GAPTEC Electronic - General Application Notes

Power architecture and product selection

Historically, DC-DC converters were often designed by the product design engineer out of discrete components, but as technology has moved on and the requirements for fasterdevelopment and improved time to market dominate, converter design is being left more and more in the hands of specialist manufacturers. The DC-DC converter is one of the most critical components in any design and the choice of converter can have a dramatic effect on the quality of the final product. Ideally power architecture design should be undertaken at the start of any design to help remove the costs associated with interference, oscillations, over heating and over current as well as improving reliability and speeding up the design of the system.

1. Determination of converter specifications

The first thing to do is to determine which converter to use, select according to requested parameters and choose to use standard converter or a custom designed one.

Basic Requirements:

A: Determine input source type

Check if the input source is AC or DC; AC would use AC-DC converters, and DC would use DC-DC converters.

B: Input Voltage

1.) Fixed input:

The type of forehead power supply and the voltage range will directly determine which converter to use. For example, with stable powers such as switch mode power supply, linear regulator or zener diode, a fixed input product (input voltage varies in ±5% range) can be selected. Typical input voltages are 5V, 12V or 24V.

2.) Wide input:

For 24V industrial bus power supply, 48V telecommunication bus power supply, 220V rectified transformer output, various batteries, and long distance transferring where the output voltage varies in a wide range, a wide input voltage range converter such as 2:1 or 4:1 input converter is to be selected. To raise the cost and performance rate, the best selection should be done based on the real situation. (4:1 converter's converting efficiency is lower than that of 2:1 converter, and it costs higher, but has wider input voltage range, e.g. 9-36V, 18-72V. Typical nominal input voltages are: 5V (4.5-9V), 12V (9-18V), 24V (18-36V)， 48V (36-72V). For converters above 3W output power, to raise operation efficiency, it is recommended to use higher voltage as input voltage, and select wide input converters.

3.) Output Voltage:

A.Output voltage is determined by the type of load circuit. For example, for common digital circuits, DC or low frequency operational amplifiers, RS232/485 or CAN bus circuits etc, where the voltage precision of power is less important, unregulated output series of products is a good selection. However for applications such as sensors, precision operational amplifiers, A/D or D/A ICs, where voltage precision and ripple are critical, regulated converter or wide input and regulated converter will be the good selection.

B. When both cost and efficiency are concerned, you may consider a combination of unregulated module and linear voltage regulator. When load needs both positive and negative source, modules with both positive and negative output or with multiple output should be considered, and make effort to reduce the channels of outputs. Also it is better to set the main output the one with large power and high accuracy and set the accuracy of the other output to ensure reliability.

C. Normally, nominal output voltages are 3.3V, 5V, 9V, 12V, 15V.

D. Too much requirement for output accuracy and ripple spec. may not be cost effective.

E. Output current

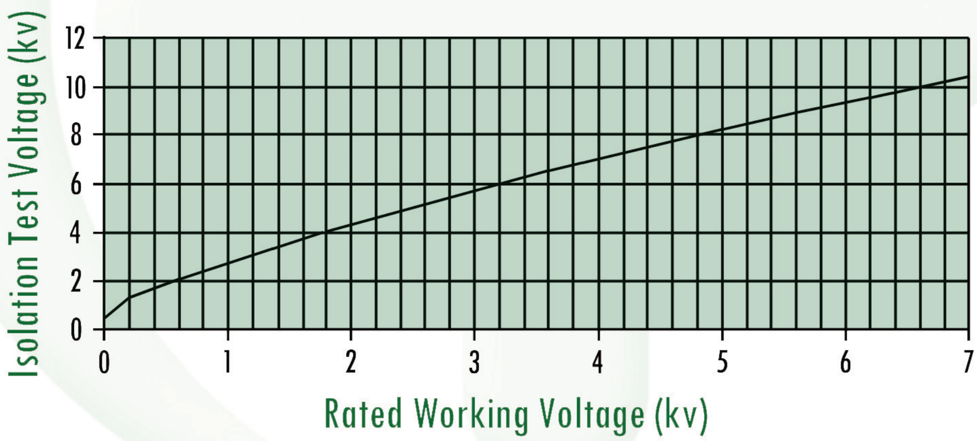
Basically, output current is fixed when load is fixed. Load current is essential to output power and affects its price directly. Residual power is recommended to be 20%~30%. In tiny load or no load circuit, e.g. using as voltage base of optocouple, Relays, RS232/485, CAN bus, it is recommended to load a dummy load to improve the reliability of modules. For a situation where load current is not stable and varies largely, the dummy load should be in a range of 10%~100% to avoid potential damage of tiny load or over load. In high temperature circumstance, converters should be used with larger residual power like 30% -40%. Constantly using in ambient temperature of 70'C or above, please consult technicians for a right module. Anyway, the selection of output current is a key factor in successfully designing a module, over or too low of a output current both lead to poor reliability or high cost.

4.) Isolation feature:

Isolation makes input and output of modules two isolated circuits (separate ground connection). Isolation helps in safely facing a cruel circumstance (lightning, arc interference) in industrial power bus system, avoids grounding ring circuit, isolates noise in analog circuit and digital circuit, transfers voltage in multiple voltage power source.

5.) Isolation Voltage vs. Rated Working Voltage

The isolation voltage given in the datasheet is valid for 60 second flash tested only. If a isolation barrier is required for longer or infinite time the Rated Working Voltage has to be used. According to the standard IEC950, conversion of isolation voltage to rated working voltage can be done by using this table or graph.



Typical Breakdown Voltage Ratings According to IEC950

Isolation Test Voltage (V)	Rated Working Voltage (V)
1000	130
1500	230
3000	1100
6000	3050

6.) Package and Space:

Enough space should be left in converters for avoiding the effect of heat radiation to data acquisition and other performance, so the size, cost and reliability of converters should be considered comprehensively. In another words, standard sizes should be adopted so that we can save cost, improve technology, lessen developing difficulty and save developing time. For other complex technical problem, such as high isolation, ultra-wide voltage range, high operation temperature, EMC approval and so on, you'd better inquiry from our technical service engineers.

