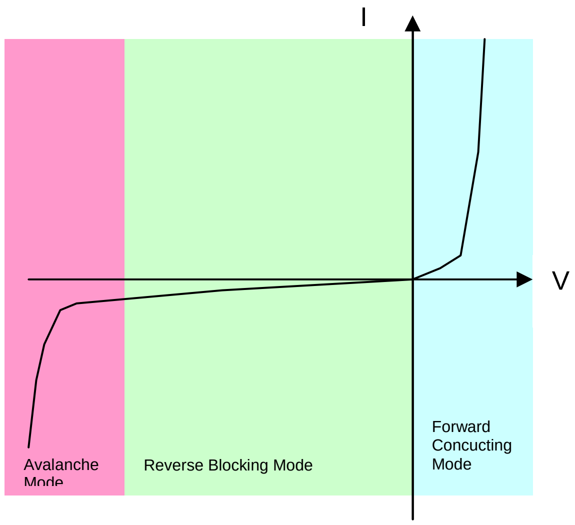
Avalanche Rectifiers

Avalanche Rectifiers are diodes that can tolerate voltages above the repetitive reverse maximum blocking voltage (Vrrm) and, furthermore, dissipate a specified maximum energy during these pulses. Here we describe how these diodes differ from normal rectifiers and the applications to which they are suited.

Introduction

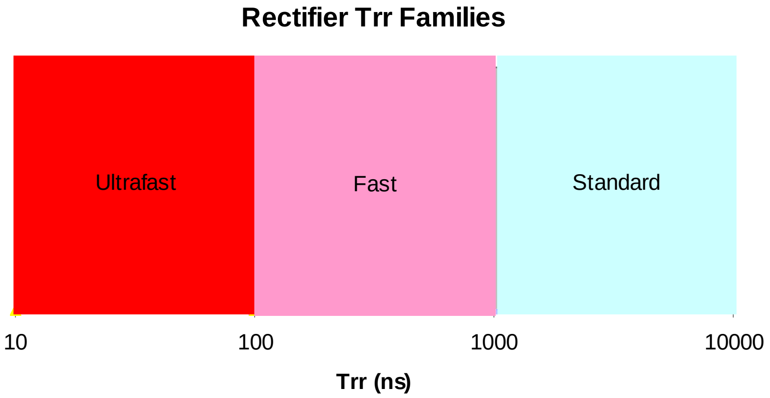
Rectifiers are two-terminal devices that are used to conduct current in one direction but block in the other according to a characteristic of the type shown in Figure 1. Standard rectifiers operate stably in either the Reverse Blocking Mode or in the Forward Conducting Mode. In the first case, only a very small leakage current flows so that power dissipation in the device is not important. In the second case, the forward voltage is more than a volt so considerable power may be dissipated in the device, but provided the heat is extracted efficiently the junction temperature will not exceed the maximum rated value and the device will be stable.

Figure 1
Modes of Operation within the I-V characteristic of Rectifiers.



Further limitations apply when the rectifier is switched from conducting a large forward current to blocking a large reverse voltage. During a time after switching, the current that flows in the reverse direction greatly exceeds the reverse leakage value. Even if the delay in establishing the blocking condition is not important in the application, the additional power dissipated may cause the device to overheat and eventually fail. The recovery time depends strongly on the forward current before switching but standard conditions have been established to measure the Trr parameter (Typically: I_F=0.5A switched to I_R=1A at t=0 and recuperation defined has having occurred when I_R=0.25A). On the basis of this value, different p-n junction designs can be divided into families as shown in Figure 2. In heavy duty switching applications, Fast or even Ultrafast rectifiers may be required to function properly or, in the worst cases, to avoid destructive failure. Note that this switching speed protection is at the cost of a higher voltage drop in the forward direction.

Figure 2
Names of families of Rectifiers as a function of the value of Trr.



Avalanche Mode

Irrespective of recovery time, if the voltage is excessive in the reverse direction in any of these rectifiers, the Avalanche Mode is entered. The current can increase rapidly and significant power can be dissipated in the device. Standard rectifiers are not designed to handle such dissipation and may fail. To ensure that this does not happen in circuits with capacitances that can charge to the peak applied voltage (V_p), it is common practice to use rectifiers with $V_{rrm} \geq 2V_p$. In circuits with inductances however, this choice may not be sufficient to prevent Avalanche in the device. Diodes designed to suppress voltage spikes are designed to operate under these conditions.

Applications of Avalanche Diodes

In electronic circuits that regulate the power delivered to inductive loads (relays, motors, lamp ballasts, etc) by switching, special precautions are required to deal with the energy stored in these inductances.

