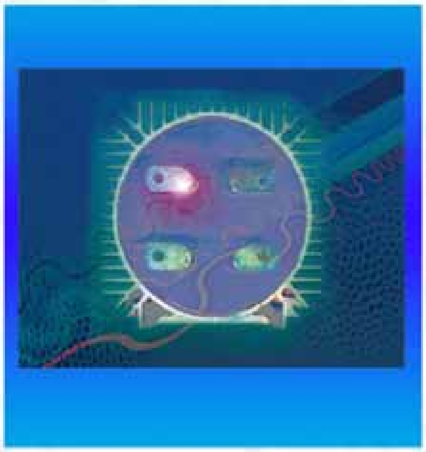
REO INDUCTIVE COMPONENTS AG



High-frequency components for switch-mode power supplies

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REO

High-frequency components for switch-mode power supplies

Whilst linear power supplies based on transformers, rectifiers and LC smoothing provide better line and load regulation, output ripple, transient recovery and longer hold-up times compared with switching power supplies, they are not as efficient and have a low power to volume ratio. Nowadays, weight, efficiency, availability of raw materials such as electrical steel and copper and manufacturing costs, together with the new developments in power switching devices, are invariably leading to predominance of switch-mode power supplies, certainly for power ranges from 100W up to a few kW.

Comparison of Linear versus Switching Power Supplies (typical values)

Specification	Linear	Switching
Line Regulation	0.02% - 0.05%	0.05% - 0.1%
Load Regulation	0.02% - 0.1%	0.1% - 1.0%
Output Ripple	0.5 mV - 2 mV rms	10 mV - 100 mV$_{P-P}$
Input Voltage Range	± 10%	± 20%
Efficiency	40% - 55%	60% - 95%
Power Density	0.03 W/cm^3	0.12W - 0.6 W/cm^3
Transient Recovery	50 µs	300 µs
Hold-up time	2 ms	34 ms

The main reason why switch-mode power supplies are lighter and more efficient is because they operate at frequencies which are much higher than that mains frequency, and linear power supplies use uncontrolled rectifiers which have to operate at 50/60Hz. The present frequency limit seems to be 1MHz but switching frequencies in the tens of megahertz range are being contemplated. Usually domestic switch-mode power supplies do not run at frequencies below 20kHz because they would then be within audible noise range discernable by humans.

A low frequency transformer usually transfers energy through its core made from electrical grade steel, whilst the core of a high-frequency transformer is only there to limit leakage. The cores of high-frequency transformers are usually made from ferrite or amorphous materials because conventional cores have levels of losses that are unacceptable. Furthermore much smaller capacitors can be used in switching circuits, unlike those required for linear power supplies. Invariably switch-mode power supplies are more complicated and since the waveforms are generally high speed (PWM square waves) the windings of transformers and inductors have to support high harmonics of the fundamental frequency and skin effect is a major source of power loss, hence expensive litz wire has to be used for some windings.

If the output is required to be isolated from the input, as is usually the case in mains power supplies, the inverted AC is used to drive the primary winding of a high-frequency transformer. This also converts the voltage up or down to the required output level on its secondary winding.

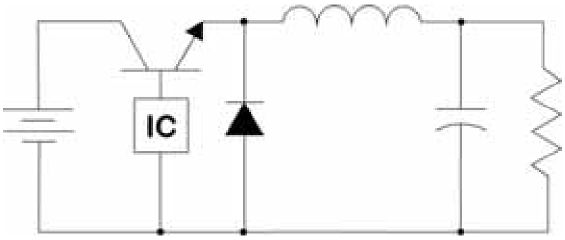
DC-DC Converters

The simpler switch-mode power converters contain an inductor instead of a transformer. These normally have a single input, single output and utilise one active switch and an inductor. DC-DC Converters fall into this category are widely used to transform and distribute DC power in systems and instruments. DC power is usually available to a system in the form of a 5V, 28V, 48V DC system power supply or battery. Nowadays the most common applications for DC-DC converters are mobile phones and lap-top computers.

In general when DC voltages are low, safety isolation is not such an important consideration; however, these types of converters can still be used with an electrical isolation transformer in switch-mode DC power supplies but there are some DC motor drive applications where an isolation transformer is not used.

