Your analog power IC and the best power management

TOREX

Circuit Design Guide for DC/DC Converters (For printing)

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Circuit Design Guide for DC/DC Converters （1/10）

What is DC/DC Converter?

This manual provides tips for designing the circuits of DC/DC converters. How to design DC/DC converter circuits that satisfy the required specifications under a variety of constraints is described by using concrete examples as much as possible.

The properties of DC/DC converter circuits (such as efficiency, ripple, and load-transient response) can be changed with their external parts. Optimal external parts are generally dependent of operating conditions (input/output specifications). The power supply circuit is often used as a part of the circuits of the commercially available products and must be designed so that it satisfies the constraints such as size and cost as well as the required electrical specifications. Usually, the standard circuits listed on the catalogs have been designed by selecting such parts that can provide reasonable properties under the standard operating conditions. Those parts are not necessarily optimal under individual operating conditions. Therefore, when designing individual products, the standard circuits must be changed according to their individual specification requirements (such as efficiency, cost, mounting space, etc.). Designing the circuit satisfying the specification requirements usually needs a great deal of expertise and experience. In this manual, which parts to be changed and how to change them to implement required operations, without expertise and experiences, are described by using concrete data. You will be able to operate your converter circuits quickly and successfully without performing complicated circuit calculations. You may verify your design either by carefully calculating later by yourself or having personnel with expertise and experience review for you if you feel uncertain.

Types and Characteristics of DC/DC Converters

DC/DC converters are available in two circuit types:

1. Non- Isolated types:
   1. Basic (one coil) type
   2. Capacity coupling (two-coil) type —— SEPIC, Zeta, etc.
   3. Charge pump (switched capacitor/coil less) type
2. Isolated types:
   1. Transformer coupling types—— Forward transformer type
   2. Transformer coupling types—— Fly-back transformer type

Characteristics of individual types are shown in Table 1.

Table 1. Characteristics of DC/DC Converter Circuits

Circuit type		No. of parts (Mounting area)	Cost	Output power	Ripple
Non-Isolated	Basic	Small	Low	High	Small
	SEPIC, Zeta	Medium	Medium	Medium	Medium
	Charge pump	Small	Medium	Small	Medium
Isolated	Forward transformer	Large	High	High	Medium
	Fly-back transformer	Medium	Medium	Medium	High

With the basic type circuit, the operation is limited to either stepping up or stepping down to minimize the number of parts, and the input side and the output sides are not insulated. Figure 1 shows a step-up circuit and Figure 2 shows a step-down circuit. These circuits provide advantages such as small size, low cost and small ripples, and the demand for them is increasing in accordance with the needs for downsizing of equipment.

Figure 1: Step-up Circuit

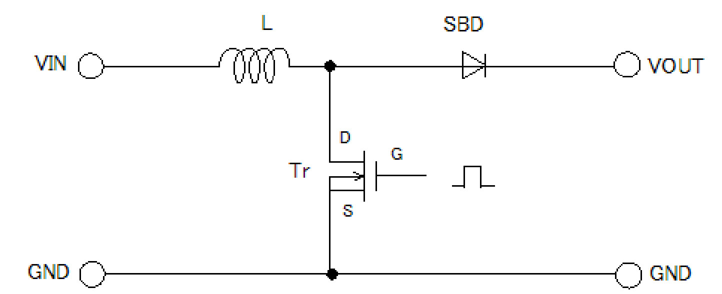
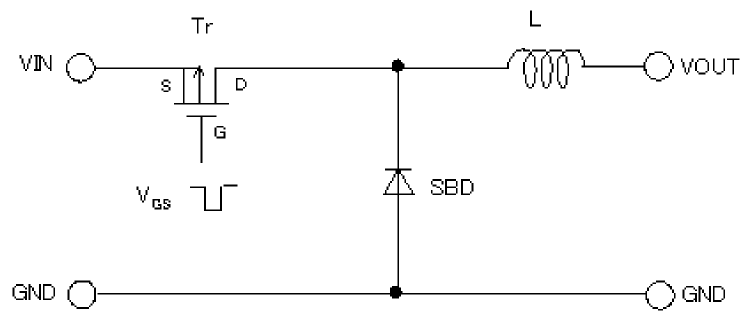


Figure 2: Step-down Circuit



With SEPIC and Zeta, a capacitor is inserted between V_{IN} and V_{OUT} of the step-up circuit and the step-down circuit of the basic type, and a single coil is added. They can be configured as step-up or step-down DC/DC converters by using a step-up DC/DC controller IC and a step-down DC/DC controller IC, respectively. However, as some DC/DC controller ICs do not assume to be used with these circuit types, make sure your DC/DC controller ICs can be used with these circuit types. The capacitor coupling two-coil type has an advantage to allow insulation between V_{IN} and V_{OUT}. However, the increased coils and capacitors will reduce the efficiency. Especially, at the step-down time, the efficiency is substantially reduced, usually to about 70% to 80%.

The charge pump type requires no coil, enabling to minimize the mounting area and height. On the other hand, this type is not liable to provide high efficiency for the applications that need a wide variety of output powers or larger currents, and is limited to applications for driving white LED or for the power supply of LCD.

The insulated type circuit is also known as the primary power supply (main power supply). This type is widely used for the AC/DC converters that generate DC power mainly from a commercially available AC source (100V to 240V) or for the applications that require the insulation between the input side and the output side to eliminate noises. With this type, the input side and the output side are separated by using a transformer, and the stepping up, stepping down, or reverse operation can be controlled by changing the turns ratio of the transformer and the polarity of the diode. Therefore, you can take out many power supplies from a single power circuit. If fly-back transformer is used, the circuit can be composed of a relatively small number of parts and may be used as a secondary power supply (local power supply) circuit. Fly-back transformer, however, requires void to prevent magnetic saturation in the core, increasing its dimensions. If forward transformer is used, a large power source can be easily retrieved. This circuit, however, requires a reset circuit on the primary side to prevent magnetization of the core, increasing the number of parts. Also, the input side and the output side of the controller IC must be grounded separately.

Basic Operation Principles of DC/DC Converters

The operating principles of stepping up and stepping down in DC/DC converter circuits will be described using the most basic type. Circuits of other types or those using coils may be considered composed of a combination of step-up circuit and step-down circuit or their applied circuits.

Figure 3 and Figure 4 illustrate the operations of a step-up circuit. Figure 3 shows the current flow when the FET is turned on. The broken line shows a slight leak current that will deteriorate the efficiency at the light- load time. Electric energy is accumulated in L while the FET is turned on. Figure 4 shows the current flow when the FET is turned off. When the FET is turned off, L tries to keep the last current value and the left edge of the coil is forcibly fixed to V_{IN} to supply the power to increase the voltage to V_{OUT} for step-up operation. Therefore, if the FET is being turned on longer, much larger electric current is accumulated in L, allowing retrieval of larger power. However, if the FET is being turned on too long, the time to supply the power to the output side becomes too short, and the loss during this time is increased, deteriorating conversion efficiency. Therefore, the maximum duty (ratio of on/off time) value is generally determined to keep an appropriate value.