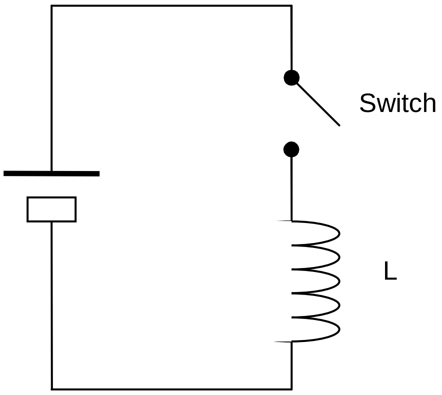


Figure 3
Schematic circuit for power regulation to an inductive load by switching.

When the switching element (Transistor, Thyristor, Relay etc) is closed (t=0 Fig. 4) the supply voltage is immediately applied across the load. The inductance restricts the rate at which the current increases exponentially until it is limited by the internal resistance of the coil (R). The time constant is given by R/L.

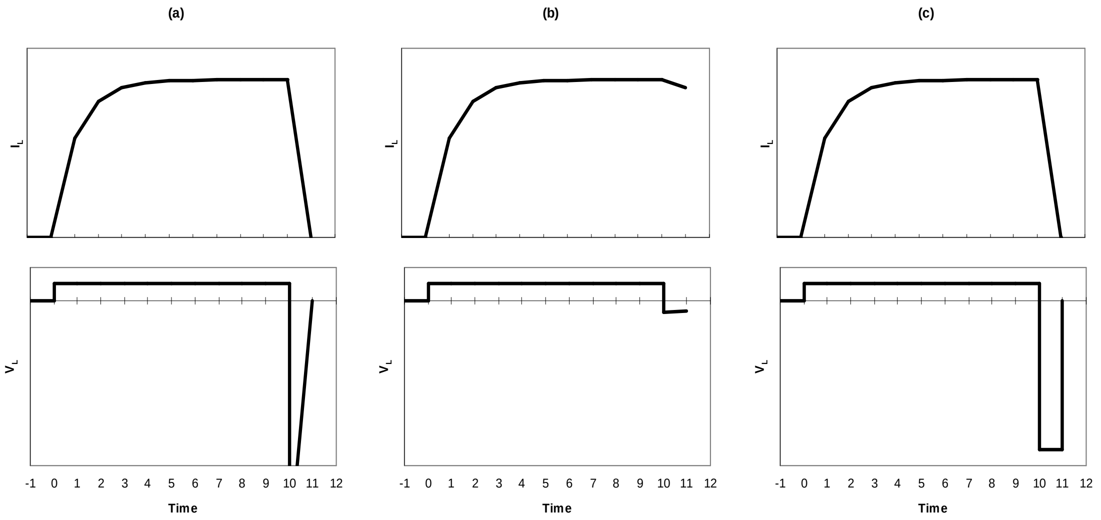


Figure 4
The current and voltage in an inductive load switched on at t=0 and off at t=10 for an inductive load (a), the corresponding graphs for a circuit with a flyback diode (b) and those of one with an avalanche diode (c).

The energy stored in the inductance is determined by the inductance and the current flowing through it prior to switching.

$$E_R = \frac{1}{2} L I^2$$

When the switch is opened, the supply is removed but the inductance generates a back emf or ‘flyback´ to prevent the current dropping to zero.

$$V_R = -L \frac{dI}{dt}$$

The energy stored in the inductance forces it to act as a voltage source. Notice that the magnitude to the voltage is not limited as it would be in the case of energy stored in a capacitance. This voltage is negative and increases until eventually arcing occurs, usually across the switching device (Fig 4a). Not only is the switching element likely to be damaged but this arcing will also cause energy to be radiated as electromagnetic noise.

To avoid such arcing it is common practice to connect a diode across the inductive load. This 'flyback' diode prevents the appearance of the flyback voltage by allowing the current to continue to flow in the inductance after it has been switched off. The surge voltage is limited to the forward voltage drop across the diode.

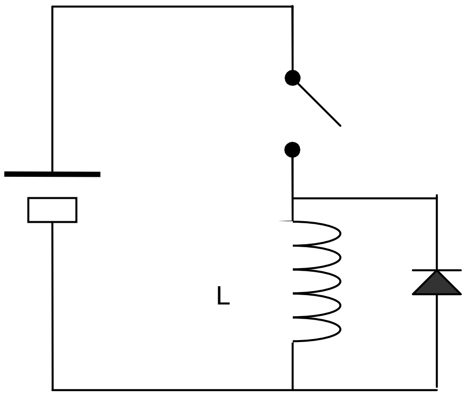


Figure 5
Schematic circuit with a flyback diode connected across the inductance.

