Fuji Power MOSFET
Power calculation method

Design Tool

Chapter 1. Overview

It is necessary to check whether the power loss has not exceeded the Absolute Maximum Ratings for using MOSFET. Since the MOSFET loss cannot be measured using a power meter, it is required to calculate it from drain-source voltage V_{DS} and drain current I_D waveforms obtained by using a device such as an oscilloscope. This document provides the method to calculate the MOSFET loss. In addition, how to use the loss-calculation assistance tool is provided.

Chapter 2. Calculating electric energy [J]

Generally, the electric energy J_{ab} [J] for a period t_a-t_b as indicated in Figure 1 can be calculated by the integration of voltage times current as indicated in the following formula:

$$J_{ab} = \int_{t_a}^{t_b} V(t) \cdot I(t)\, dt \cdots\cdots(1)$$

While, I(t) and V(t) can be expressed as follows:

$$V(t) = -\frac{V_a - V_b}{t_b - t_a} t + V_a \cdots\cdots(2)$$

$$I(t) = -\frac{I_a - I_b}{t_b - t_a} t + I_a \cdots\cdots(3)$$

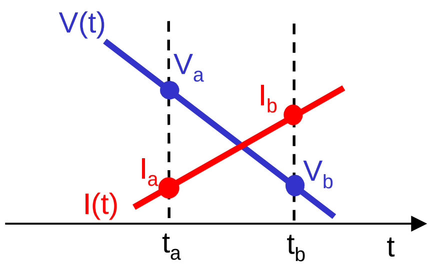


Figure 1: Voltage V(t) and current I(t) for a period t_a-t_b

Thus, integrate them for the time period of t_a-t_b to obtain the following electric energy [J]:

$$J_{ab} = \frac{1}{3}(V_a - V_b)\cdot(I_a - I_b)\cdot(t_b - t_a) - \frac{1}{2}(V_a - V_b)\cdot(t_b - t_a)\cdot I_a - \frac{1}{2}(I_a - I_b)\cdot(t_b - t_a)\cdot V_a + V_a \cdot I_a \cdot (t_b - t_a) \cdots\cdots(4)$$

By using the above formula and arbitrarily separating the period t_a-t_b, you can even obtain the electric energy [J] for nonlinear waveforms.

Chapter 3. Calculating electric energy [J] from voltage and current waveforms

To calculate the power loss from voltage and current waveforms for the period T, divide T into ranges where linear approximation can be applied, as indicated in Figure 2.

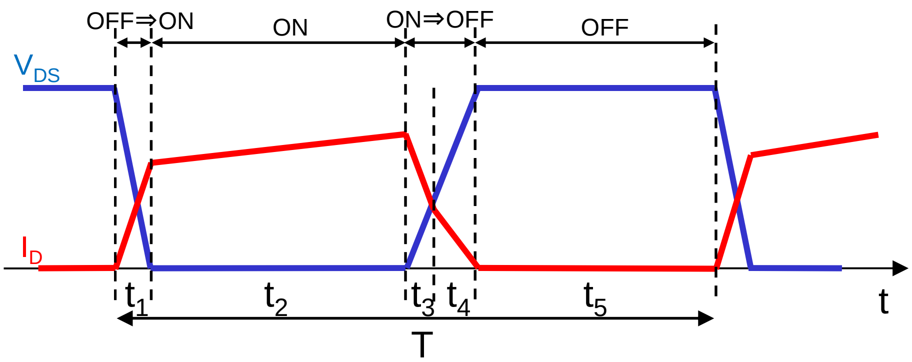


Figure 2: Example of loss calculation waveforms

In Figure 2, the current waveform slope changes during MOSFET is being turned off. Therefore, to calculate the loss from waveforms of Figure 2, divide T into t_1, t_2, ..., t_5. In actual circuits that include parasitic capacitance of MOSFET, the voltage and current change exponentially during transition between on and off. Because it is difficult to exponentially represent voltage and current from the observed waveforms on a device such as oscilloscope, linear approximations are used.

