Free-Wheeling Diodes
for Inductive-Load Switches in Motors and Relays

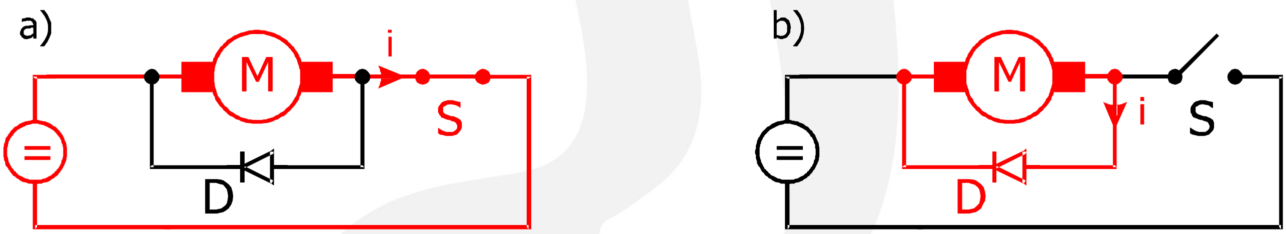
Free-wheeling diodes are mandatory devices in every application where inductors – such as motor coils or relay windings – are used. Inductive loads like that are normally controlled by a switch. The complexity of the control can hereby vary: from a simple on/off switch to a complex 3-phase control method. In many cases, the switch is realized electronically, such as a MOSFET or IGBT. But why a diode is needed? This application note gives the answer and proposes suitable diodes, including the Protectifiers®.

Let's start with some physics. The voltage v across a coil having the inductance L is proportional to di/dt, the change of current flow over the time:

$$v = L \times di/dt \quad (1)$$

Once a constant voltage v is applied to an inductor, a current starts to rise linearly at a rate of di in the time dt. In case v turns back to zero, also the change of current over the time becomes zero – with other words, the current i keeps to flow constantly through the coil at its actual value!
On the other hand, at a rapid change in current flow – e. g. when a switch interrupts the circuit – a high di/dt occurs and as a result an extreme voltage spike v. At ignition coils, such high voltage peaks are desired for generating sparks.

The circuit below shows a typical DC motor application, where both of above issues are of practical interest. Instead of the motor (M), also the coil of a relay or valve might be placed. As long as the switch (S) is closed, a current (i) flows through the motor coils, while the diode blocks - figure a). When the switch turns off, the current finds a so-called free-wheeling path through the diode (D), figure b). Voltage across the coils is zero, so current flows with constant value (practically, the power losses and the forward voltage of the diode are leading to a decreasing current). Without the free-wheeling path, the current would be forced to decay in a very short time to zero, di/dt would get an extreme high value. According to formula (1), this would result in a high voltage peak v, which could destroy the switch component. Thus, the usage of a free-wheeling diode eliminates any turn-off peak and protects the switch and the entire circuit.



In low voltage systems, a Schottky diode is in many cases the preferred choice. However, Schottkys have a limited breakdown voltage. At 100V their V_F is no longer competitive. Schottkys are advantageous at very high switching frequencies f_S; but in most industrial applications f_S is quite low – below 40kHz – to avoid EMI problems. At low and medium switching frequencies, Fast to Ultrafast Recovery rectifiers can be used. In simple on/off DC systems even Standard Recovery devices are possible.

The high switching speed of a MOSFET, and also sparks generated by the collector of DC motors, can generate inductive voltage spikes, which can harm the diode. Careful analysis is needed to make sure the diode is not destroyed by reverse energy.

A new solution for all of these applications are the so-called **Protectifiers®** developed by Diotec Semiconductor: These are "protected rectifiers", having a **low forward voltage drop V_F** and a **very robust reverse characteristic**, comparable to suppressor diodes (TVS). They are much more rugged than some Schottky diodes on the market where a certain (low) reverse avalanche energy is given. Parts can be supplied with a reverse recovery time of about 200ns, allowing them to be used up to several 10 kHz.

Protectifiers® are characterized and tested with 10/1000µs lightning pulses to determine the reverse energy they can absorb; they can easily withstand the lower energy ESD pulses. The guaranteed reverse energy capability and tested clamping voltage is an advantage for the designer. It eliminates uncertainty in the circuit and in some applications it also allows a reduction in the voltage of the MOSFET used. This can be a significant cost saving!

Typical free-wheeling diodes in different technologies and package outlines are shown in below table.

Part Number	Technology	Package	Type	V_{F1}	I_{FAV}	V_{WM}/V_{RRM}	t_{rr}
F5K120	Protectifiers®	DO-201	Axial	0.99 V	5 A	120 V	<350 ns
P1000M	Standard Recovery	D8 x 7.5	Axial	0.90 V	10 A	1000 V	~1500 ns
F12K120	Protectifiers®	D8 x 7.5	Axial	0.82 V	12 A	120 V	<300 ns
F1200D	Superfast Recovery	D8 x 7.5	Axial	0.82 V	12 A	200 V	<200 ns
F12K120	Protectifiers®	D8 x 7.5	Axial	0.82 V	12 A	120 V	<300 ns
PX1500M	Standard Recovery	D8 x 7.5 x d1.6	LowRth Axial	0.90 V	15 A	1000 V	~1500 ns
FX2000D	Superfast Recovery	D8 x 7.5	Axial	0.82 V	20 A	200 V	<200 ns
FX20K120	Protectifiers®	D8 x 7.5 x d1.6	LowRth Axial	0.82 V	20 A	120 V	<300 ns
FT2000AA	Superfast Recovery	TO-220AC	Anode to tab	0.84 V	20 A	50 V	<200 ns
FT2000AB	Superfast Recovery	TO-220AC	Anode to tab	0.84 V	20 A	100 V	<200 ns
FT2000AC	Superfast Recovery	TO-220AC	Anode to tab	0.84 V	20 A	150 V	<200 ns
FT2000AD	Superfast Recovery	TO-220AC	Anode to tab	0.84 V	20 A	200 V	<200 ns
FT2000KA	Superfast Recovery	TO-220AC	Cathode to tab	0.84 V	20 A	50 V	<200 ns
FT2000KB	Superfast Recovery	TO-220AC	Cathode to tab	0.84 V	20 A	100 V	<200 ns
FT2000KC	Superfast Recovery	TO-220AC	Cathode to tab	0.84 V	20 A	150 V	<200 ns
FT2000KD	Superfast Recovery	TO-220AC	Cathode to tab	0.84 V	20 A	200 V	<200 ns
KT20A120	Protectifiers®	TO-220AC	Anode to tab	0.85 V	20 A	120 V	<300 ns
KT20K120	Protectifiers®	TO-220AC	Cathode to tab	0.85 V	20 A	120 V	<300 ns
P2000M	Standard Recovery	D8 x 7.5	Axial	0.87 V	20 A	1000 V	~1500 ns
P2000MTL	Standard Recovery	D8 x 7.5 x d1.6	LowRth Axial	0.87 V	20 A	1000 V	~1500 ns
BYZ35K33	Protectifiers®	Pressfit	Cathode to wire	1.10 V	35 A	26.8 V	~1500 ns

For more detailed data sheets, type the part number into the "Search" field on
http://www.diotec.com/