7.) Power Supply System

The design of power supply system is usually needed optimizing for several times in the consideration of products features and circuit requirement. Accurate data for the parameter and temperature varied range of the operation circuit is conducive for us to precisely choose suitable converters.

A: Ambient factors: Temperature

Ambient temperature can affect converters and the connecting components. Considering that the converters in application may in high temperature, low temperature or in the recycle between high temperature and low temperature (such as: engine room and cabin), different parameter change should be known clearly when converters operating in the different ambient temperature. Particularly, please note that the ambient temperature refers to the ambient, where the converter is operating. It is the temperature inside the frame of the device and not the room temperature. Because the device contains many heat generating components, temperature in the frame is usually higher than room temperature of the time. 0 to 70°C is required in commerce field. -40 to 85°C is required in industry field. -40 to 105°C is required for in car equipment. -55 to 85°C is required for field exploration instrument. -55 to 125°C is required in military field. Operating at high temperature the converter must be derated and a sufficient margin should be left out when design. Meanwhile the output capacitor should not be aluminum electrolytic capacitor, but TA capacitor or other capacitor with good feature in high temperature. When operating in high temperature the isolation voltage of the capacitor may significantly derate, please refer to the datasheet for instructions. Besides, some electrolytic capacitor may become disabled under -10°C or lower temperature.

For AC/DC converters, most of our products contain electrolytic capacitors of various quantities. You should pay attention to their rated operating temperature and avoid operating under cruel circumstances and damage the product. All AC/DC products operation temperatures have achieved -25 to 70°C range of industrial class requirements.

8.) Surge and group pulse

In the circumstance with outside interference such as arc, ESD, unstable AC electric network, start-up switch, lighting strike, input voltage and current will extremely exceed the application limitation, therefore the converters and load circuit will be permanently destroyed, so it is necessary to add protection circuit to ensure safe operation of the power.

9.) Long distance transmission

Whatever in or outside door, the transmission distance is one of the key factors in system. Non-isolation or mini-power products can be used in doors for its little temperature drop and weak interference. Wide input and isolated, high-efficiency converters can be used in long-distance transmission in field to push long-distance equipments, for fear that insufficient start-up power cause failed start. Moreover, you'd better consider the start-up current, although we adopt soft-start technology, the start current commonly is 1.3-1.6 times input current, but the transmission distance is too long and the loss is too large, so it is important have enough power in the front pole of the converter to ensure the converter enable start well andoperate well. Additionally, it is advisable to parallel a capacitor beside the input pinout to improve start performance.

10.) Working Circumstance

A: Heat dissipation
All converters will lose some power and then change it into heat energy when in working and lead the ambient environment calefactive and data interference (high heat-sensitivity parts), performance reduction, even to short circuit and fire, thus, larger ventilate room or larger heat dissipation room is essential to ensure safety.

11.) Interference

For DC/DC adopts switching technology, its switching oscillation circuit and inner magnetic parts will produce EMI (electromagnetic interference) and pollution to surrounding parts. EMI refers to the pollution from electromagnetic energy to environment trough electromagnetic radiation transmission and data cable and AC cable. It's impossible to completely avoid EMI, but some measures can be taken to degrade it until reach the safety class. For EMI restraining, the common measures are:

A: Electromagnetic radiation shielding. To decrease radiation, metal shielding case or extra outer shielding case is recommended.

B: Right grounding.

C: Filter data cable and AC cable. E.g. both appropriate filter and filter network can lessen electromagnetic interference.

D: Separate layout between converter supply system and weak signal circuit can effectively avoid all interference from converters to weak signal circuit.

12.) Layout

Wrong grounding and layout will easily cause unstable system and high noise and some bad phenomenon which is hard to explain.

The three common circuit connection:

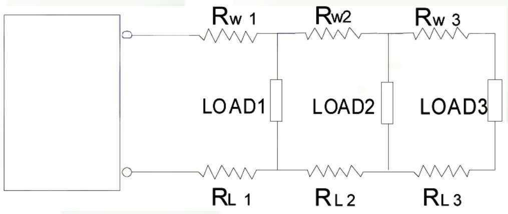


Diagram 1: Parallel connection
Every load and other load resistance produce DC loop circuit together. Every load voltage varies form other load currents.

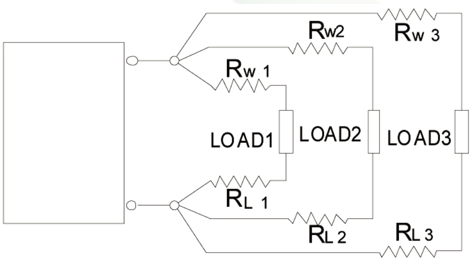


Diagram 2: Radiated connection
Every load and power supply constitute an independent loop circuit, which erase the crossed influence between AC loop grounding and different load, every load voltage has own difference for its loop current and resistance but no interference with each other.

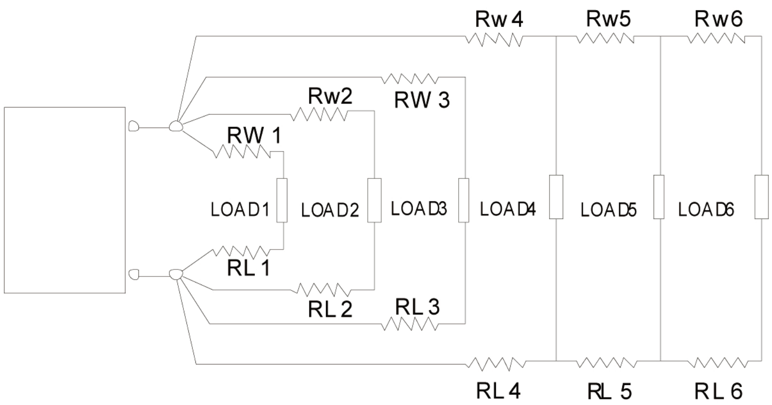


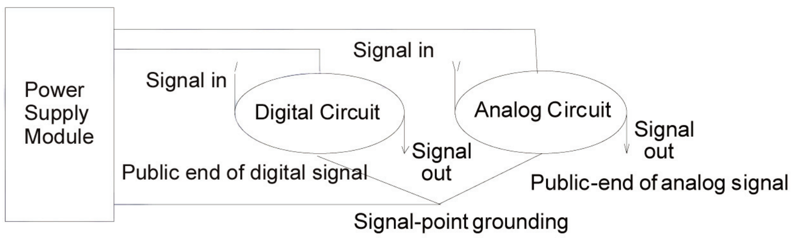
Diagram 3: Mixed connection

In a complicated power system, both parallel connection and crossed connection are regularly used. Crossed connection usually adopted in high-current load and close to power supply for its weak crossed influence. Parallel connection usually adopted in low-current load for its low voltage drop.