With step-up operation, the current flows shown in Figure 3 and Figure 4 are repeated:

Figure 3: Current flow when the FET is turned on in a step-up circuit

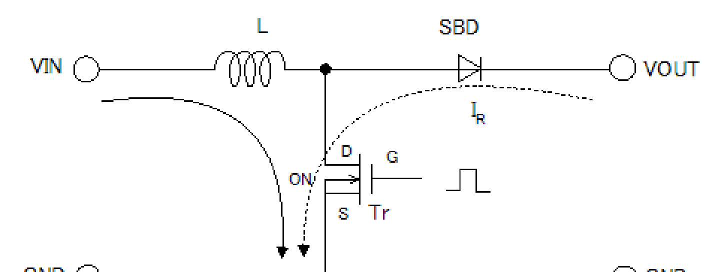


Figure 4: Current flow when the FET is turned off in a step-up circuit

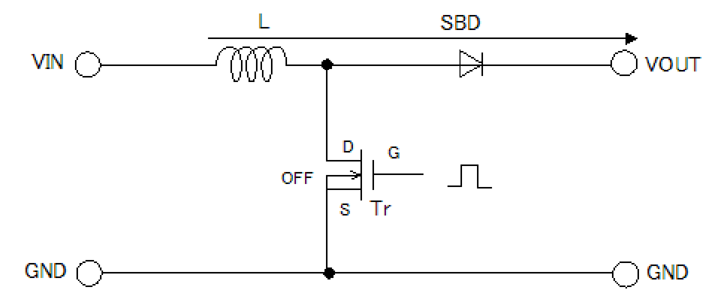


Figure 5 and Figure 6 illustrate the operations of a step-down circuit. Figure 5 shows the current flow when the FET is turned on. The broken line shows slight leak current that will deteriorate the efficiency at the light-load condition. Electric energy is accumulated in L while the FET is on and is supplied to the output side. Figure 6 shows the current flow when the FET is turned off. When the FET is turned off, L tries to keep the last current value and turns on the SBD. At this time, the voltage at the left edge of the coil is forcibly dropped below 0V, reducing the voltage at V_{OUT}. Therefore, if the FET is being turned on longer, much larger electric current is accumulated in L, allowing retrieval of larger power. With a step-down circuit, while the FET is being turned on, power can be supplied to the output side, and the maximum duty needs not to be determined. Therefore, if input voltage is lower than output voltage, the FET is kept on. However, as the step-up operation is disabled, the output voltage is also lowered to the input voltage level or less.

With the step-down operation, the current flows shown in Figure 5 and Figure 6 are repeated:

Figure 5: Current flow when the FET is turned on in a step-down circuit

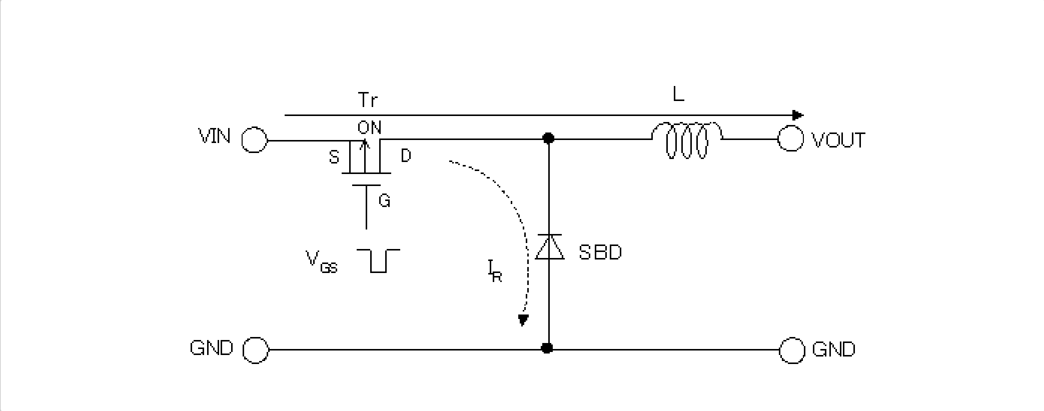
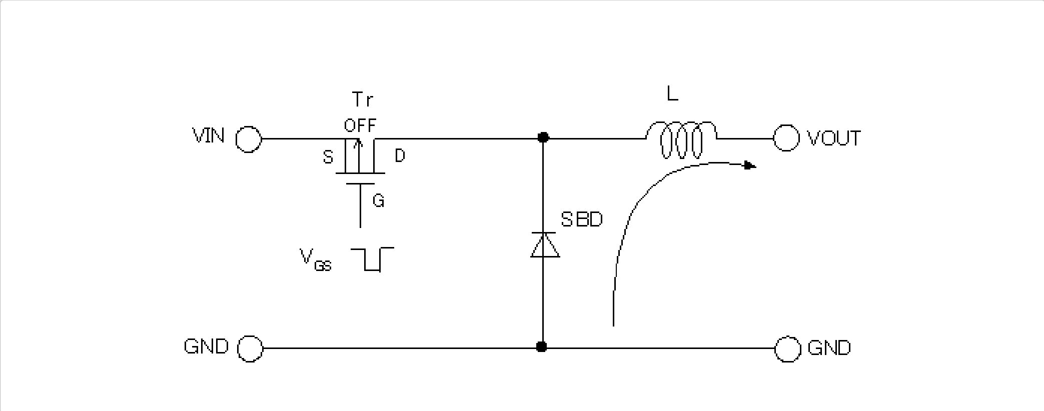


Figure 6: Current flow when the FET is turned off in a step-down circuit



4 Critical Points in Designing DC/DC Converter Circuits

Among specification requirements for DC/DC converter circuits, the following are considered critical:

1. Stable operation (Not to be broken down by operation failure such as abnormal switching, or burnout or over-voltage)
2. High efficiency
3. Small output ripple
4. Good load-transient response

These properties can be improved to some extent by changing the DC/DC converter IC and external parts. Weightings of these four properties vary with individual applications. In the following, let’s consider how to select individual parts to improve these properties.

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How to select the Switching Frequency

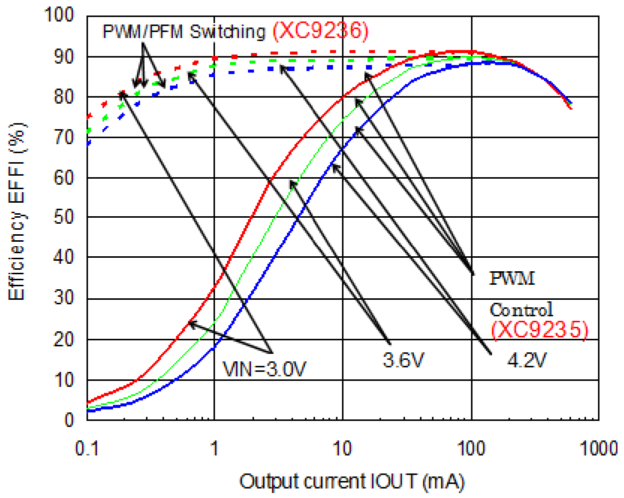
DC/DC converter circuits have their unique switching frequencies. In general, they affect the circuit properties as shown in Table 2 below:

Table 2. Relationships between switching frequency and properties

Properties	Low	High
Maximum efficiency	High	Low
Output current at maximum efficiency	Light load	Heavy load
Ripple	Large	Small
Response speed	Slow	Fast

