
<td>12.3 W</td>
</tr>
<tr>
<td>Copper loss</td>
<td>12.7 W</td>
</tr>
<tr>
<td>Others</td>
<td></td>
</tr>
</tbody>
</table>

Figure 9. Analysis of $P_{total}$ in inverter A at 5 kW
1) Conduction loss in MOSFET of half bridge B1:
Each MOSFET of B1 (SCT3017AL, ROHM) has $R_{ON}$ of 22mΩ at 125°C. The effective current is 25 Arms and the total conduction loss in these MOSFET is $(25 \text{ Arms})^2 \times 22\text{mΩ} = 13.8 \text{ W}$. Since $f_{SW}$ of B1 is 50 Hz, the dead time loss and switching loss $E_{loss,sw}$ in these MOSFET are negligible.

2) Conduction loss in MOSFET of half bridges B2 and B3 (PWM part):
Each MOSFET in B2 and B3 (SCT3030AL, ROHM) has $R_{ON}$ of 40mΩ at 125°C. The effective current flowing in each phase of the coupling reactor is 12.5 Arms. Since the high side MOSFET ($Q_{H2}$ and $Q_{H3}$) and the low side MOSFET ($Q_{L2}$ and $Q_{L3}$) are operated with synchronous rectification, either of the high or low side MOSFET remain ON except for the dead time (DT) of 220 ns. Since one cycle of the MOSFET is 25 µs, the conduction loss in the MOSFET of the PWM parts is $(12.5 \text{ Arms})^2 \times 40\text{mΩ} \times (1 - (220 \text{ ns} \times 2)/25 \text{ µs}) \times 2 \text{ phases} = 12.3 \text{ W}$. 

3) Switching loss in MOSFET of half bridges B2 and B3 (PWM part):
Figure 10 shows the $E_{total,sw}$ curve of the SiC MOSFET used in the PWM part as a function of drain current $I_d$.

The total energy of switching loss in MOSFET ($E_{total,sw}$) is mainly composed of the energy of turn ON loss ($E_{on}$), energy of turn OFF loss ($E_{off}$), and energy of reverse recovery loss ($E_{rr}$). These loss energies were measured with the double pulse test (*11), and the measurement circuit used for this test is shown as an inset in Figure 10. $V_{ds}$ and $I_{dH}$ represent the drain-source voltage and the drain current of the high side MOSFET, respectively, while $V_{ds}$ and $I_{dL}$ represent the corresponding values for the low side. $E_{on}$ and $E_{off}$ can be calculated by multiplying $V_{ds}$ and $I_{dL}$ during the switching transient periods for turning ON and OFF the low side MOSFET, respectively. $E_{rr}$ can be calculated from $V_{ds}$ and $I_{dH}$ during the switching transient period for turning ON the low side MOSFET. The average current flowing through $L_1$ or $L_2$ at the point of phase angle $\theta$ is expressed as Equation (20). Therefore, the average $P_{sw}$ of the MOSFET in the PWM part is the integrated value of $E_{total,sw} \cdot f_{sw}$ over the entire period, and the integration can be calculated with averaging Equation (21).

\[
I = \sqrt{2} \cdot 12.5 \cdot \sin \theta \quad (A)
\]

\[
P_{SW} = \frac{1}{T} \int_{0}^{T} E_{total,sw} f_{sw} dt \cdot 2\text{phase} = 12.7 \text{W}
\]
4) Power loss during DT period:
   For inverter A, DT is set to 220 ns. During this period, the current flows into the free wheeling SBD (SCS212AM, ROHM).
   The average current flowing through the diode can also be expressed with Equation (20). As with \( P_{sw} \), the power loss during the DT period \( (P_{DT}) \) is calculated according to the following equation.

\[
P_{DT} = \frac{1}{T} \int_{0}^{T} V_F I_F f_{sw} \cdot 2DT \cdot 2\text{pcs.}
\]  

\[\text{Eq. (22)}\]

\( V_F \) and \( I_F \) represent the forward voltage and current of the SBD, respectively. Calculation based on the \( V_F-I_F \) characteristics on the data sheet of SCS212AM used (*12) results in \( P_{DT} = 0.3 \text{ W} \cdot 2 \text{ pcs} = 0.6 \text{ W} \).