Analog and digital circuit distribution

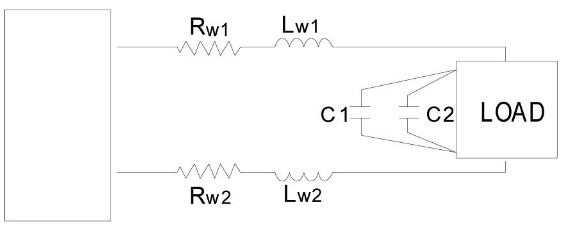
In many application fields, analog circuit and digital circuit share the same power supply. For the design, it is very important that analog circuit should be separated from digital circuit or power supply is isolated with loop grounding, in order to avoid the interference from digital DC voltage drop variation and logic suppressor process to analog circuit system.

As the figure shows:



Eliminate high-frequency noise

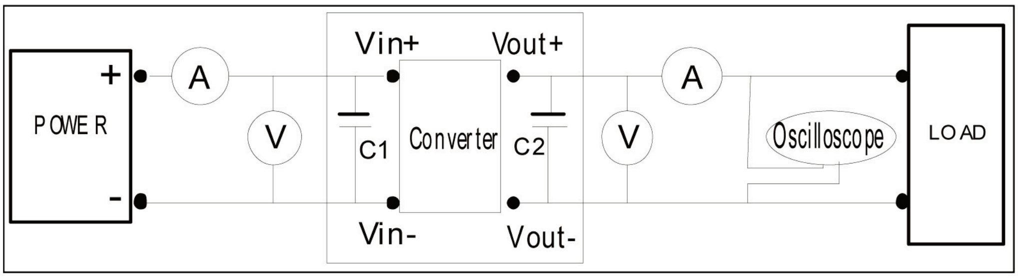
In high-speed circuit, dynamic analog circuit, digital circuit, the distributed resistance and inductance become obvious and sensitive and even scream for quick change of load current. Thus, high frequency is required to be eliminated, meanwhile the resonant which caused by series resistance and distributed parameter is also required to be erased.



C1 use 1-10uF electrolytic or tantalum capacitor; C2 use 0.1uF ceramic capacitor (see technical information for details).

DC/DC Converter testing suggestions

After selecting the right converter based on input and output requirements, the correct testing method must be used to insure and verify specified performance parameters. The following are suggested test methods and test equipment requirements. Test conditions: room temperature TA = 25°C humidity <75%, rated input and rated load.



The model contains:

A) DC adjustable regulated power supply : output voltage range is suitable for DC/DC converter under test.
B) current meter A : accuracy 0.001A
C) voltage meter V: accuracy 0.001V
D) load resistance: rated load Rfull-load = Vout/Iout
unload Rmin-load =10× Rfull-load
E) wire: The larger cross section of copper the better. Using ohm's law, V=IR, make sure the wire used represents less than 0.1% of the overall voltages you are measuring.

Test

1. Wire
The proper wire shall be selected as described above. Smaller gauge wire will result in potential errors in measuring the true efficiency and regulation parameters. Ensure all mechanical and solder connections are sound as this will also introduce errors.

2. Grounding
Improper grounding can cause unintended noise in the circuit. When testing ripple and noise, it is suggested that the single pole test method be used to lessen test error (see graph "ripple and noise").

3. Load
To insure useful test data, the testing load of regulated products should be within 10~100% of the rated output current/power, for unregulated product it is OK to test at no load, but be aware that the voltage accuracy is not specified at this load level.

4. Converter performance
After the input and output have been properly connected, performance testing can begin.

A) Input voltage accuracy: Set input voltage at nominal value, output at rated load, the output voltage reading will be Vout, nominal output voltage will be Vnom.

The formula:

$$\frac{V_{OUT} - V_{NOM}}{V_{NOM}} \times 100\%$$

E.g. regulated products when the nominal input voltage is 12V, rated load is 144 ohm, the output voltage reading will be 12.039V.

$$\frac{12.039VDC - 12.000VDC}{12.000VDC} \times 100\,\% = 0.325\%$$

Line regulation:

At nominal input voltage and full load, adjust input voltage over its full specified range.

A) Fixed input, isolated unregulated series:

$$\frac{\triangle V_{OUT}}{\triangle V_{IN}}$$

$$\triangle V_{OUT} = \frac{V_{OUT+10\%} - V_{OUT-10\%}}{V_{OUTNOM}} \%$$

$$\triangle V_{IN} = \frac{V_{IN+10\%} - V_{IN-10\%}}{V_{INNOM}} \%$$

In the formula:

- Vin+10% nominal input voltage and add 10% as for its upper limit
- Vin-10% nominal input voltage and minus 10% as for its lower limit
- Vout+10% output voltage reading under full load when input voltage at its upper limit
- Vout-10% output voltage reading under full load when input voltage at its lower limit
- Vinnom nominal input voltage
- Voutnom output voltage reading under full load and nominal input voltage

For example:

Connect a 25 ohm resistive load, input voltage range: ±10% (or 4.5V~5.5V), Vin+10% =5.5 V; Vin-10% = 4.5 V ;Vinnom = 5V

Vout+10% reads: 5.32V; Vout-10% reads: 4.2V; Voutnom reads: 4.77V

Vin+10% reads: 5.5 V; Vin-10% reads: 4.5 V; Vinnom reads: 5V

$$\triangle V_{OUT} = \frac{5.32VDC - 4.2VDC}{4.77VDC} X100\% = 23.5\%$$

$$\triangle V_{IN} = \frac{5.5VDC - 4.5VDC}{5VDC} X100\% = 20\%$$

So the line regulation is:

$$= \left| \frac{\triangle V_{OUT}}{\triangle V_{IN}} \right| = 1.174$$

△ Vout = (5.32V-4.2V) / 4.77V *% = 0.2348

△ Vin = (5.5V-4.5V) / 5V *% = 0.2

B) Fixed input, isolated and regulated series, and wide input, regulated series:

Line regulation:

$$\frac{V_{OUTN} - V_{MDEV}}{V_{OUTN}} X100\%$$

- At nominal input voltage, rated load, read output voltage as V_{OUTN}
- At input voltage upper limit, rated load, read output voltage as V_{OUTH}
- At input voltage lower limit, rated load, read output voltage as V_{OUTL}
- V_{MDEV} chose in V_{OUTH} or V_{OUTL} the one deviated from V_{OUTN}

APPLICATION NOTES

3) Load regulation

As the input voltage is rated value, you can connect 10% and 100% constant resistance load and test the difference between 10% load and rated value & the difference between 100% load and rated value respectively.

$$\frac{V_{OUTNL} - V_{OUTFL}}{V_{OUTFL}} \%$$

Vout NL output voltage at 10% load
Vout FL output voltage at 100% voltage

e.g. fixed input 1 watt converter 5Vin, 5Vout: rated load is u2/p =144ohm, load range is 10%~100%, read:

VoutNL = 5.29 V; VoutFL = 4.77 V ; Voutnom = 5V

Load regulation:

$$\frac{5.29VDC - 4.77VDC}{4.77VDC} X100\% = 10.9\%$$

4) Efficiency

The proportion of input power and output power at rated input and rated load.

The formula:

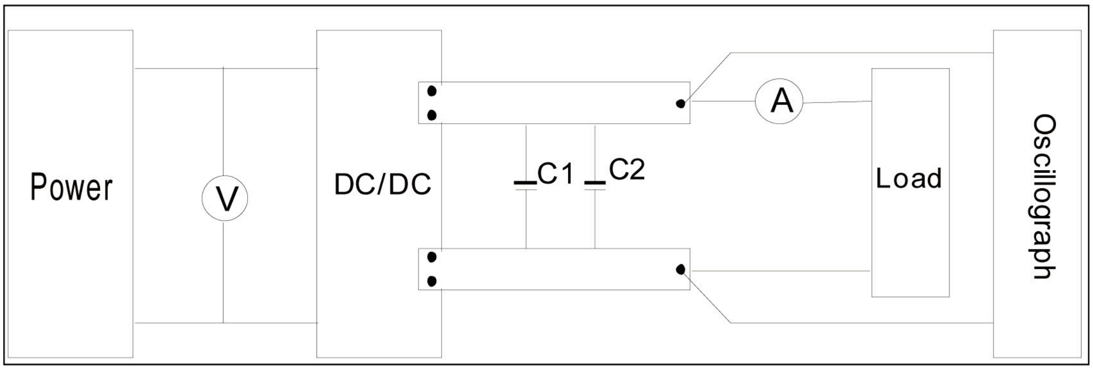
$$\frac{I_{OUT} \times V_{OUT}}{I_{IN} \times V_{IN}} X100\%$$

e.g.: 1S7A_1.5RP, rated input 12V, full-load output 12.039V; current is 83.3mA, input current is115.0mA.

$$\frac{0.0833A \times 12.039V}{0.1150A \times 12.000V} X100\% = 73\%$$

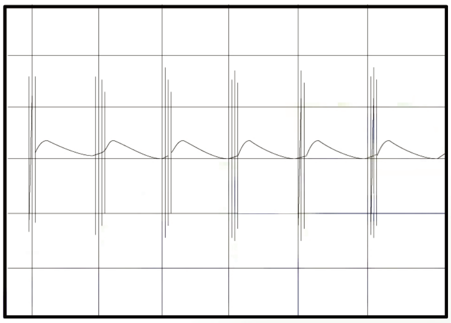
5) Ripple and noise:

Ripple and noise is the AC component at the DC output, which affects output accuracy, we usually calculated ripple and noise with a peak to peak value (mVp.p) and test with parallel cable.



As the DC/DC converter output end/side can contains high-frequency harmonics, and the common mode rejection ratio of most scopes is not so good, it is best to not use the ground wire provided on most probes. Attach the ground sleeve as shown in the figure above.

Tall, high frequency spikes are normally noise, and smaller lower frequency plots are generally ripple.



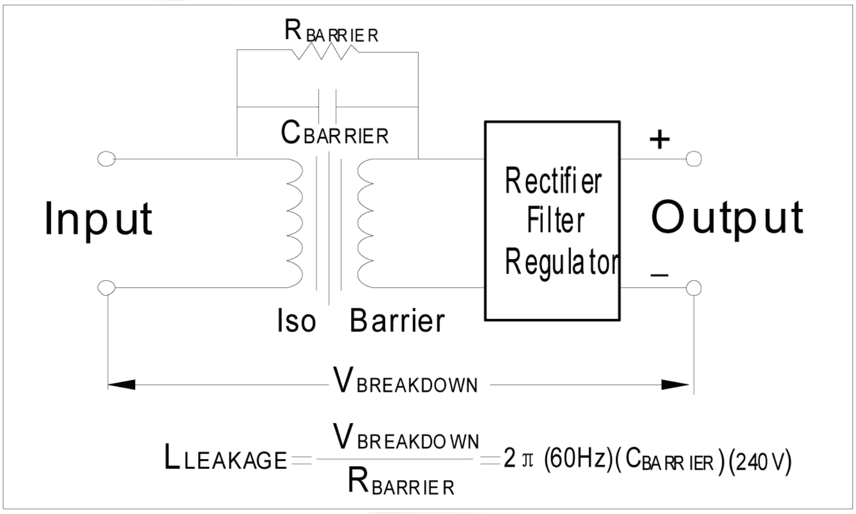
6) Start-up time

Start-up time is the time once the input voltage is present and within the specified range, the time it takes for the output of the converter to rise between 10% and 90% of its nominal value. This is usually tested and specified with a resistive load only. Other factors like additional output capacitance added by the customer can effect this time.