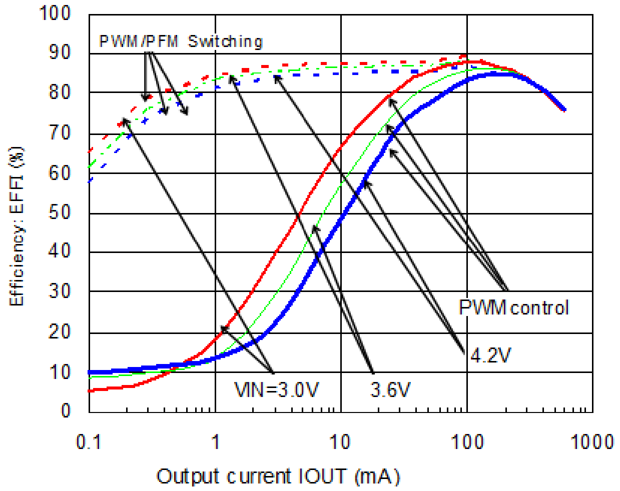
Figure 7 and Figure 8 show the relationships between switching frequencies and efficiencies of the step-down models XC9235/XC9236 (1.2MHz) and XC9235/XC9236 (3MHz), respectively, as examples. As you see, the Influences of switching frequency on efficiency as indicated in Table 2 are apparent. With two models, electric current values at the maximum efficiency are different. This is because if switching frequencies differ, complying inductance values differ too. With coils of the same structure, the larger the inductance is, the larger the direct-current resistance becomes, increasing the loss at times of heavy-load. Thus, if the switching frequency becomes lower, the current value at the maximum efficiency moves toward the light-load side. On the contrary, if the switching frequency becomes higher, the charge/discharge frequency of the FET and the IC's unique quiescent current increase: On the 3MHz model, the efficiency at the light-load condition is substantially reduced compared to the 1.2MHz model. When totally reviewing these influences, we can see that the 1.2MHz model has a higher maximum efficiency (the peak value is higher than the 3MHz model on the graph) and the output current at the maximum efficiency is small (the peak is to the leftward of the 3 MHz model on the graph). Also, when PFM is actuated, the frequencies at the light-load time are lowered in both models, substantially improving the efficiencies.

Figure 7: XC9235/XC9236, V_{OUT}=1.8V (with switching frequency of 1.2 MHz)



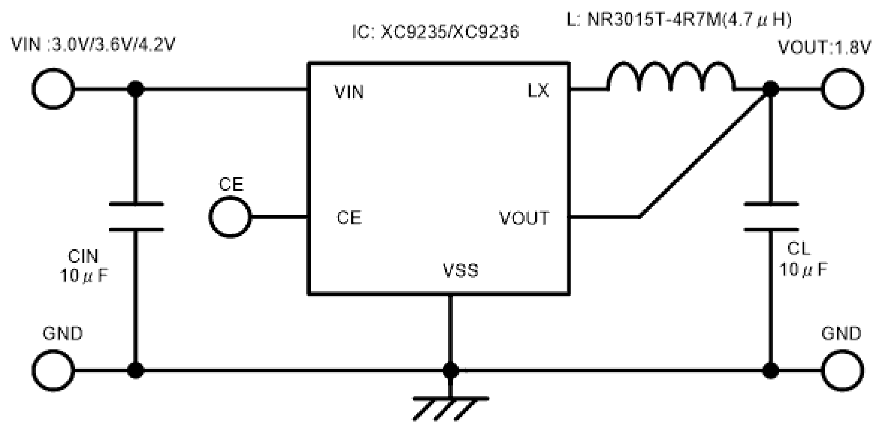
C_{IN}:10μF　C_L:10μF　L=4.7μH（NR3015T-4R7M）　Topr=25℃

Figure 8: XC9235/XC9236, V_{OUT}=1.8V (with switching frequency of 3 MHz)



C_{IN}:10μF　C_L:10μF　L=4.7μH（NR3015T-4R7M）　Ta=25℃

Figure 9: Test circuit for XC9235/XC9236 illustrated in. Figures 7 and 8


IC: XC9235/XC9236
L: NR3015T-4R7M(4.7 μ H)
VIN :3.0V/3.6V/4.2V
VOUT:1.8V
VIN
LX
CE
CE
VOUT
VSS
CIN
10 μ F
CL
10 μ F
GND
GND

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Selecting the Field Effect Transistor(FET)

Efficient DC/DC converter circuits may be designed by selecting the absolute maximum ratings of the voltage and the current that are equal to 1.5 to 2 times of the operating voltage and current to reduce the failure rates against spike noises and impulse noises at the switching time, and that minimize the losses by R_{DS} and C_{ISS}. If R_{DS} and C_{ISS} are smaller, the losses become smaller. However, the effects of R_{DS} and C_{ISS} oppose each other. Therefore, it is effective to improve the one whose loss is larger than the other.

Loss by C_{ISS} is the power dissipated at the condition of charging/discharging between the gate and the source of the FET and can be expressed with $C_{ISS}V_{GS}^2f/2$. Thus, if the driving voltage and the switching frequency become larger, the loss is increased. As the loss values at the heavy-load condition and light-load condition are almost the same, the efficiency at the light-load condition is substantially degraded.

Loss by R_{DS} is the heat dissipated by resistance components between the drain and the source of the FET and is expressed as $R_{DS}I_D^2$. This loss increases when the load increases. Therefore, it can be said that at the light-load condition, minimizing the loss by C_{ISS} is effective for increased efficiency, and at the heavy-load condition, minimizing the loss by R_{DS} is effective.

This is summarized in Table 3 below.

Table 3: Tips for selecting the FET

Items		Tips
Electric properties	R_{DS}, C_{ISS}	Minimize C_{ISS} to increase efficiency at the light-load time. Minimize R_{DS} to increase efficiency at the heavy-load time.
Absolute Maximum Ratings	V_{DS}	Select approx. twice the output voltage for a step-up circuit. Select approx. twice the input voltage for a step-down circuit.
	V_{GS}	Select approx. twice the supply voltage for a step-up circuit. Select approx. twice the input voltage for a step-down circuit.
	I_D	Select approx. twice the input current for a step-up circuit. Select approx. twice the output current for a step-down circuit.

Input current can be obtained by:
{Output (load) current} x (output voltage) ÷ (input voltage) ÷ (efficiency)

If efficiency value is unknown, tentatively use 70% at the step-up time and 80% at the step-down time.

Figure 10 shows the graphs of efficiencies measured by replacing only the FET amongst the external parts of XC9220C093 (step-down) circuit shown in Figure 11. The specifications of individual FETs used here are shown in Table 4.

In Figure 10, using a FET (XP162A11C0) with small R_{DS} value enables the driving of a large current, and tends to improve the efficiency at the heavy-load condition to some extent. However, the efficiency at the light-load time is substantially degraded. This result shows that using a FET with a driving capability of unnecessarily large current is not appropriate.