5) Copper loss:
   The measured resistance was 18\( \mu \Omega \) for the copper wire wound around one side of the outer leg. Since the effective current is 12.5 Arms, the total copper loss is \((12.5 \text{ Arms})^2 \cdot 18\mu \Omega \cdot 2 \text{ wires} = 5.6 \text{ W}\).

6) Others:
   The power losses other than those described above are approximately 5.1 W, including the core loss in the coupling reactor, \( C_a \) and \( C_c \), and the conduction loss in the wiring parts of the circuit board. From the core loss data for ferrite MB3 (*8) and Liguialloy™ (*9), the total power loss in this inverter core is calculated to be approximately 2.5 W.
   From these loss analyses, the sum of power losses in \( Q_{H2} \), \( Q_{H3} \), \( Q_{L2} \), and \( Q_{L3} \) is approximately 25 W.
   Since this loss is small, the cooling system can be simplified. In inverter A, a heat sink with a thermal resistance \( (R_{th}) \) of 5°C/W is attached to all SiC MOSFET via a thermal sheet with \( R_{th} \) of 1.7°C/W. It is estimated that the fin temperature on the contact surface of the SiC MOSFET is low (approximately 80°C) and the junction temperature \( (T_j) \) is lower than 130°C. Since this level is lower than the maximum rating for \( T_j \) of the SiC MOSFET, the fan-less cooling is feasible.

![Figure 11. Comparison of breakdown of \( P_{total} \) of inverters at 5 kW](image)

For \( P_{total} \) of inverters B and C at 5 kW, breakdowns are calculated with a similar method. The breakdowns of \( P_{total} \) of inverters A, B, and C are compared in Figure 11. The loss in the transistors is reduced by a factor of 2 or greater by replacing the Si IGBT with the SiC MOSFET, making fan-less operations feasible even for inverter C. Since the actual surface temperature of the cooling fins was also 80°C for inverter C operated at 5 kW, the fan-less operations were feasible. However, due to the copper loss in the smoothing reactor, efficiency \( \eta \) of 99% at 5 kW cannot be achieved for inverter C. The copper loss in the coupling reactor is significantly smaller for inverter A compared with inverter C. The reason is that the coupling reactor reduces the number of windings, effectively reducing the copper loss.
Table 4 summarizes the performances of inverters A, B, and C. If inverter A is employed instead of inverter B, efficiency $\eta$ is improved by 1.6%, $P_{\text{total}}$ is reduced by 62%, and the size and the weight are reduced by 56% and 50%, respectively. In addition, compared with inverter C, efficiency $\eta$ of inverter A is 0.7% better and $P_{\text{total}}$ is also improved by 41%. The differences between inverter A and inverter B or C are also evident in Figure 1.

Table 4 Comparison of performance of inverter circuits

<table>
<thead>
<tr>
<th></th>
<th>Inverter A</th>
<th>Inverter B</th>
<th>Inverter C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switching transistors</td>
<td>SiC MOSFETs</td>
<td>Si IGBTs</td>
<td>SiC MOSFETs</td>
</tr>
<tr>
<td>Conversion efficiency (@5 kW)</td>
<td>99.0%</td>
<td>97.4%</td>
<td>98.3%</td>
</tr>
<tr>
<td>Total loss (@5 kW)</td>
<td>51 W</td>
<td>133 W</td>
<td>85 W</td>
</tr>
<tr>
<td>Size</td>
<td>4180 cm³</td>
<td>9480 cm³</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>2.5 kg</td>
<td>5.0 kg</td>
<td></td>
</tr>
</tbody>
</table>

Summary

We developed trans-linked interleaved 5 kW inverters that use SiC MOSFET as switching devices. The SiC MOSFET show an excellent switching performance compared with that of Si IGBT. This enables higher switching operations and downsizing of the entire system. Furthermore, when the trans-linked interleaved circuit topology that employs a reverse polarity coupling reactor is operated at a switching frequency of 40 kHz, the number of windings is reduced, leading to a significant reduction in the copper loss. As a result, a high efficiency of 99.0% at an output power of 5 kW is achieved, enabling fan-less operations.
■ Inverter A circuit diagram (Schematics)