7) Isolation and insulation characters

Isolation is one of the most important parameters of a DC/DC converter. Depending on the application, isolation values are typically between 1KV and 6KV depending on the DC/DC converter series. The isolation circuit drawing is shown in the figure below.

Isolation equivalent circuit:



C BARRIER: Isolation capacitance; coupled between primary and secondary windings

R BARRIER : Isolation resistance: DC resistance between input and output.

I LEAKAGE : Leakage current; the current as a result of the input/output capacitance.

V BREAKDOWN: Test voltage. It is usually 240VAC/60HZ.

In general, DC/DC converters are constructed to minimize isolation capacitance, and therefore minimize leakage current.

For isolation testing:

Isolation, dielectric strength test: test 1 min., input/output (at AC/DC specified peak value).

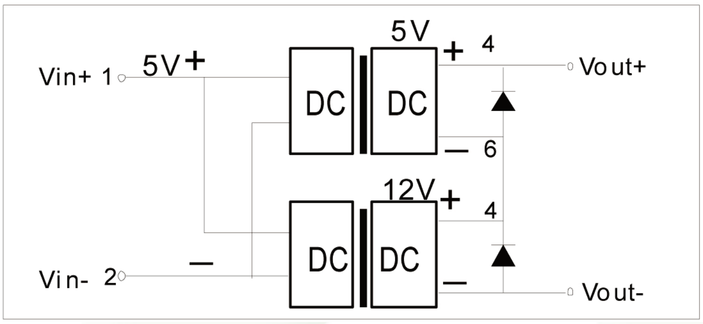
For insulation resistance test:

The value should be above 1GOhm when applying 500VDC from input/output.

Additional converter applications

1. DC/DC converters used in series

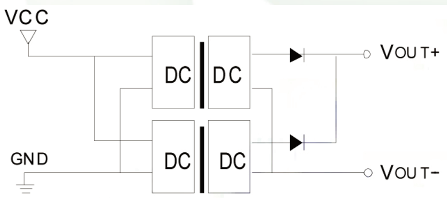
Isolated DC/DC converters allow the connections of their outputs in series to create higher voltages if necessary. Please see figure below for proper series connection.



Converter 1 is 5Vout, and Converter 2 is 12Vout. As you can see a nominal 17VDC output converter can be created by applying the 5V and 12V converters in series. Be careful not to exceed the rated current either of the converters, as now the rated current is equal to which ever one is the lesser.

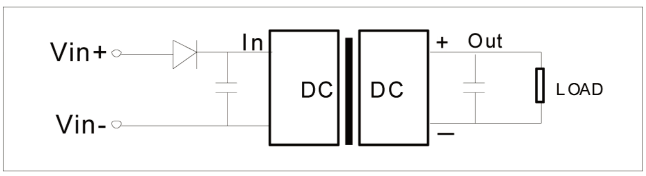
2. DC/DC converters connected in parallel

While it is possible with some converters in some applications to be connected for parallel operation, it is generally not recommended as one cannot guarantee that an equal current is shared by each converter. Isolation diodes help this, but it is not guaranteed. The following figure shows a parallel connection, but the actual application is redundancy. As long as the total power taken from the pair is equal to just a single converter, then if a converter fails, then the other will take over without loss of service. Only identical converters should be connected in this manner.



3. Input reverse polarity protection

The "+" input is connected with positive pole of power supply and "-"input is connected with negative pole of power supply (in telecommunication field is -48VDC), So the high-voltage terminal should be connected with "+" input and the low-voltage terminal should be connected with "-" output, otherwise, it will cause the permanent damage. It is recommended to connect a diode to protect the input stage, if inadvertent connection of the input is possible. Note that the diode will dissipate power and create heat.



It is recommended to connect a low voltage drop Schottky diode at "+" input as shown.

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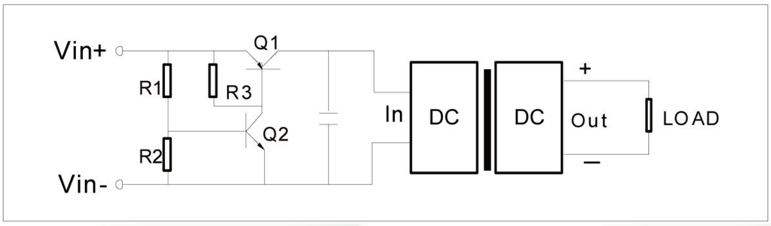
4. Input under voltage protection

When the DC/DC converter is sharing a power source with other circuits, a large input voltage drop caused by external circuits or over load can lead to an input voltage that is below the minimum input voltage specified by the converter. So it is recommended to adopt an under voltage protection circuit to cut off the DC input when the input voltage drops below the minimum specified for the converter.

Low voltage turn-off circuit

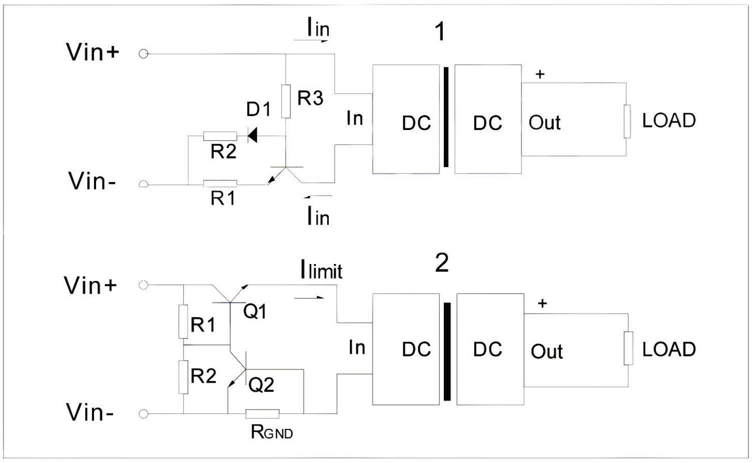


Where R1, R2 set as low voltage switching limit, PNP transistor can be used, or a p-channel MOSFET. Please consult factory for proper calculations. Note: For low voltage input products, the above circuit will produce a 0.7V voltage drop.

5. Input short-circuit protection

Most unregulated DC/DC converters with RCC open loop circuit have no short-circuit protection. We especially recommend the following circuit to implement short circuit protection.