Figure 10: XC9220C093 Efficiencies varied with FET

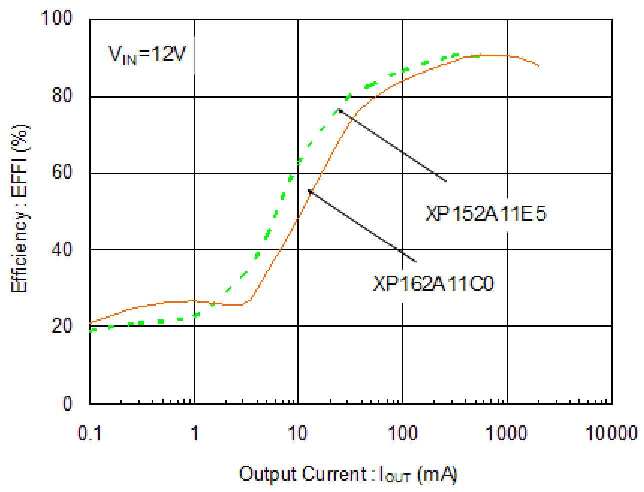

Figure 11: Test circuit for XC9220C093 shown in Figure 10

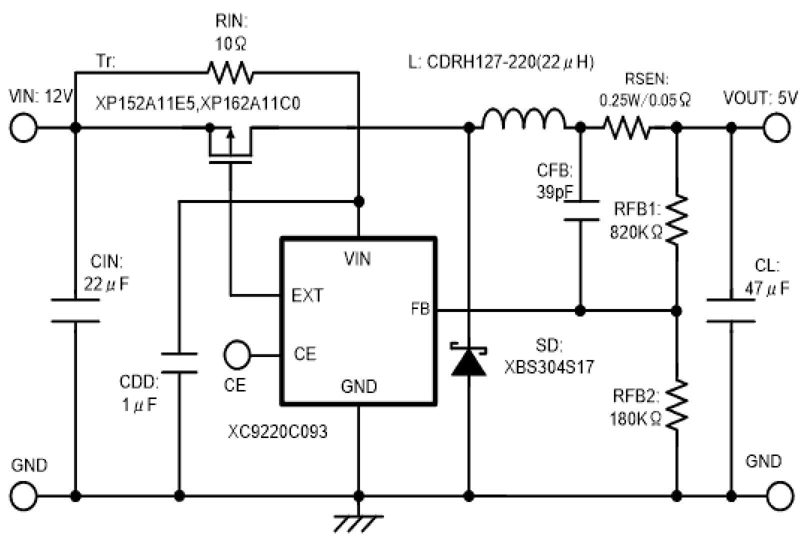

Table 4: Properties of FETs

Items	Electric Properties		Absolute Maximum Ratings		
	R_{DS}（mΩ）	C_{ISS}（pF）	V_{DS}（V）	V_{GS}（V）	I_D（A）
XP152A11E5	200	160	-30	±20	-0.7
XP162A11C0	110	280	-30	±20	-2.5

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Selecting the Coil

An optimal L value varies with switching frequency as the coil current is in proportion to the duration of activation of the FET and is in reverse proportion to the L value.

Loss by coil appears as a sum of the coil's wire-wound resistance RDC and the loss generated in the ferrite core. In switching frequencies of up to 2MHz, it is considered that the RDC of the coil is mainly responsible for the coil losses. Therefore, firstly select a coil with a small RDC value. However, if minimizing RDC results in selection of too small a L value, the current value while the FET is activated becomes too large, increasing heat losses from the FET, SBD and coil, and reducing the efficiency. Also, the ripple becomes larger due to this increased current.

On the contrary, if the L value is too large, the RDC value becomes larger, degrading the efficiency at the heavy-load time, and magnetic saturation occurs in the ferrite core, rapidly reducing the L value. In this state, the coil cannot properly function, and heat generated by over-current becomes dangerous. Therefore, to allow large current flow in the coil with a large L value, the dimensions of the coil need to be increased to some extent to avoid magnetic saturation.

From the above mentioned, an appropriate L value for an individual switching frequency is determined by considering both dimensions and efficiencies.

Table 5 shows the standard L values for individual switching frequencies. This is reference data for a typical DC/DC converter circuit where the input and output voltages (V_{IN} & V_{OUT}) are 6.0V or less. For higher Voltage circuits the recommended values will be slightly different.

Table 5: Standard L values and rated current values for switching frequencies

Item	Condition	Recommended Values		
L value	Switching frequency	When light-load time weighted	Standard value	When heavy-load time weighted
	30kHz, 50kHz	330μH	220μH	100μH
	100kHz	220μH	100μH	47μH
	180kHz	100μH	47μH	22μH
	300kHz	47μH	22μH	10μH
	500kHz	33μH	15μH	6.8μH

	600kHz	22μH	10μH	4.7μH
	900kHz	10μH	4.7μH	3.3μH
	1.2MHz	6.8μH	3.3μH	2.2μH
	2MHz	3.3μH	2.2μH	1.5μH
	3MHz	2.2μH	1.5μH	1.0μH
Rated current	Step-up circuit	Approx. 2 to 3 times of Max. input current		
	Step-down circuit	Approx. 1.5 to 2 times of Max. output current		

Figure 12 shows example of variations of efficiency respectively when only the L value is varied in the XC9104D093 (step-up) circuit shown in Figure 13.

Figure 14 and Figure 15 show the examples of efficiency and ripple in the XC9220A093 (step-down) circuit shown in Figure 16.

In both examples, if the coil structure is identical, increasing the L value decreases the maximum output current, increases the efficiency at the light-load condition, and reduces the ripple. This result shows that selecting the L value optimal for output current is very important.

Figure 12: Relationship between L value and efficiency (step-up: XC9104D093)

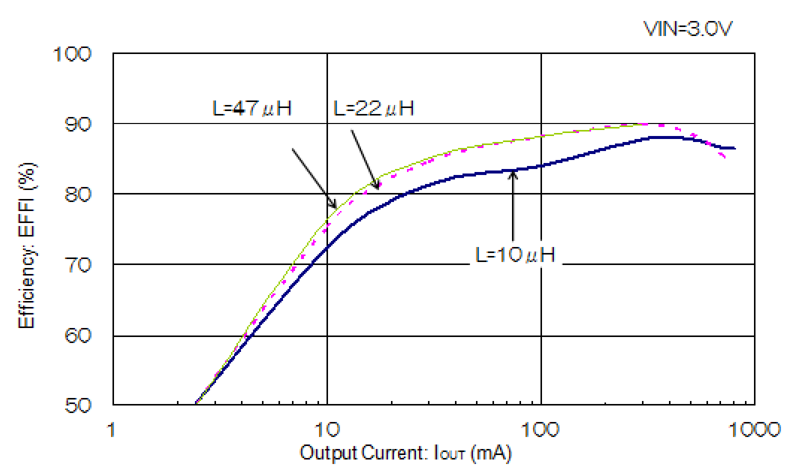


Figure 13: Test circuit for XC9104D093 shown in Figures 12.