(a) Power PCB and Sub PCB

(b) Control PCB
5 kW High-Efficiency Fan-less Inverter Circuit

(c) driver PCB
### 5 kW High-Efficiency Fan-less Inverter Circuit

#### Application Note

- **Film Capacitor**
  - Symbol: C1, C8, C9, C10, C11, C12
  - Parts Number: BFC2339020105
  - Values: 1μF, 630V ±10%
  - Manufacture: Vishay
  - Package Size: 26x10x13.5

- **AI- E Capacitor**
  - Symbol: C2, C3, C4
  - Parts Number: ELX3S451V55N15A50S
  - Values: 560μF, 450V ±20%
  - Manufacture: Nichicon
  - Package Size: D35x50

- **Film Capacitor**
  - Symbol: C5, C16, C25
  - Parts Number: 450MPH0105J
  - Values: 1μF, 450V ±5%
  - Manufacture: RUBYCON
  - Package Size: 18.5x15x23

- **Capacitor**
  - Symbol: C7, C9, C35, C37, C38
  - Parts Number: GRM18531E105K4A12
  - Values: 1μF, 25V ±10%
  - Manufacture: MURATA
  - Package Size: 16x6.8

- **Capacitor**
  - Symbol: C15, C16, C17, C24, C35, C53, C58
  - Parts Number: GRM18531E105M5A12
  - Values: 1μF, 25V ±20%
  - Manufacture: MURATA
  - Package Size: 16x6.8

- **Capacitor**
  - Symbol: C13, C12, C28, C40, C41, C42, C46, C57, C50, C70
  - Parts Number: GRM188BH1102K0A1
  - Values: 1000μF, 50V ±10%
  - Manufacture: MURATA
  - Package Size: 16x6.8

- **Capacitor**
  - Symbol: C56, C68, C72
  - Parts Number: GRM188R71E104K0A1
  - Values: 1μF, 25V ±10%
  - Manufacture: MURATA
  - Package Size: 16x6.8

- **Capacitor**
  - Symbol: C59
  - Parts Number: GRM188R11H104K4A3
  - Values: 0.1μF, 50V ±10%
  - Manufacture: MURATA
  - Package Size: 16x6.8

- **AL- E Capacitor**
  - Symbol: C62, C30, C67, C72, C34, C35, C39, C44, C48, C52, C54, C55, C56, C57
  - Parts Number: Transformer
  - Values: Resistor
  - Manufacture: MURATA
  - Package Size: 6x4.9

- **Capacitor**
  - Symbol: C67
  - Parts Number: Transformer
  - Values: Resistor
  - Manufacture: MURATA
  - Package Size: 6x4.9

### Diode

- Symbol: D1, D3, D5, D7, D10, D11
- Parts Number: ES1A
- Values: 50V, 1A
- Manufacture: Fairchild
- Package Size: TO-24AC

- Symbol: D2, D4, D6, D8
- Parts Number: SCS212AM
- Values: 650V, 12A
- Manufacture: ROHM
- Package Size: 10.16x4.7x19

- Symbol: D9
- Parts Number: 1S5324
- Values: 90V, 225mA
- Manufacture: ROHM
- Package Size: 2.3x1.25x0.7

- Symbol: D12, D18
- Parts Number: EQ01C
- Values: 1000V, 0.5A
- Manufacture: SANKEN
- Package Size: qux±x

- Symbol: D13, D14, D15, D16, D17
- Parts Number: SBRI15105A-13
- Values: 150V, 1A
- Manufacture: DIODES
- Package Size: 4.3x2.6x2.2

- Symbol: Zener Diode
- Parts Number: U2D25.1B
- Values: 5.1V, 5mA
- Manufacture: ROHM
- Package Size: SC-90

- Symbol: Photocoupler
- Parts Number: PS200TL-1
- Values: 80V, 30mA
- Manufacture: NEC
- Package Size: 6x4.3x3.6

- Symbol: Transistor
- Parts Number: SCT3030AL
- Values: Ncm, 650V, 30mA
- Manufacture: ROHM
- Package Size: TO-247N

- Symbol: Transistor
- Parts Number: SCT3017AL
- Values: Ncm, 650V, 17mA
- Manufacture: ROHM
- Package Size: TO-247N