As the figure shows:



Please consult our technical service for complete calculations.

Solution 1: Iin = 1.4 * I (rated input current I);

R1 = 200/Iin (accurracy: 1%);

R2 = R1 * β (accuracy: 1%)

Vb = 0.7+ [Iin * R1 * (β+1) / β * 1000]

R3 =[(Vin-Vb) *R1 * R2 * (β+1)]/ { (Vb-0.7) * [R2+R1 (β+1)] }

Solution 2: RGND = 0.7V/I limit (recommended)

Q1,Q2 can be common switching transistor

6. Over current and over voltage protection

The permitted input voltage and input current is restricted to be within the range specified on the dataheets to prevent damage to the DC/DC converter. Below are some techniques to add some additional over voltage protection and over current protection on a standard DC/DC converter.

As the figure below:

Please consult our technical service for specific recommendations.

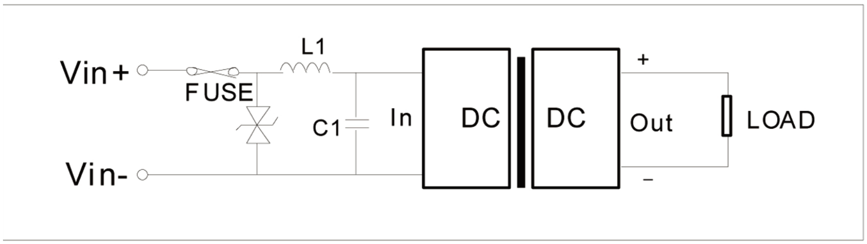


Figure 1: Instant over voltage and over current protection circuit.

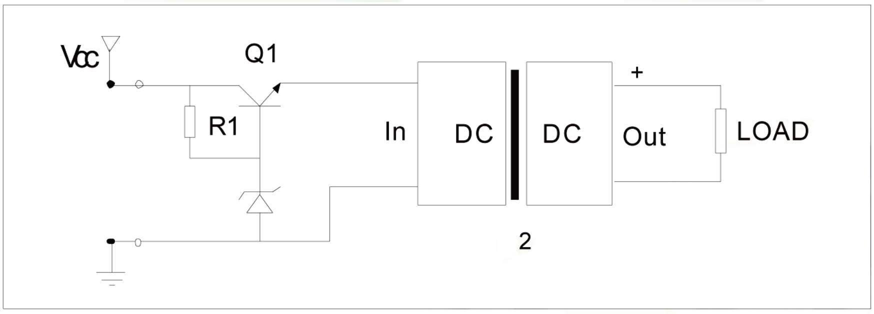


Figure 2: Continuous over voltage protection circuit.

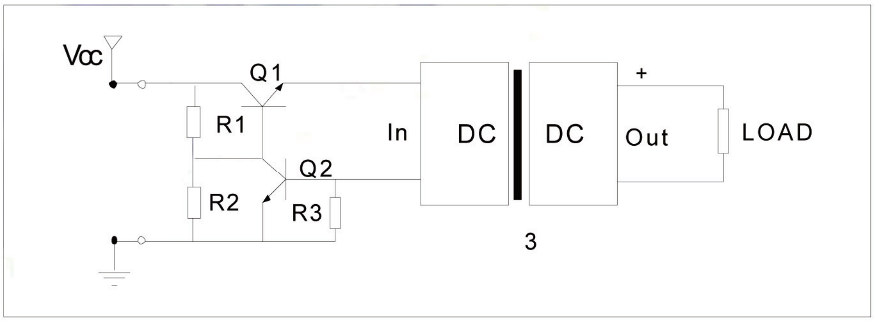


Figure 3: Continuous over current protection circuit

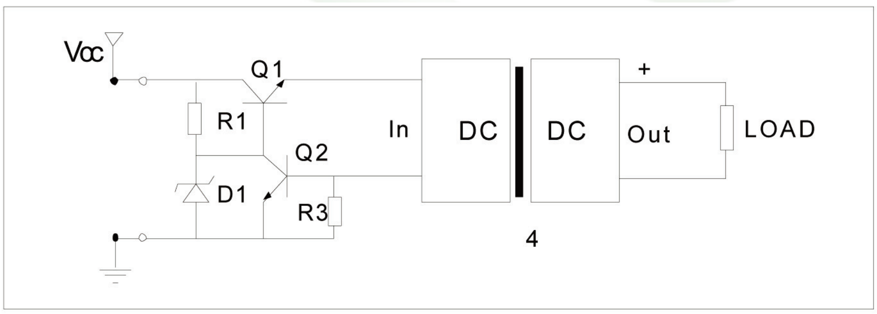


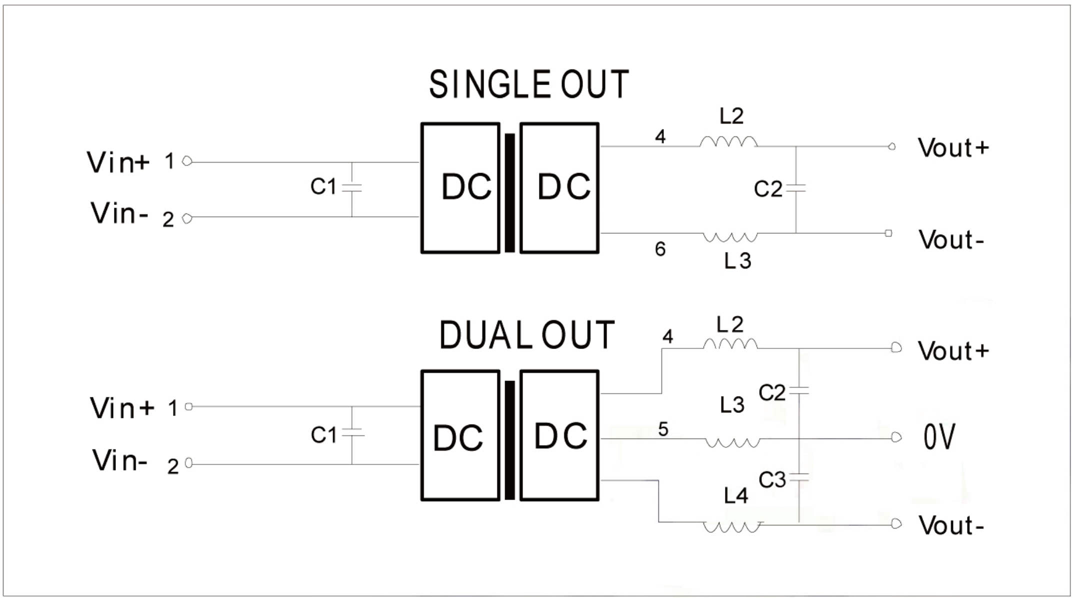
Figure 4: Continuous over voltage and over current protection circuit

7. Input and output filtering circuit

Most of our DC/DC converters do not require additional components for filtering, etc. however, if further noise and ripple voltage reduction are required, here are some techniques.