Chapter 4. Calculating electric power [W] from electric energy [J]

As indicated in Figure 3, read the voltage and current values of waveform for the period T. Use the read values and formula (4) to calculate the loss.

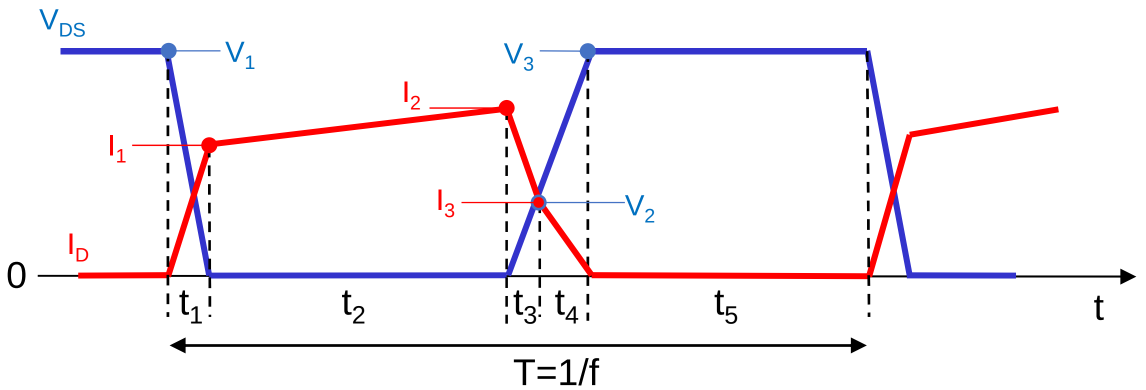


Figure 3: Read voltage and current values from waveform example

By calculating the loss for each of the sections t_1 [s] to t_5 [s], the loss for each of the sections J_1 [J] to J_5 [J] can be derived. Since MOSFET is electrically conducting in the section t_2 [s], the voltage is a product of the MOSFET's ON-resistance R_{ON} and the current. Formula (5) to (9) show expressions for each of the sections. The period T [s] is also inverse of frequency f [Hz], therefore the power P [W] consumed by MOSFET can be obtained from formula (10). Note that the following formulas are simplified to the final forms based on the voltage and current slopes and zero-cross. Formulas for each pattern are shown in Appendix Table 1.

$$J_1 = \frac{1}{6} V_1 \cdot I_1 \cdot t_1 \cdots\cdots (5)$$

$$J_2 = R_{ON} \cdot \left(\frac{1}{3} (I_1 - I_2)^2 - (I_1 - I_2) \cdot I_1 + I_1^2 \right) \cdot t_2 \cdots\cdots (6)$$

$$J_3 = \frac{1}{6} V_2 \cdot (I_2 + 2I_3) \cdot t_3 \cdots\cdots (7)$$

$$J_4 = \frac{1}{6} (2V_2 + V_3) \cdot I_3 \cdot t_4 \cdots\cdots (8)$$

$$J_5 = 0 \cdots\cdots (9)$$

$$P = \frac{J_1 + J_2 + J_3 + J_4 + J_5}{T} = (J_1 + J_2 + J_3 + J_4 + J_5) \cdot f \cdots\cdots (10)$$

Supplementary information <Effective value current>

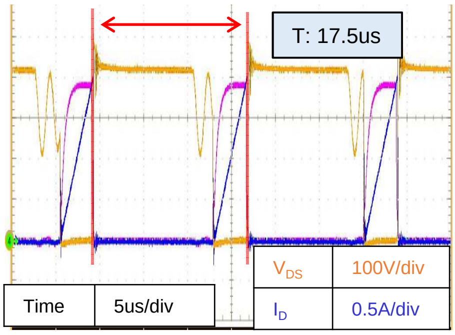
Formula (6) is used to obtain electric energy [J] at ON-resistance R_{ON}. In the ON-period t_2, power [W] can be obtained from effective values. Using I_{2rms} [A] as the effective current in the section t_2, the power P_2 [W] in the ON-period can be expressed by formula (11) from formula (6).