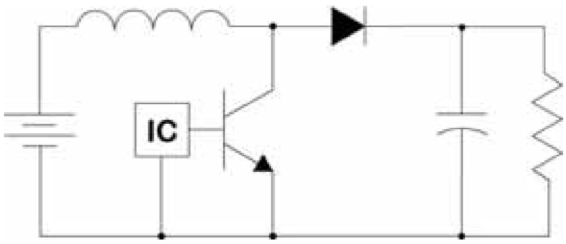
Typical examples of DC-DC converters are:

Buck Regulator



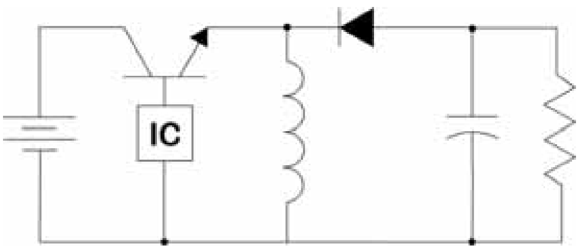
The buck or step-down regulator provides an output voltage which is lower than the input voltage. Its main application is in regulated DC power supplies and DC-motor speed control. Another typical application would be for the reduction of a standard military 28 VDC bus voltage to 5 VDC to power TTL logic.

Boost Regulator



A typical circuit of a power supply which could be used for boosting the input of 5 VDC from a battery to 12V for interface circuits or even as high as 150 VDC for electro-luminescent displays. Its main application is in regulated DC power supplies and the regenerative braking of DC motors.

Buck-boost or Inverting Regulator



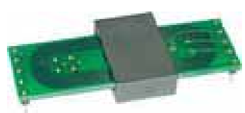
This is a switching circuit which produces an output voltage with the opposite polarity to the input voltage. It is referred to as a buck-boost regulator because the output voltage can be higher or lower than the input voltage depending upon the ratio of on-time to off-time of the pass transistor.

There are other types of converters which fall into this category, including the **Ćuk** type, which can be used for step up or step down but is essentially a polarity reverser and also the **Charge-pump** but this only used in relatively low power applications.

Examples of high-frequency power components from REO INDUCTIVE COMPONENTS AG

HPTB

HPTK



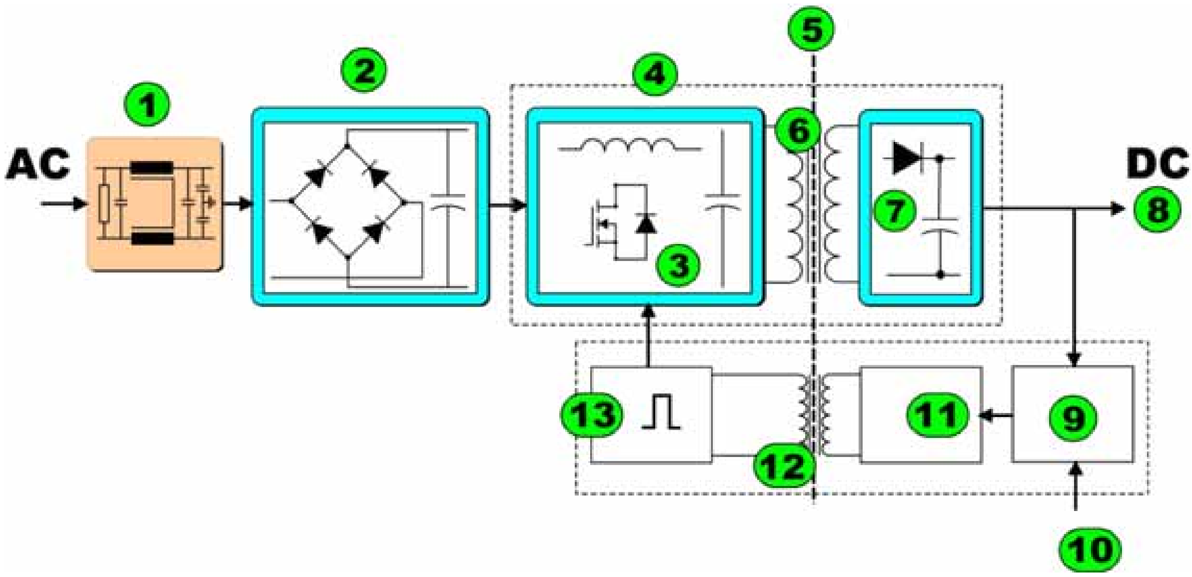
PMT (Planar)

HPTA

AC-DC Converters

A power supply which is used for converting AC mains voltage to DC power must perform the following functions efficiently and be cost effective:
1) Rectification: Convert the AC line voltage to DC voltage
2) Voltage transformation: Supply the required DC voltage level(s)
3) Filtering: Smooth out the ripple on the rectified voltage
4) Regulation: Control the output voltage so that it remains at a constant level irrespective of mains supply variations or load/temperature changes
5) Isolation: Provide electrical separation of the output voltage from the mains supply
6) Protection: Prevent damaging voltage surges from reaching the output and to provide ride-through power or shut-down during a power sag

Schematic of a switch-mode AC-DC power supply



The main components in an AC-DC switch-mode power supply, as shown in the schematic diagram are:

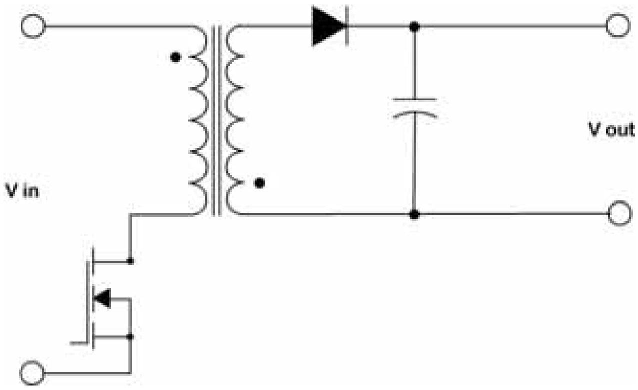
1) Filter for reducing mains borne conducted interference
2) Rectifier and capacitor for maintaining a steady but unregulated DC level
3) Power converter, comprising switching semiconductors, inductors diodes and capacitors in various configurations
4) DC-DC conversion with isolation which converts DC from one level to another
5) Isolation boundary
6) High-frequency transformer: The high-frequency switching produces high-frequency AC across the isolation transformer.
7) Rectifier and filter
8) Regulated DC output
9) Error amplifier
10) Reference voltage
11) Pulse-width modulation controller
12) High-frequency signal transformer
13) Switch base/gate drive circuit

Such circuits employ solid-state devices such as transistors, MOSFETs or IGBTs, which operate as a switch – either completely on or completely off. Since the power devices are not required to operate in their active region, this mode of operation results in lower power dissipation. Increased switching speeds, higher voltage and current ratings, and a relatively lower cost of these devices are the factors which have contributed to the emergence of switching power supplies.

The following circuits denote the DC-DC conversion with isolation as shown as (4) in the previous schematic diagram.

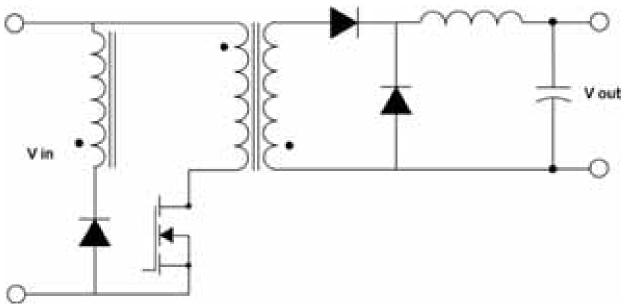
Unidirectional core excitation

Flyback Converter



Used with a mains supply of 110/220V, the requirement for mains isolation is absolutely essential. This is achieved by using a transformer in place of an inductor. This type of converter is normally used in power supplies with up to 150W rating. The transformer has a dual function of providing energy storage as in an inductor and electrical isolation as in a transformer. This is the basic power supply used in computers, test instruments and video terminals.

Forward Converter

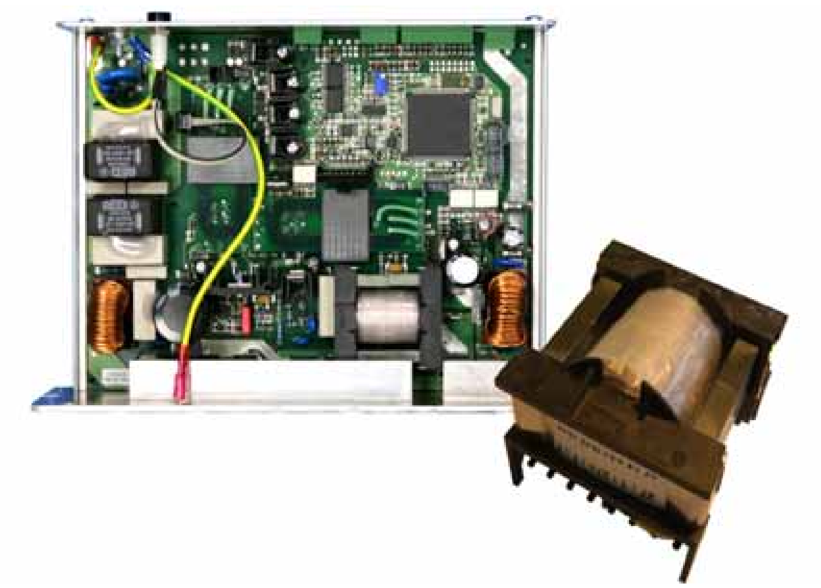


The forward converter has a transformer with a third winding and a series diode which is used to transfer the magnetising energy in the core back to the DC supply so that it does not have to be dissipated in the switching device or some other voltage suppressor. The turns ratio between the primary and extra winding is normally 1:1 so that the forward converter can run at 50% duty-cycle. The power range for this type of converter is 100W - 500W.

Further variations of forward converters are used including **2-Switch Forward** and **Active Clamp Forward** types, which use a second switching device instead of the additional winding on the transformer.