A) Reduce ripple

Considerations here are that the additional output capacitance added, if excessive, may cause the DC/DC converter some difficulty during power up. In most cases this value is shown in the datasheet. If you have any questions, please contact our technical service.



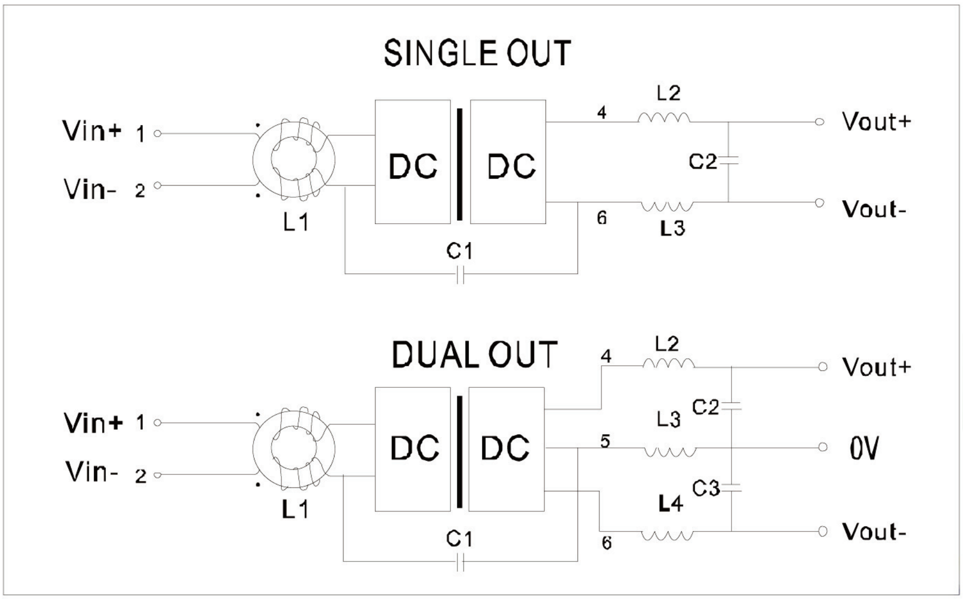
C1: EMI Filter and to reduce input ripple: connect aluminum electrolytic capacitor, please refer to datasheet to verify maximum capacitance value.

L2/L3/L4: Form an LC filter network to reduce output noise and ripple. It is recommended to use powered iron magnetic cores and copper magnet wire suitably rated.

C2/C3: Form an LC filter network to reduce output noise and ripple. It is recommended to use aluminum electrolytic capacitors. Please see datasheet for maximum values.

B) Noise reduction

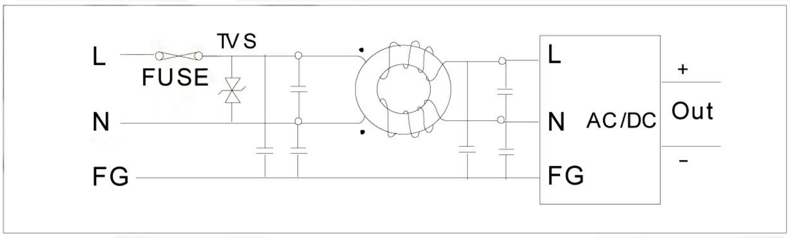
For proper calculations of these filter networks, please consult the factory for suggestions. A typical example is shown below.



8. Electromagnetic compatibility

As DC-DC converter is typically down stream from the incoming system AC power, where EMC requirements and regulations are required. However our AC/DC products may fall into the requirements of these EMC regulations. Below is a recommended EMC filter circuit that can be employed on the same PCB that the AC/DC converter is installed. Please contact our technical support for detailed calculations and suggestions. With the proper filter our AC/DC power supplies will meet the standard Class B levels of EN55022 and others.

The following diagram is for your reference:



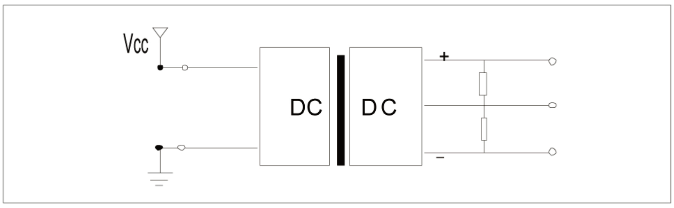
9. Capacitive load

To meet the requirements of capacitive loads, it is recommended for wide input series, the recommended capacitor is 100uF.

10. Output low load and overload protection

A) Low load prevention circuit

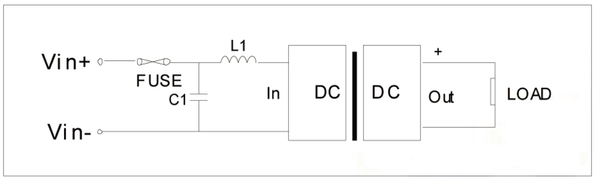
Most isolated DC/DC converters have some minimum load required to guarantee proper operation and regulation. Typically, this is 10% (non-isolated series can stand continuous unload). The output voltage will increase above stated spec for unregulated, for example, when converter is supplying power to a relay, MOSFET or IC of low power consumption (such as 485), it is recommended to guarantee a 10% load under worst case conditions.