$$P_2 = \frac{J_2}{T} = R_{ON} \cdot I_{2rms}{}^2 = R_{ON} \cdot \left(\sqrt{\frac{t_2}{T}} \cdot \sqrt{\frac{1}{3} (I_1 - I_2)^2 - (I_1 - I_2) \cdot I_1 + I_1^2} \right)^2 \cdots\cdots (11)$$

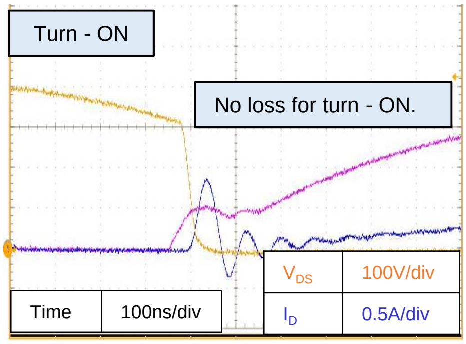
In the ON-period, MOSFET will consume the power that is the product of ON-resistance R_{ON} and square of effective current. Therefore, the power increases quadratically depending on the increase of the current value. Formula to calculate the effective current varies depending on the current waveform.
Appendix Table 2 shows typical waveforms and formulas to calculate effective values.

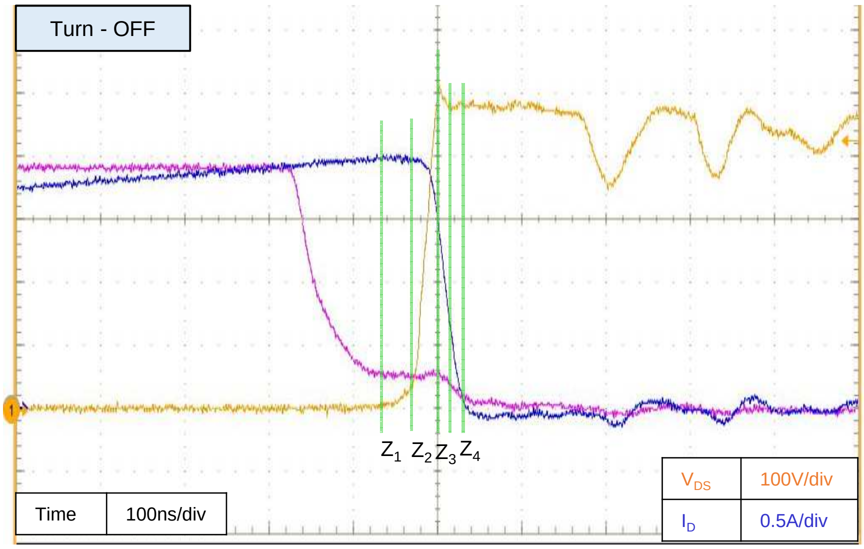
Chapter 5. Calculating loss from waveform

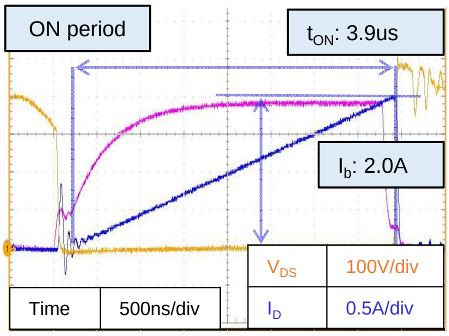
Actual operating waveforms are used for loss calculation example. For calculation from operating waveforms, check that the wave cycle is clear, the turn-ON and turn-OFF voltages and current can be read, and the current values can be read in the ON-period. The followings show actually measured waveforms and read values. Check the ON-resistance R_{ON} in the data sheet for MOSFET that you are using. (The following calculation uses the max value at Tch = 150℃, which is read from a chart in the data sheet.)