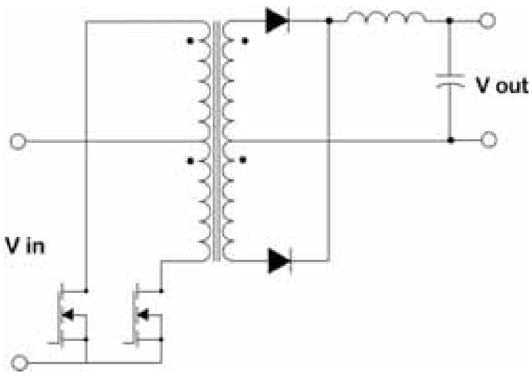
Application example

The picture shows a 24VDC, 300W forward converter which uses a high-frequency transformer. The switch-mode power supply is used for cathodic protection where the application demands low ripple, actual value feedback and closed-loop control using a remote set-point.

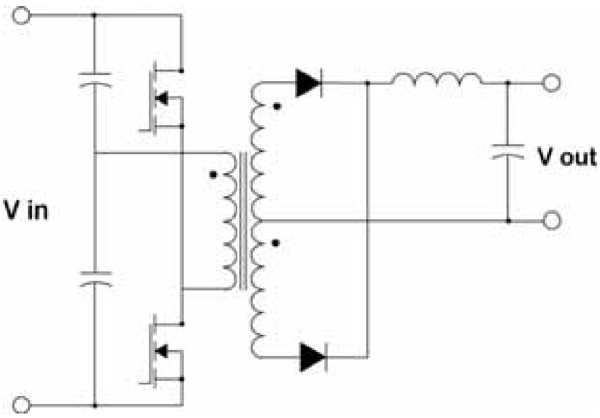


Bidirectional Core Excitation

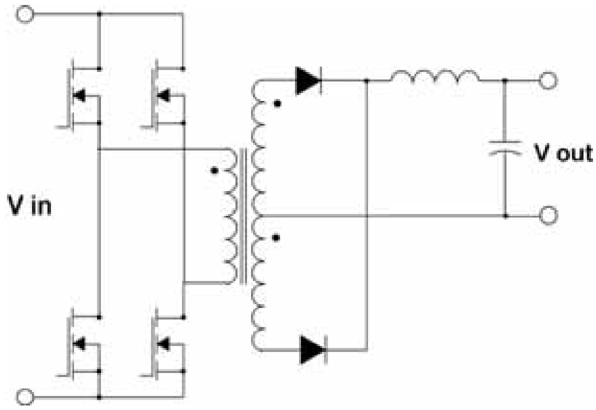
Push-pull Converter



Half-bridge Converter



Full-bridge Converter



The full bridge converter is used more for higher power ratings and since all voltages are shared equally between two switching semiconductors the maximum voltage rating of the device can approach V in.

Application example

This is an example of a 200V 5kW full-bridge converter, which uses a choke and high-frequency transformer produced by REO INDUCTIVE COMPONENTS AG.

A summary of some of the most commonly used power conversion circuits

Type	Power (W)	Typical efficiency (%)	Relative Cost	Input Range (V)	Isolation	Energy Storage	Voltage Relation	Features
Step-down or Buck	0 - 1000	75	1.0	5 - 1000	N	Single Inductor	Out < In	
Step-up or Boost	0 - 150	78	1.0	5 - 600	N	Single Inductor	Out > in	
Inverter or Buck-boost	0 - 150	78	1.0	5 - 600	N	Single Inductor	up or down	Inverted output voltage
Fly back	0 - 150	78	1.0	5 - 600	Y	Transformer with larger core	up or down	Multiple outputs
Half-forward	0 - 250	75	1.2	5 - 500	Y	Transformer + Inductor		
Forward	100 - 500				Y	Transformer with third winding + Inductor		Multiple outputs
Push-Pull	100 - 1000	72	1.75	50 - 1000	Y	Transformer		
Half-Bridge	0 - 500	72	1.9	50 - 1000	Y	Transformer		
Full-Bridge	400 - 2000	69	> 2.0	50 - 1000	Y	Transformer		
Resonant zero voltage switched	> 1000		> 2.0			Transformer		
Ćuk					N	Capacitor + 2 Inductors	Negative voltage for positive input	
Inverting charge-pump (Modified Ćuk)					N	Single Inductor	Output voltage negative and higher magnitude than positive input voltage	
SEPIC					N	2 Inductors	up or down	
Charge pump					N	Capacitors only	Charge pumps used to generate very high voltages are usually called voltage multipliers.	

REO INDUCTIVE COMPONENTS AG is located in Kyritz in the state of Brandenburg, approximately equidistant from Berlin and Hamburg.

We use the latest techniques and materials for core manufacturing (including amorphous types), coil winding, vacuum impregnation and encapsulation.

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