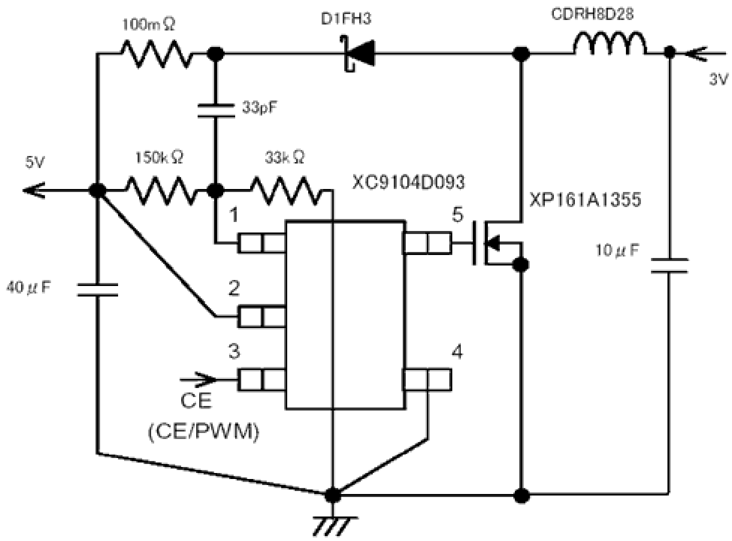
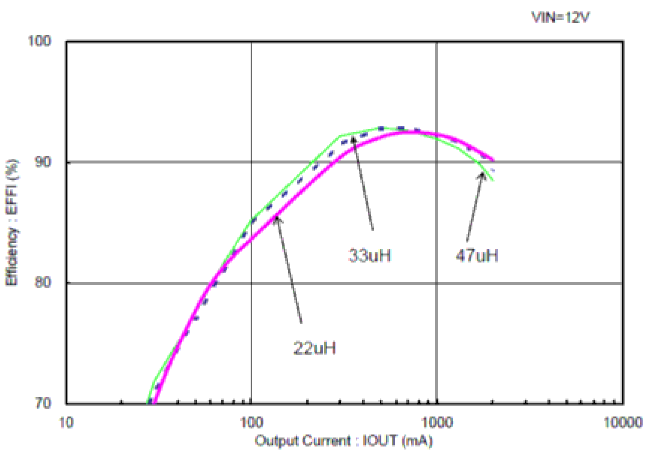
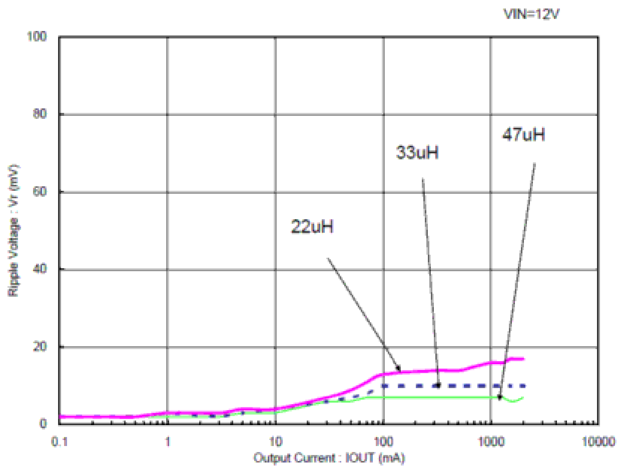


Figure 14: XC9220A093 Relationship between L value and efficiency (step-down)



L：VLF10045T（L：VLF10045T（22μH、33μH、47μH）

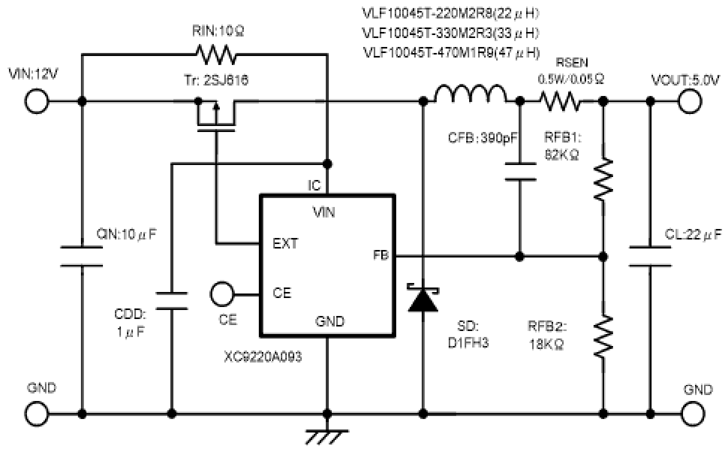
Figure 15: Relationship between L value and ripple (step-down: XC9220A093)



L：VLF10045T（22μH、33μH、47μH）

CL：22μF、Tr：2SJ616

Figure 16: Figures 14 and 15 Circuit used for measurements shown in XC9220A093 (PWM=CE=V_{IN})



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Selecting the Schottky Barrier Diodes(SBD)

As to absolute maximum ratings, approximately 1.5 to 2 times of the working ratings should be selected due to the same reason as for selecting the FET. Loss by SBD is the sum of the forward heat loss $V_F \times I_F$ and the reverse leakage current I_R. Therefore, selecting smaller values for both VF and I_R are desirable. However, V_F and I_R are in inverse relation to each other, so the choice of the most appropriate SBD will depend on the load current of the application. As V_F increases at the heavy-load and I_R is constant independent of the load current, selecting a smaller I_R value at the light-load condition is effective for improved efficiency, and selecting a smaller VF value is effective at the heavy-load condition. These statements are summarized in Table 6.

Table 6: Tips for selecting the SBD

Item		Tips
Electrical properties	Selecting V_F, I_R	Select small V_F value at the heavy-load. Select small I_R value at the light-load.
Absolute maximum ratings	V_{RM}	Select approx. 2 or more times of output voltage for a step-up Select approx. 2 or more times of input voltage for a step-down
	I_{FM}	Select approx. 2 or more times of input current for a step-up Select approx. 1.5 or more times of output current for a step-down

Figure 17 shows the variation of efficiency in the XC9220A093 circuit when only the SBD properties shown in Table 7 are changed. The result shows that the efficiency of the XBS204S17, having larger V_F and smaller I_R compared to the XBS203V17, is excellent under light-load conditions but is degraded under heavy-load conditions.

Figure 17: XC9220A093 efficiencies resulting from SBDs' characteristics

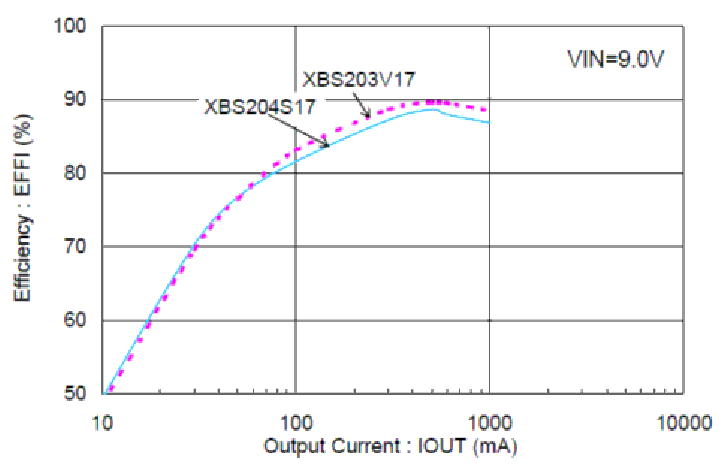

Figure 18: Test circuit XC9220A093 shown in Figure 17

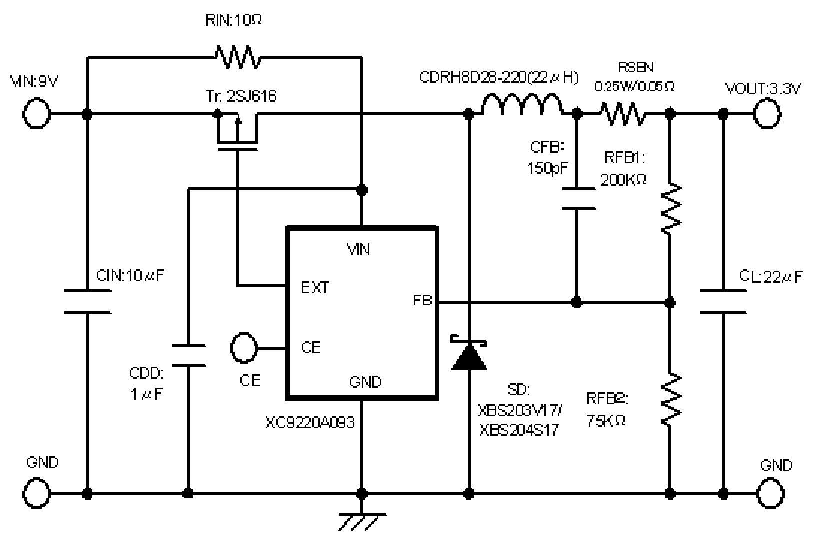

Table 7: SBD Properties used for measurements shown in Figure 17

Characteristics	Electrical properties		Absolute maximum ratings	
	$V_F(I_F=2A)$	I_R	V_R	I_F
XBS203V19(TOREX)	0.35V	0.35mA(V_R=30V)	30V	2A
XBS204S19(TOREX)	0.485V	6μA(V_R=40V)	40V	2A