Measurement points	Flyback-Converter of the switching MOSFET
Device type	FMV60N380S2 (600V/8.1A/$R_{DS(on)@150℃max}$=0.94[Ω])
Output power	65W (DC:19V/3.4A)







Measured values		⊿t	V_a	V_b	I_a	I_b
Turn - ON		0us	0V	0V	0A	0A
ON period		3.9us	0V	0V	0A	2.0A
Turn - OFF	Z_1	30ns	0V	40V	2.0A	2.0A
	Z_2	35ns	40V	420V	2.0A	1.5A
	Z_3	20ns	420V	370V	1.5A	0.7A
	Z_4	25ns	370V	385V	0.7A	0A

The read values are used for the loss calculation. The followings are the calculation results with the respective values assigned to the formula (4).

$$Turn-ON: J_1 = 0[J]$$

$$ON-period: J_2 = 0.94[\Omega]\times\left(\frac{1}{3}(-2.0[A])^2\right)\times 3.9[us] = 4.89[uJ]$$

$$Z_1: J_3 = \frac{1}{2}\times 40[V]\times 2.0[A]\times 30[ns] = 1.20[uJ]$$

$$Z_2: J_4 = \left\{-\frac{1}{3}(380[V]\times 0.5[A]) + \frac{1}{2}(380[V]\times 2.0[A]) - \frac{1}{2}(0.5[A]\times 40[V]) + 40[V]\times 2.0[A]\right\}\times 35[ns] = 13.53[uJ]$$

$$Z_3: J_5 = \left\{\frac{1}{3}(50[V]\times 0.8[A]) - \frac{1}{2}(50[V]\times 1.5[A]) - \frac{1}{2}(0.8[A]\times 420[V]) + 420[V]\times 1.5[A]\right\}\times 20[ns] = 8.76[uJ]$$

$$Z_4: J_6 = \left\{-\frac{1}{3}(15[V]\times 0.7[A]) + \frac{1}{2}(15[V]\times 0.7[A]) - \frac{1}{2}(0.7[A]\times 370[V]) + 370[V]\times 0.7[A]\right\}\times 25[ns] = 3.28[uJ]$$

From the following calculation results, the MOSFET loss P [W] that can be calculated from waveforms is 1.81 [W].

$$P = \frac{0[J] + 4.89[uJ] + 1.20[uJ] + 13.53[uJ] + 8.76[uJ] + 3.28[uJ]}{17.5[us]} = 1.81[W]$$

Chapter 6. Using MOSFET power calculation tool (Excel)

The loss calculation methods described above are all intended for manual calculation. In this section, Excel is used. This Excel file is designed to be used for the loss calculation and channel temperature calculation. The file contains a sheet that describes how to use the tool. Please check the content before using it.

Section 1

Download the Excel file from the Fuji Electric's home page:
URL http://www.fujielectric.com/
Home > Products & Solutions > Power Semiconductors > Product Information > Power MOSFET > Design Tools
< File name > Power calculation tool_Rev_0_0_E.xlsx

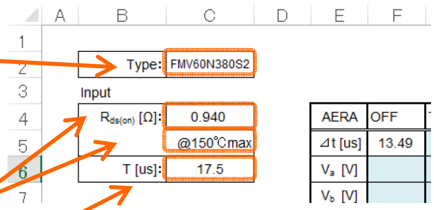
Section 2

Open the downloaded file, Power calculation tool_Rev_0_0_E.xlsx, and click the "calculation" sheet.

Section 3

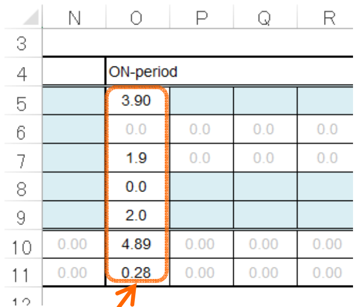
Input required values from the obtained waveforms and the data sheet of MOSFET that you are using. Use the obtained waveforms in Chapter 5 and MOSFET data sheet for comparing the calculation.

[C2]
Input the model of MOSFET that you are using.
This cell is optional; calculation is not affected if it is empty.