- Symbol: Potentiometer
- Parts Number: VRT3, VR5, VR3
- Values: 50kΩ, 0.5A
- Manufacture: TOSHIBA
- Package Size: SC-59

- Symbol: Resistor
- Parts Number: R1, R2, R4
- Values: 5kΩ, 1/2W ±1%
- Manufacture: TOSOPAL
- Package Size: 7x7x8

- Symbol: Resistor
- Parts Number: R6, R8, R9, R10
- Values: 1MΩ, 1/4W ±5%
- Manufacture: KOA
- Package Size: 3216

- Symbol: Resistor
- Parts Number: R3, R5, R12, R14
- Values: 4.7Ω, 1/4W ±5%
- Manufacture: KOA
- Package Size: 3216

- Symbol: Resistor
- Parts Number: R6, R8, R11, R13
- Values: 58kΩ, 1/4W ±5%
- Manufacture: KOA
- Package Size: 3216

- Symbol: Resistor
- Parts Number: R7, R15
- Values: 2200pF, 50V ±5%
- Manufacture: MURATA
- Package Size: 20

- Symbol: Resistor
- Parts Number: R9, R17
- Values: 10kΩ, 1/10W ±5%
- Manufacture: MURATA
- Package Size: 1608

- Symbol: Resistor
- Parts Number: R15, R16, R18, R19, R20, R21, R22, R25, R42, R43, R45, R47, R49, R50, R51, R52, R54, R56, R57, R58, R59, R60, R65, R66, R67, R68, R69, R70, R71, R72, R73, R74, R75, R76, R77, R78, R79, R80
- Values: 10kΩ, 1/10W ±5%
- Manufacture: MURATA
- Package Size: 1608

- Symbol: Resistor
- Parts Number: R23, R24
- Values: 47Ω, 1/10W ±5%
- Manufacture: KOA
- Package Size: 1608

- Symbol: Resistor
- Parts Number: R25, R44, R48, R53, R61, R62, R63
- Values: 4.7kΩ, 1/10W ±5%
- Manufacture: KOA
- Package Size: 1608

- Symbol: Resistor
- Parts Number: R27, R29, R32, R43, R53, R58, R67
- Values: 100Ω, 1/10W ±5%
- Manufacture: KOA
- Package Size: 1608

- Symbol: Resistor
- Parts Number: R64
- Values: 3kΩ, 1/2W ±15%
- Manufacture: ROHM
- Package Size: 1608

- Symbol: Resistor
- Parts Number: R68
- Values: 1kΩ, 1/10W ±15%
- Manufacture: ROHM
- Package Size: 1608

- Symbol: Resistor
- Parts Number: R74
- Values: 1kΩ, 1/10W ±15%
- Manufacture: ROHM
- Package Size: 1608

- Symbol: Resistor
- Parts Number: R94
- Values: 33kΩ, 1/10W ±15%
- Manufacture: ROHM
- Package Size: 1608

- Symbol: Transformer
- Parts Number: T1
- Values: 6mA, 67-1
- Manufacture: NICON PULSE
- Package Size: 24.5x21x22

- Symbol: Transformer
- Parts Number: T2
- Values: 120V
- Manufacture: PAIL
- Package Size: 1608

- Symbol: Line filter
- Parts Number: ADR-48-50-95YA
- Values: 0.5mH, 50A
- Manufacture: UENO
- Package Size: 65x60x40

- Symbol: Current Sensor
- Parts Number: CO-3303
- Values: ±20A 60mA/V
- Manufacture: Asahikasei
- Package Size: 7x9.5x6.1

- Symbol: IC
- Parts Number: U2, U7, U8
- Values: Dual RtoR OP-amp
- Manufacture: NJRC
- Package Size: SOP-8

- Symbol: IC
- Parts Number: U4
- Values: Isolation AMP
- Manufacture: AVAGO
- Package Size: 8x8x6.3x2

- Symbol: IC
- Parts Number: U5, U6
- Values: 8 CMS0 Inverter
- Manufacture: TOSHIBA
- Package Size: SOP-14

- Symbol: IC
- Parts Number: U9
- Values: 5V, 0.5A LDO
- Manufacture: TOSHIBA
- Package Size: 6x5.3x2.3