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Selecting the C_L

If a larger C_L value is selected, the output ripple becomes smaller. However, an unnecessarily large C_L value increases the dimensions of the capacitor, increasing the cost. Determine the C_L value based on the targeted ripple level. If the targeted ripple level is to be in the range of 10mV to 40mV, you may begin by using the C_L values shown in Table 8 and Table 9 for a step-up and for a step-down, respectively. Note: If your DC/DC converter is not compatible with low ESR capacitors, using these C_L values may cause abnormal switching. If a low ESR capacitor is to be used in the continuous mode, check the load-transient response to confirm that the output voltage is rapidly stabilized (converges within two switching cycles).

Figure 19 shows the variation of output ripple measured by changing only the C_L in the XC9104D093 circuit shown in Figure 20. The ripple increases in proportion to the ESR value and in inverse proportion to the C_L value. In the case of an aluminum electrolytic capacitor, the ESR value is so large that a ceramic capacitor connected in parallel is required for getting output current.

Table 8: Recommended CL values for a step-up

Output current	Ceramic	OS	Tantalum	Aluminum electrolytic
0mA-300mA	20μF	22μF	47μF	100μF+2.2μF(with ceramic capacitor)
300mA-600mA	30μF	47μF	94μF	150μF+2.2μF(with ceramic capacitor)
600mA-900mA	40μF	100μF	150μF	220μF+4.7μF(with ceramic capacitor)
900mA-1.2A	50μF	150μF	220μF	470μF+4.7μF(with ceramic capacitor)

Actual values to be used are obtained by multiplying the above values by the step-up ratio (=V_{OUT}/V_{IN}).

Table 9: Recommended C_L values for a step-down

Output current	Ceramic	OS	Tantalum	Aluminum electrolytic
0mA-500mA	10μF	15μF	22μF	47μF+2.2μF(with ceramic capacitor)
500mA-1.5A	20μF	22μF	33μF	100μF+2.2μF(with ceramic capacitor)
1.5A-3A	20μF	33μF	47μF	100μF+4.7μF(with ceramic capacitor)
3A-5A	30μF	47μF	68μF	220μF+4.7μF(with ceramic capacitor)

Actual values to be used are obtained by multiplying the above values by the step-up ratio (=V_{OUT}/V_{IN}).

Figure 19: Output ripple varied with C_L value (XC9104D093)

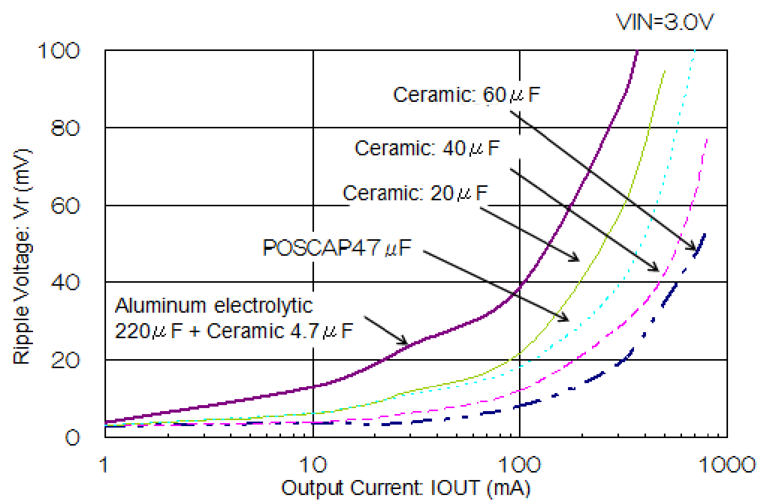
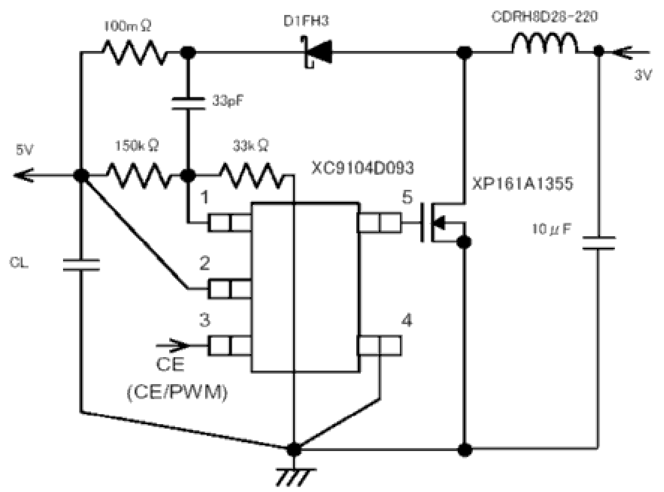


Figure 20: Test circuit for XC9104D093 shown in Figure 19



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Selecting the C_{IN}

Although its influence on output stability is not as significant as C_L, C_{IN} also has a large capacity, and the smaller the ESR is, the more the output is stabilized and the smaller the ripple voltage becomes. Increasing C_{IN} to some extent will reduce the effect of minimizing the output ripple. In order to prevent EMI on the input side, the C_{IN} value should start with about half that of the C_L value. With C_{IN}, even if ESR is too small, the output will not oscillate. Therefore, using capacitors with ESR as small as possible is recommended.

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Selecting the R_{FB1} and R_{FB2}

With an FB (feedback) model, R_{FB1} and R_{FB2} are used to determine output voltage. If a wide variety of combinations of R_{FB1} and R_{FB2} are available for an identical output voltage, the sum of R_{FB1} and R_{FB2} is recommended to be in the range of 150kΩ to 500kΩ. In this case, the efficiency at the light-load condition and the output stability at the heavy-load condition need to be considered. The currents flowing through R_{FB1} and R_{FB2} are not used for the output power and regarded as loss of the DC/DC converter. Therefore, to improve the efficiency at the light-load condition, larger values (R_{FB1}+R_{FB2}<1MΩ) should be selected.

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Selecting the C_{FB}

C_{FB} is a capacitor for adjusting the ripple feedback and influences the load-transient response. The optimum C_{FB} values for L values are shown in Table 10. Selecting C_{FB} values either smaller or larger than the optimum values will deteriorate the operation stability.

Influences of C_{FB} in the XC9220C093 have been measured in the circuit shown in Figure 26. In this circuit, when R_{FB1} is 82kΩ, F_{ZFB} will be 10kHz with C_{FB} of about 390pF. Load-transient responses varied with C_{FB} are shown in Figure 23 (C_{FB}=39pF), Figure 24 (C_{FB}=390pF) and Figure 25 (C_{FB}=1000pF). With C_{FB}=39pF, the voltage drops sharply when the load becomes heavy but the normal voltage is restored shortly. With C_{FB}=1000pF, the voltage drop is small when the load current is increased heavily but restoration of the normal voltage takes time.