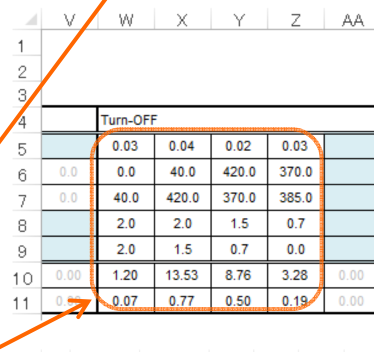
[C4, C5]
Read and input the ON-resistance from the Drain-Source On-state resistance chart in the MOSFET data sheet. The C5 cell is intended for MEMO. Use it to record the data such as channel temperature.

[C6]
Input the switching cycle in an [us] unit from waveforms.



[F column]
You can input voltages and currents in the OFF-period; however, those data can be omitted because the calculation result is zero. The OFF-time can also be omitted because there will be shown the difference between the value input in C6 and values input for Turn-ON, ON-period and Turn-OFF.

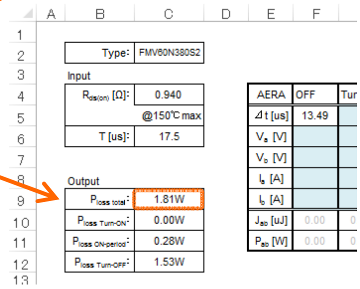
[G to N columns]
Input the read values of waveforms in the Turn-ON time, voltage and current values. In the waveforms for this document, no data is input since there is no intersection of voltage and current.



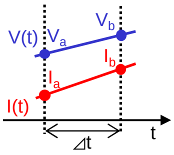
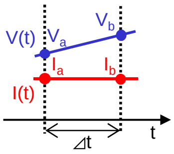
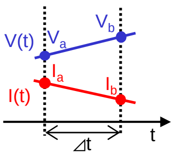
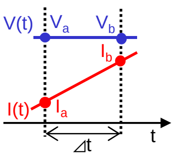
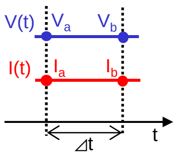
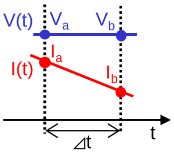
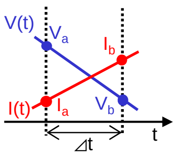
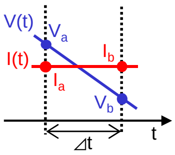
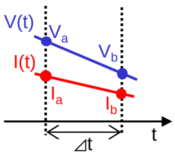
[O to X columns]
Input the read values of waveforms in the ON-period time and current values. For voltages in the ON-period, a product of R_{ON} and current value is shown as the calculation result.

[Y to AF columns]
Input the read values of waveforms in the Turn-OFF time, voltage and current values.

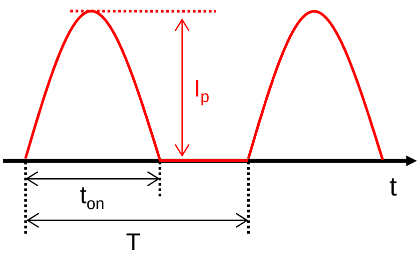
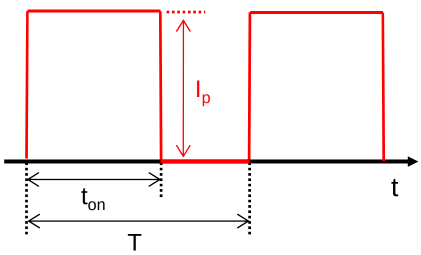
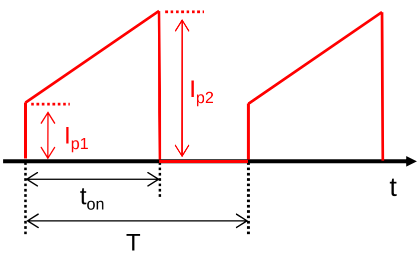
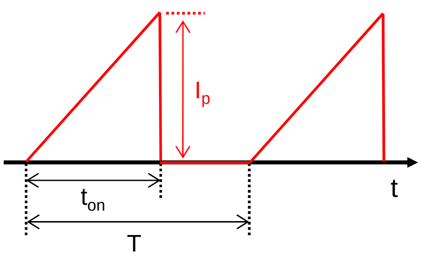
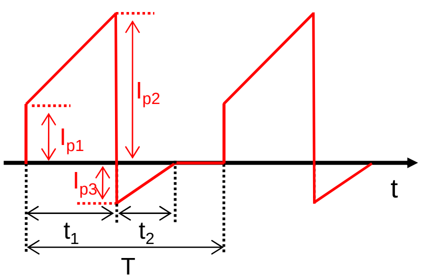
Input those values, and you will see 1.81W in C9 as the result of the loss calculation. The result is the same as those obtained when the loss calculation is manually executed.