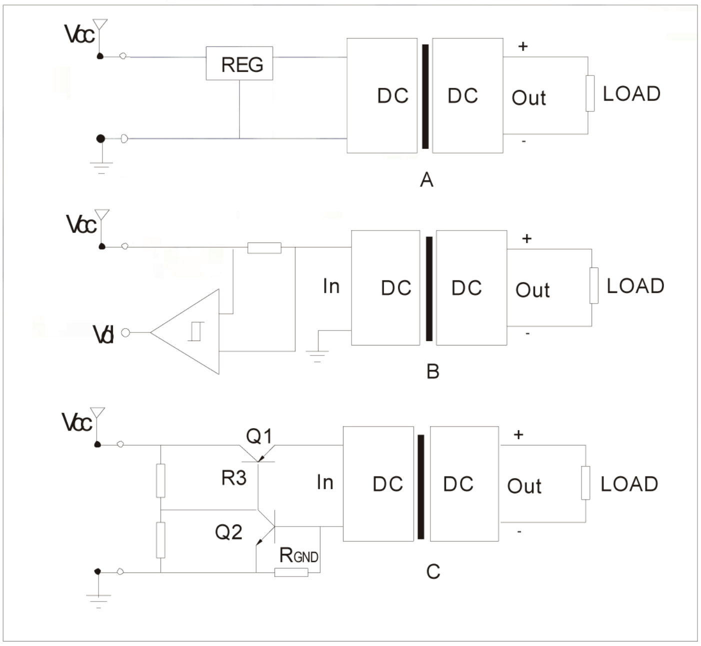


B) Overload prevention circuit

Though some current can be limited by a filter, when overload and/or short circuit conditions occur, a high current can cause damage to DC/DC converters. It is recommended that one installs a slow blow type fuse of rating 3 times max input current on the input as shown. Please contact our technical service for more details.

As the figure shows: simple overload protection





1.) Sometimes a circuit breaker can be used.

2.) Sometimes we also can avoid overload by limiting the input current as the above figure shows:

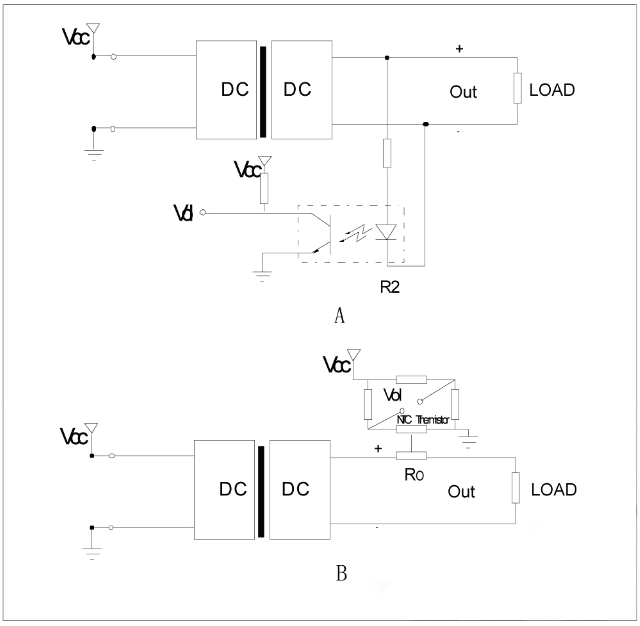
A): Utilize a pre-regulator to limit the input current, but the overall efficiency will be reduced.

B): A series resistor network may be placed before the converter to limit current, but in all but a few cases, this is usually impractical.

C): To limit input current by setting RGND, 0.7V = RGND*ILIMIT with an op amp circuit.

3.) A: An opto-isolator can be used to limit PWM duty cycle.

B: A thermistor can be used to measure the current and provide feedback to the PWM.



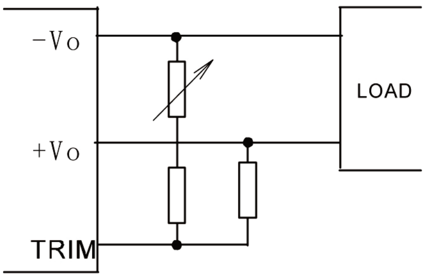
11. Special function pin explanation

A.) Output voltage trimming range

Through adding a resistor at the TRIM terminal, the user can adjust the output voltage ±10% around its rated value. The total output power of the converter should be limited to its maximum specified output power.

Figure 1 shows how to connect the external trim resistors. If only to adjust to higher (or lower) voltage, the resistor could be connected only between TRIM terminal and negative output (or positive output). The general rules are, to increase output voltage, adding resistor between TRIM terminal and negative output is all that is needed; to decrease output voltage, then adding resistor between TRIM terminal and positive output is all that is needed. If TRIM is not needed, just leave it open circuit.

Figure 1: How to connect resistors for trimming



B) Remote on/off control

Remote ON/OFF control refers to the turning on or off the converter by external means.
Remote on/off control pin is usually called CTL terminal, CNT terminal or REM terminal.

There're two standard remote control models.

Positive Logic:

CTL terminal connected directly to – VIN, output OFF; CTL terminal open or connected to up level (TTL High) output ON.

Negative Logic:

CTL terminal connected directly to – VIN, output ON; CTL terminal open, output OFF.

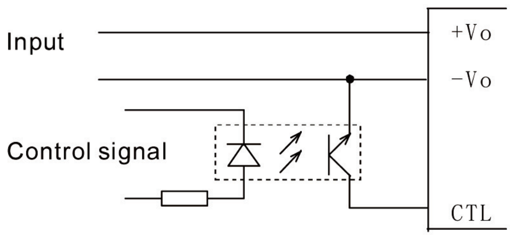


Figure 2: isolated control method

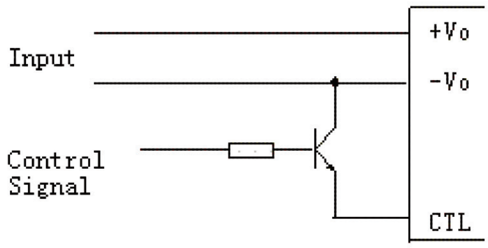


Figure 3: general control method

In some special applications, isolated control method is required, see figure 2 for the reference circuit.