Table 10: Standard f_{ZFB} for determining optimum C_{FB}

Item	f_{ZFB} = (1/(2π x R_{FB1} x C_{FB})) ( ) indicates the adjustable range
XC9103/XC9104/XC9105 XC9106/XC9107	30kHz when L=10μH 20kHz when L=22μH 10kHz when L=47μH
XC9101D09A	10kHz
XC9201D09A	10kHz
XC9210B092 XC9210B093	12kHz (Adjustable between 1kHz and 50kHz)
XC9213B093	10kHz (Adjustable between 1kHz and 50kHz)
XC6365B/XC6365D XC6366B/XC6366D	10kHz (Adjustable between 0.5kHz and 20kHz)
XC6367B/XC6367D XC6368B/XC6368D	10kHz (Adjustable between 0.1kHz and 20kHz)
XC9220/XC9221	5kHz (Adjustable between 1kHz and 20kHz)
XC9223/XC9224	20kHz (Adjustable between 1kHz and 50kHz)

Figure21: Load-transient response of XC9220C093 (I_{OUT}=0mA to 200mA, C_{FB}=39pF)

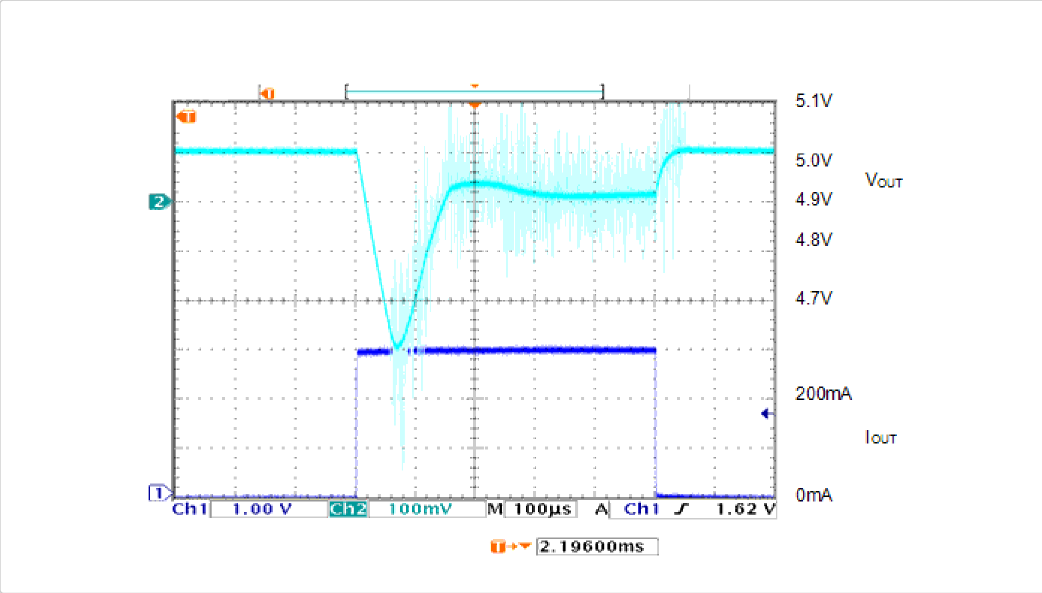


Figure 22: Load-transient response of XC9220C093 (I_{OUT}=0mA to 200mA, C_F=390pF)

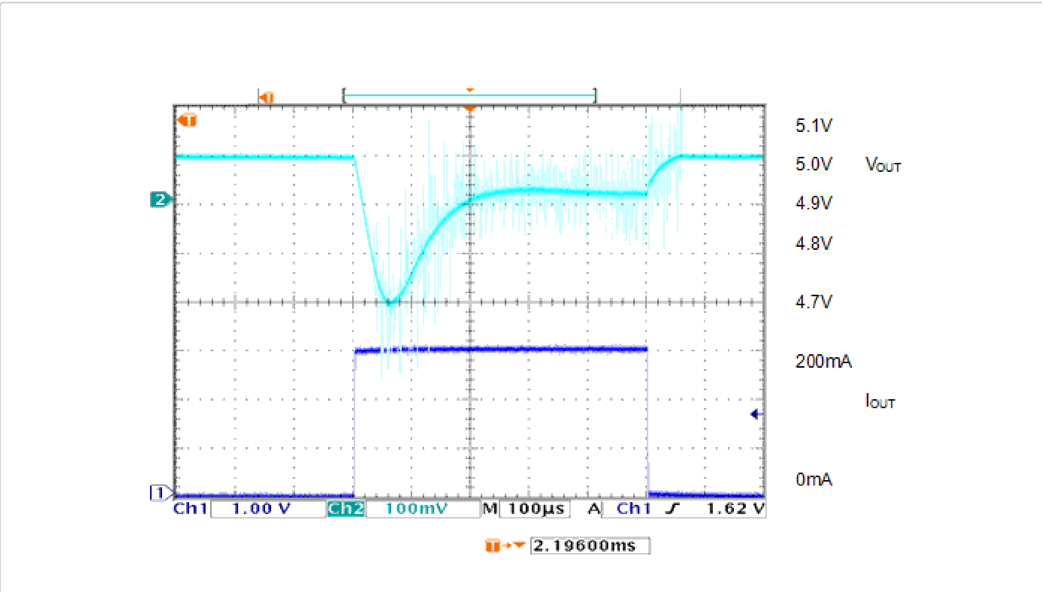


Figure 23: Load-transient response of XC9220C093 (I_{OUT}=0mA to 200mA, C_{FB}=1000pF)