Annex Table 1

Voltage condition	Current condition	Waveform	Calculation formula
$V_a<V_b$	$I_a<I_b$		$J_{ab}=\left\{\frac{1}{3}(V_a-V_b)\cdot(I_a-I_b)-\frac{1}{2}(V_a-V_b)\cdot I_a-\frac{1}{2}(I_a-I_b)\cdot V_a+V_a\cdot I_a\right\}\cdot\Delta t$ $\langle If: V_a=0\rangle: J_{ab}=\frac{1}{6}V_b\cdot(I_a+2I_b)\cdot\Delta t$ $\langle If: I_a=0\rangle: J_{ab}=\frac{1}{6}(V_a+2V_b)\cdot I_b\cdot\Delta t$
$V_a<V_b$	$I_a=I_b$		$J_{ab}=\frac{1}{2}(V_a+V_b)\cdot I_a\cdot\Delta t$ $\langle If: V_a=0\rangle: J_{ab}=\frac{1}{2}V_b\cdot I_a\cdot\Delta t$
$V_a<V_b$	$I_a>I_b$		$J_{ab}=\left\{\frac{1}{3}(V_a-V_b)\cdot(I_a-I_b)-\frac{1}{2}(V_a-V_b)\cdot I_a-\frac{1}{2}(I_a-I_b)\cdot V_a+V_a\cdot I_a\right\}\cdot\Delta t$ $\langle If: V_a=0\rangle: J_{ab}=\frac{1}{6}V_b\cdot(I_a+2I_b)\cdot\Delta t$ $\langle If: I_b=0\rangle: J_{ab}=\frac{1}{6}(2V_a+V_b)\cdot I_a\cdot\Delta t$
$V_a=V_b$	$I_a<I_b$		$J_{ab}=\frac{1}{2}V_a\cdot(I_a+I_b)\cdot\Delta t$ $\langle If: I_a=0\rangle: J_{ab}=\frac{1}{2}V_a\cdot I_b\cdot\Delta t$
$V_a=V_b$	$I_a=I_b$		$J_{ab}=V_a\cdot I_a\cdot\Delta t$
$V_a=V_b$	$I_a>I_b$		$J_{ab}=\frac{1}{2}V_a\cdot(I_a+I_b)\cdot\Delta t$ $\langle If: I_b=0\rangle: J_{ab}=\frac{1}{2}V_a\cdot I_a\cdot\Delta t$
$V_a>V_b$	$I_a<I_b$		$J_{ab}=\left\{\frac{1}{3}(V_a-V_b)\cdot(I_a-I_b)-\frac{1}{2}(V_a-V_b)\cdot I_a-\frac{1}{2}(I_a-I_b)\cdot V_a+V_a\cdot I_a\right\}\cdot\Delta t$ $\langle If: V_b=0\rangle: J_{ab}=\frac{1}{6}V_a\cdot(2I_a+I_b)\cdot\Delta t$ $\langle If: I_a=0\rangle: J_{ab}=\frac{1}{6}(V_a+2V_b)\cdot I_b\cdot\Delta t$
$V_a>V_b$	$I_a=I_b$		$J_{ab}=\frac{1}{2}(V_a+V_b)\cdot I_a\cdot\Delta t$ $\langle If: V_b=0\rangle: J_{ab}=\frac{1}{2}V_a\cdot I_a\cdot\Delta t$
$V_a>V_b$	$I_a>I_b$		$J_{ab}=\left\{\frac{1}{3}(V_a-V_b)\cdot(I_a-I_b)-\frac{1}{2}(V_a-V_b)\cdot I_a-\frac{1}{2}(I_a-I_b)\cdot V_a+V_a\cdot I_a\right\}\cdot\Delta t$ $\langle If: V_b=0\rangle: J_{ab}=\frac{1}{6}V_a\cdot(2I_a+I_b)\cdot\Delta t$ $\langle If: I_b=0\rangle: J_{ab}=\frac{1}{6}I_a\cdot(2V_a+V_b)\cdot\Delta t$