- Symbol: IC
- Parts Number: U12
- Values: 10mA Analog regulator
- Manufacture: NJRC
- Package Size: SOP-8

- Symbol: IC
- Parts Number: U10
- Values: 9VDC
- Manufacture: SANKEN
- Package Size: DIP-8
### (a), (b) Power PCB, Sub PCB, Control PCB (Continued)

<table>
<thead>
<tr>
<th>Device</th>
<th>Symbol</th>
<th>Parts Number</th>
<th>Values</th>
<th>Manufacture</th>
<th>Package Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connector</td>
<td>J1,J2,J3,J6,J10,J11,J12</td>
<td>FHU-2+5G</td>
<td>3A, 8pin, female</td>
<td>Useconn</td>
<td>10.16x5.08x8.5</td>
</tr>
<tr>
<td>Connector</td>
<td>J4</td>
<td>FHU-2x85G</td>
<td>3A, 16pin, female</td>
<td>Useconn</td>
<td>20.8x5x8.5</td>
</tr>
<tr>
<td>Connector</td>
<td>J5,J8</td>
<td>PH-1x04SG</td>
<td>Pin header 1x4P</td>
<td>Useconn</td>
<td>10.16x2.54x8.5</td>
</tr>
<tr>
<td>Connector</td>
<td>J7</td>
<td>FHU-2x95G</td>
<td>3A, 18pin, female</td>
<td>Useconn</td>
<td>23.4x5x8.5</td>
</tr>
<tr>
<td>Connector</td>
<td>J9</td>
<td>PH-2x08SG</td>
<td>Pin header 2x8P</td>
<td>Useconn</td>
<td>20.8x5x8.5</td>
</tr>
<tr>
<td>Connector</td>
<td>J13</td>
<td>PH-2x04SG</td>
<td>Pin header 2x4P</td>
<td>Useconn</td>
<td>10.16x5.08x8.5</td>
</tr>
<tr>
<td>Connector</td>
<td>J14</td>
<td>PH-2x09SG</td>
<td>Pin header 2x9P</td>
<td>Useconn</td>
<td>22.8x5x5.08x8.5</td>
</tr>
<tr>
<td>Connector</td>
<td>CN1</td>
<td>B3P-EH</td>
<td>10A, 3pin</td>
<td>JST</td>
<td>13.8x9.7x11</td>
</tr>
<tr>
<td>Connector</td>
<td>CN2</td>
<td>3S8-EH</td>
<td>3A, 3pin</td>
<td>JST</td>
<td>10x3.8x6</td>
</tr>
<tr>
<td>Connector</td>
<td>CN3</td>
<td>PH-1x10RG2</td>
<td>10pin, Side</td>
<td>Useconn</td>
<td>25.4x10.62x2.54</td>
</tr>
<tr>
<td>Connector</td>
<td>CN4</td>
<td>B58-PH-K-S</td>
<td>3pin</td>
<td>JST</td>
<td>11.9x4.5x6</td>
</tr>
<tr>
<td>Connector</td>
<td>CN5</td>
<td>S48-EH</td>
<td>4pin</td>
<td>JST</td>
<td>12.5x3.8x6</td>
</tr>
<tr>
<td>FET-2 Module</td>
<td>MJ1,MJ2</td>
<td>PC092-01-00</td>
<td>10pin</td>
<td>PAT</td>
<td>56x3x13x</td>
</tr>
<tr>
<td>FET Module</td>
<td>MJ3</td>
<td>PC045-00-00</td>
<td>10pin</td>
<td>PAT</td>
<td>--</td>
</tr>
<tr>
<td>CPU Module</td>
<td>MJ4</td>
<td>PC089-01-00-50P</td>
<td>36pin</td>
<td>PAT</td>
<td>26x40x26</td>
</tr>
<tr>
<td>Test Point</td>
<td>TP1,TP2,TP3,TP4,TP6,TP7,</td>
<td>KRB-408</td>
<td>Screw, internal</td>
<td>HIROSUGI</td>
<td>φ8x8</td>
</tr>
<tr>
<td>Check Pin</td>
<td>CP1,CP2,CP3,CP4,CP5,CP6,CP7,</td>
<td>HOT-2608B</td>
<td>Black</td>
<td>HIROSUGI</td>
<td>2.5x1.75</td>
</tr>
</tbody>
</table>