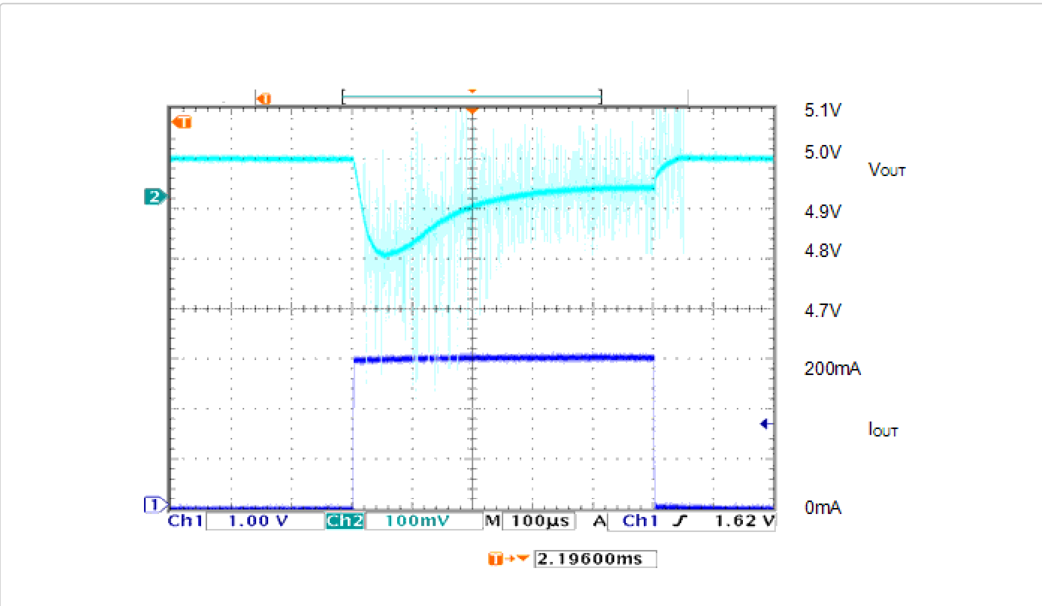


Figure 24: Test circuit for XC9220C093 Figures 23 through 25

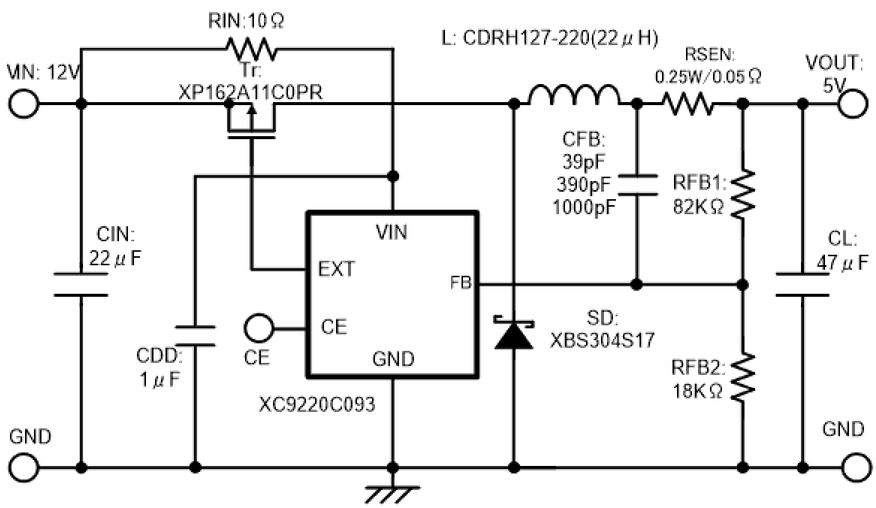
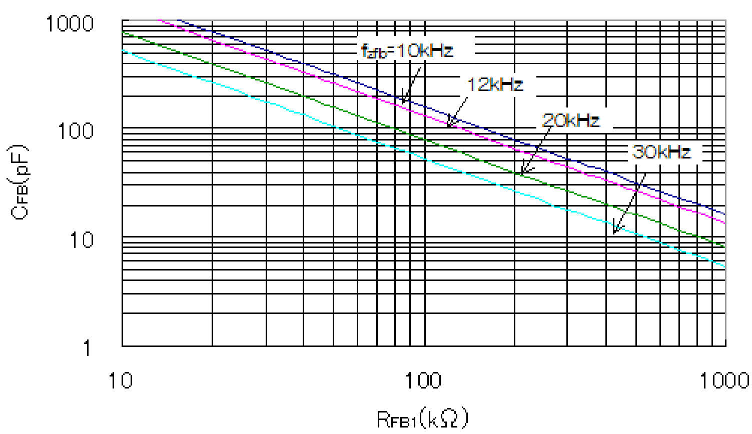


Figure 25 shows the standard C_{FB} values varied with R_{FB1} and F_{ZFB}.

Figure 25: Relationship between R_{FB1} and C_{FB}



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Appendix Lists of Major External Parts recommended by Torex

(1)FETs

Part number	Manufacturer	V_{DSS}	V_{GSS}	I_D	R_{DS}	MAX. Dimensions
XP152A11E5	TOREX	-30V	±20V	-0.7A	350mΩ（V_{GS}=-4.5V）	3.1 x 3.0 x 1.2H
XP162A11C0	TOREX	-30V	±20V	-2.5A	200mΩ（V_{GS}=-4.5V）	4.6 x 4.25 x 1.6H
XP161A1355	TOREX	20V	±8V	4A	100mΩ（V_{GS}=1.5V）	4.6 x 4.25 x 1.6H

(2)SBDs

Part number	Manufacturer	V_{RM}	I_{FM}	V_F	I_R	MAX. Dimensions
XBS203V19	TOREX	30V	2A	0.305V	0.35mA（V_R=30V）	2.8 x 4.65 x 2.15H
XBS204S19	TOREX	40V	2A	0.485V（I_F=2A）	6μA（V_R=40V）	2.8 x 4.65 x 2.15H
XBS303V19	TOREX	30V	3A	0.355V（I_F=3A）	0.35mA（V_R=30V）	2.8 x 4.65 x 2.15H
XBS304S19	TOREX	40V	3A	0.465V（I_F=3A）	15μA（V_R=40V）	2.8 x 4.65 x 2.15H
D1FH3	SHINDENGEN	30V	3A	0.36V（I_F=3A）	20mA（V_R=30V）	2.8 x 5.3 x 2.3H

(3)Coils

Part number	Manufacturer	Inductance	Rated Current	R_{DC}	MAX. Dimensions
CDRH4D18C-4R7	SUMIDA	4.7μH	1.15A	88mΩ	5.1 x 5.1 x 2.0H
CDRH8D28-220	SUMIDA	22μH	1.6A	76mΩ	8.3 x 8.3 x 3.0H
CDRH127-220	SUMIDA	22μH	3.6A	32mΩ	12.3 x 12.3 x 8.0H
VLF10045T-100M4R3	TDK	10μH	4.3A (MAX.)	25mΩ	10.4 x 10.1 x 4.5H
VLF10045T-220M2R8	TDK	22μH	2.8A (MAX.)	49.5mΩ	10.4 x 10.1 x 4.5H
VLF10045T-470M1R9	TDK	47μH	1.9A (MAX.)	97.6mΩ	10.4 x 10.1 x 4.5H
NR3010T-1R5M	TAIYO YUDEN	1.5μH	1.2A	80mΩ	3.1 x 3.1 x 1.0H

(4)Ceramic capacitors

Part number	Manufacturer	Capacity	Rated Voltage	MAX. Dimensions
C3216JB1A226M	TDK	22μF	10V	3.4 x 1.8 x 1.8H

C5750X5R1C476M	TDK	47μF	16V	6.1 x 5.4 x 2.5H
EMK107BJ105KA	TAIYO YUDEN	1μF	16V	1.7 x 0.9 x 0.9H
EMK212BJ106KG	TAIYO YUDEN	10μF	16V	2.15 x 1.4 x 1.35H
LMK212BJ-106KG	TAIYO YUDEN	10μF	10V	2.15 x 1.4 x 1.35H
JMK212BJ-106MG	TAIYO YUDEN	10μF	6.3V	2.15 x 1.4 x 1.35H
TMK107BJ105KA	TAIYO YUDEN	1μF	25V	1.7 x 0.9 x 0.9H
EMK316BJ226ML	TAIYO YUDEN	22μF	16V	3.4 x 1.8 x 1.8H

(5)Polymer organic semiconductor capacitors

Part number	Manufacturer	Capacity	Rated Voltage	ESR	MAX. Dimensions
10TPB68MC	Panasonic	47μF	10V	72mΩ	3.8 x 3.0 x 2.1H
16TQC47MC	Panasonic	47μF	16V	75.2mΩ	7.5 x 4.5 x 2.0H

(6)Aluminum electrolytic capacitor

Part number	Manufacturer	Capacity	Rated Voltage	ESR	MAX. Dimensions
EMHJ100ADA221MHA0G	NIPPON CHEMI-CON	220μF	10V	150mΩ	φ8 x 10.0