Annex Table 2

<table>
<tr><th>Waveform</th><th>Effective value</th><th>Average value</th></tr>
<tr><td>
</td><td>$$I_{rms}=\sqrt{\frac{1}{T}\int_0^{t_{on}}\left(I_p\sin\omega t\right)^2dt}$$ $$=\frac{I_p}{\sqrt{2}}\sqrt{\frac{t_{on}}{T}}$$</td><td>$$I_{avg}=\frac{1}{T}\int_0^{t_{on}}I_p\sin\omega t\,dt$$ $$=\frac{2I_p}{\pi}\cdot\frac{t_{on}}{T}$$</td></tr>
<tr><td>
</td><td>$$I_{rms}=\sqrt{\frac{1}{T}\int_0^{t_{on}}I_p{}^2dt}$$ $$=I_p\sqrt{\frac{t_{on}}{T}}$$</td><td>$$I_{avg}=\frac{1}{T}\int_0^{t_{on}}I_pdt$$ $$=I_p\frac{t_{on}}{T}$$</td></tr>
<tr><td>
</td><td>$$I_{rms}=\sqrt{\frac{1}{T}\int_0^{t_{on}}\left(\frac{I_{p2}-I_{p1}}{t_{on}}t+I_{p1}\right)dt}$$ $$=\sqrt{\frac{1}{3}\left(I_{p2}-I_{p1}\right)^2+\left(I_{p2}-I_{p1}\right)\cdot I_{p1}+I_{p1}{}^2}\cdot\sqrt{\frac{t_{on}}{T}}$$</td><td>$$I_{avg}=\frac{1}{T}\int_0^{t_{on}}\left(\frac{I_{p2}-I_{p1}}{t_{on}}t+I_{p1}\right)dt$$ $$=\left(\frac{1}{2}\left(I_{p1}+I_{p2}\right)\right)\frac{t_{on}}{T}$$</td></tr>
<tr><td>
</td><td>$$I_{rms}=\sqrt{\frac{1}{T}\int_0^{t_{on}}\left(\frac{I_p}{t_{on}}t\right)^2dt}$$ $$=\frac{I_p}{\sqrt{3}}\sqrt{\frac{t_{on}}{T}}$$</td><td>$$I_{avg}=\frac{1}{T}\int_0^{t_{on}}\frac{I_p}{t_{on}}tdt$$ $$=\frac{I_p}{2}\cdot\frac{t_{on}}{T}$$</td></tr>
<tr><td>
</td><td colspan="2">Effective value of synthesized wave
Effective value of synthesized wave can be obtained by a square root of sum of squares of effective values for each period.
$$I_{rms}=\sqrt{I_{rms1}{}^2+I_{rms2}{}^2}$$ $$I_{rms}=\sqrt{\left(\sqrt{\frac{1}{T}\int_0^{t_1}\left(\frac{I_{p2}-I_{p1}}{t_1}t+I_{p1}\right)dt}\right)^2+\left(\sqrt{\frac{1}{T}\int_{t_1}^{t_2}\frac{I_{p3}}{t_2}tdt}\right)^2}$$</td></tr>
</table>

Note

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