### (c) Driver PCB

<table>
<thead>
<tr>
<th>Device</th>
<th>Symbol</th>
<th>Parts Number</th>
<th>Values</th>
<th>Manufacture</th>
<th>Package Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitor</td>
<td>C1,C2,C4,C5,C9,C12</td>
<td>GRM188B31H1054KA92</td>
<td>0.1µF 50V ±10%</td>
<td>MURATA</td>
<td>1608</td>
</tr>
<tr>
<td>Capacitor</td>
<td>C3</td>
<td>GRM1815X1H472JA44</td>
<td>4700µF 50V ±20%</td>
<td>MURATA</td>
<td>1608</td>
</tr>
<tr>
<td>Capacitor</td>
<td>C6,C7,C8,C10,C11,C13,C14</td>
<td>GRM21B871E1056KA99</td>
<td>1µF 25V ±10%</td>
<td>MURATA</td>
<td>2512</td>
</tr>
<tr>
<td>Diode</td>
<td>D1,D2,D3,D4</td>
<td>1S3S5</td>
<td>90V 225mA</td>
<td>ROHM</td>
<td>2.5x1.25x0.7</td>
</tr>
<tr>
<td>Diode</td>
<td>D5</td>
<td>RB751S-10</td>
<td>30V 30mA</td>
<td>ROHM</td>
<td>1608</td>
</tr>
<tr>
<td>Connector</td>
<td>J1,J3</td>
<td>MB8P-90</td>
<td>250V 3A</td>
<td>JST</td>
<td>7.5x2.4x3</td>
</tr>
<tr>
<td>Connector</td>
<td>J2</td>
<td>MB4P-90</td>
<td>250V 3A</td>
<td>JST</td>
<td>10x2.4x3</td>
</tr>
<tr>
<td>Connector</td>
<td>J4</td>
<td>B47X-H-A</td>
<td>250V 3A</td>
<td>JST</td>
<td>12.4x5.7x7</td>
</tr>
<tr>
<td>Photocoupler</td>
<td>PC1,PC2</td>
<td>TLP070A</td>
<td>35V 3mA</td>
<td>TOSHIBA</td>
<td>4.6x6.8x4</td>
</tr>
<tr>
<td>Transistor</td>
<td>Q1</td>
<td>3E8K93</td>
<td>60V 2.5A</td>
<td>TOSHIBA</td>
<td>2.91x1.6x7.7</td>
</tr>
<tr>
<td>Transistor</td>
<td>Q2,Q4</td>
<td>2SK542P</td>
<td>30V 5A</td>
<td>ROHM</td>
<td>4.6x2.1x1.5</td>
</tr>
<tr>
<td>Transistor</td>
<td>Q3,Q5</td>
<td>2SK542P</td>
<td>30V 5A</td>
<td>ROHM</td>
<td>4.6x2.1x1.5</td>
</tr>
<tr>
<td>Resistor</td>
<td>R1,R3</td>
<td>MCR03ERTJ102</td>
<td>1Ω 1/10W ±5%</td>
<td>ROHM</td>
<td>1608</td>
</tr>
<tr>
<td>Resistor</td>
<td>R2</td>
<td>MCR03ERTJ202</td>
<td>10Ω 1/10W ±5%</td>
<td>ROHM</td>
<td>1608</td>
</tr>
<tr>
<td>Resistor</td>
<td>R4,R5</td>
<td>MCR03ERTJ303</td>
<td>100Ω 1/10W ±5%</td>
<td>ROHM</td>
<td>1608</td>
</tr>
<tr>
<td>Resistor</td>
<td>R6,R7,R8</td>
<td>MCR10ERTJ4R7</td>
<td>4.7Ω 1/8W ±5%</td>
<td>ROHM</td>
<td>2012</td>
</tr>
<tr>
<td>Resistor</td>
<td>R10,R16</td>
<td>MCR03ERTJ331</td>
<td>330Ω 1/10W ±5%</td>
<td>ROHM</td>
<td>1608</td>
</tr>
<tr>
<td>Resistor</td>
<td>R11,R17</td>
<td>MCR03ERTJ407</td>
<td>470Ω 1/10W ±5%</td>
<td>ROHM</td>
<td>1608</td>
</tr>
<tr>
<td>Resistor</td>
<td>R12,R13,R18,R19</td>
<td>MCR18ERTJ202</td>
<td>20Ω 1/8W ±5%</td>
<td>ROHM</td>
<td>3216</td>
</tr>
<tr>
<td>Resistor</td>
<td>R14,R15,R20,R21</td>
<td>MCR18ERTJ4R7</td>
<td>4.7Ω 1/4W ±5%</td>
<td>ROHM</td>
<td>3216</td>
</tr>
<tr>
<td>Resistor</td>
<td>R22,R23</td>
<td>MCR18ERTJ100</td>
<td>1Ω 1/4W ±5%</td>
<td>ROHM</td>
<td>3216</td>
</tr>
<tr>
<td>Transformer</td>
<td>T1</td>
<td>TRF068A</td>
<td>--</td>
<td>Shinsen denki</td>
<td>8x13x8</td>
</tr>
<tr>
<td>Inductor</td>
<td>U1</td>
<td>NJM7805UA</td>
<td>5V 20mH</td>
<td>JRC</td>
<td>4.5x2.5x1.5</td>
</tr>
<tr>
<td>IC</td>
<td>U2</td>
<td>NE555D</td>
<td>18V 225mA</td>
<td>TI</td>
<td>DIP-8</td>
</tr>
</tbody>
</table>
■ Inverter A PCB layout
(1) Power PCB

(a) top

(b) bottom
(2) Control PCB

(a) top

(b) bottom
(3) Driver PCB

(a) Top Silk

(b) top

(c) bottom
References:


Notice

Notes

1) The information contained herein is subject to change without notice.

2) Before you use our Products, please contact our sales representative and verify the latest specifications.

3) Although ROHM is continuously working to improve product reliability and quality, semiconductors can break down and malfunction due to various factors. Therefore, in order to prevent personal injury or fire arising from failure, please take safety measures such as complying with the derating characteristics, implementing redundant and fire prevention designs, and utilizing backups and fail-safe procedures. ROHM shall have no responsibility for any damages arising out of the use of our Products beyond the rating specified by ROHM.

4) Examples of application circuits, circuit constants and any other information contained herein are provided only to illustrate the standard usage and operations of the Products. The peripheral conditions must be taken into account when designing circuits for mass production.

5) The technical information specified herein is intended only to show the typical functions of and examples of application circuits for the Products. ROHM does not grant you, explicitly or implicitly, any license to use or exercise intellectual property or other rights held by ROHM or any other parties. ROHM shall have no responsibility whatsoever for any dispute arising out of the use of such technical information.

6) The Products specified in this document are not designed to be radiation tolerant.

7) For use of our Products in applications requiring a high degree of reliability (as exemplified below), please contact and consult with a ROHM representative: transportation equipment (i.e., cars, ships, trains), primary communication equipment, traffic lights, fire/crime prevention, safety equipment, medical systems, servers, solar cells, and power transmission systems.

8) Do not use our Products in applications requiring extremely high reliability, such as aerospace equipment, nuclear power control systems, and submarine repeaters.

9) ROHM shall have no responsibility for any damages or injury arising from non-compliance with the recommended usage conditions and specifications contained herein.

10) ROHM has used reasonable care to ensure the accuracy of the information contained in this document. However, ROHM does not warrant that such information is error-free, and ROHM shall have no responsibility for any damages arising from any inaccuracy or misprint of such information.

11) Please use the Products in accordance with any applicable environmental laws and regulations, such as the RoHS Directive. For more details, including RoHS compatibility, please contact a ROHM sales office. ROHM shall have no responsibility for any damages or losses resulting from non-compliance with any applicable laws or regulations.

12) When providing our Products and technologies contained in this document to other countries, you must abide by the procedures and provisions stipulated in all applicable export laws and regulations, including without limitation the US Export Administration Regulations and the Foreign Exchange and Foreign Trade Act.

13) This document, in part or in whole, may not be reprinted or reproduced without prior consent of ROHM.

Thank you for your accessing to ROHM product informations.
More detail product informations and catalogs are available, please contact us.

ROHM Customer Support System

http://www.rohm.com/contact/