The energy is dissipated very slowly in R and in the forward-biased diode (Fig. 4b).

In cases where the time taken to dissipate the inductively stored energy must be short, rather than preventing the flyback voltage, it can be controlled. The voltage surge can be suppressed at a value V_{BR} which, although much greater then the forward voltage drop in a flyback diode, does not damage the switching device. This allows the energy to be dissipated several orders of magnitude more quickly. This can be done by connecting an avalanche diode across the switching element. When the switch is ON, the diode is short-circuited. After switching off, the flyback voltage reverse biases the diode into the avalanche condition allowing the stored energy to be dissipated in it.

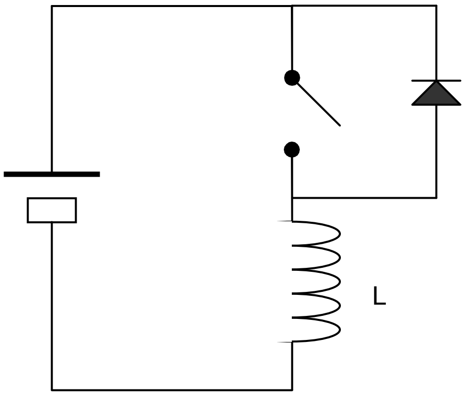


Figure 6
Schematic circuit with an avalanche diode connected across the switching element.

In order to completely dissipate the inductively stored energy, current must be allowed to flow for the time necessary.

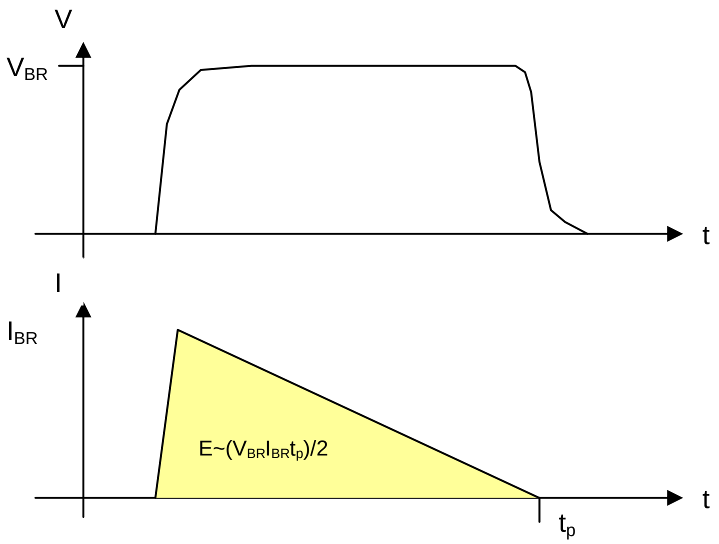


Figure 3
The dissipation of energy in a freewheeling diode when the current through the inductive load tries to turn-off.

$$E_R = \frac{1}{2} L I^2 = \frac{1}{2} V_{BR} I t$$

$$t = \frac{LI}{V_{BR}}$$

An additional feature of Avalanche diodes is that they can be connected in series with confidence that the power dissipated when the chain reaches the avalanche condition will divide fairly evenly among the individual diodes and the total energy that can be safely dissipated and the total VBR that the switching device must withstand will be close to the sum of those of the individual diodes in the chain.

Notice that in the simple schematic of Fig. 6 the Avalanche Diode is never forward biased. Under these circumstances a standard Avalanche Rectifier is adequate. On the other hand, Fast devices should be chosen in switching applications where the Avalanche Diode must also pass large forward currents.

Avalanche Diode Chip Design

The Avalanche mechanism occurs when the electric field in a reverse biased p-n junction reaches values that accelerate mobile carriers sufficiently that they generate more mobile carriers. The passage of current at those points where avalanche initially occurs is initially stable and reversible. When the cores of these regions heats so much that more carriers are generated thermally, a regenerative process called ‘thermal runaway’ leads to local melting of the silicon and to destruction of the device.

In order to maximise the capacity of the device to operate stably under Avalanche conditions it is necessary to optimise both the level and homogeneity of the semiconductor doping at the junction. In addition, it is necessary to take special precautions at the junction terminations to ensure that the area of the chip in which avalanche initially occurs, is as great a fraction of the chip area as possible.

In this way, the much longer pulses of voltage and current can be sustained across the device and more inductively stored energy can be safely dissipated without damaging the device. In Figure 4 a general purpose rectifier is compared with the new avalanche rectifier.

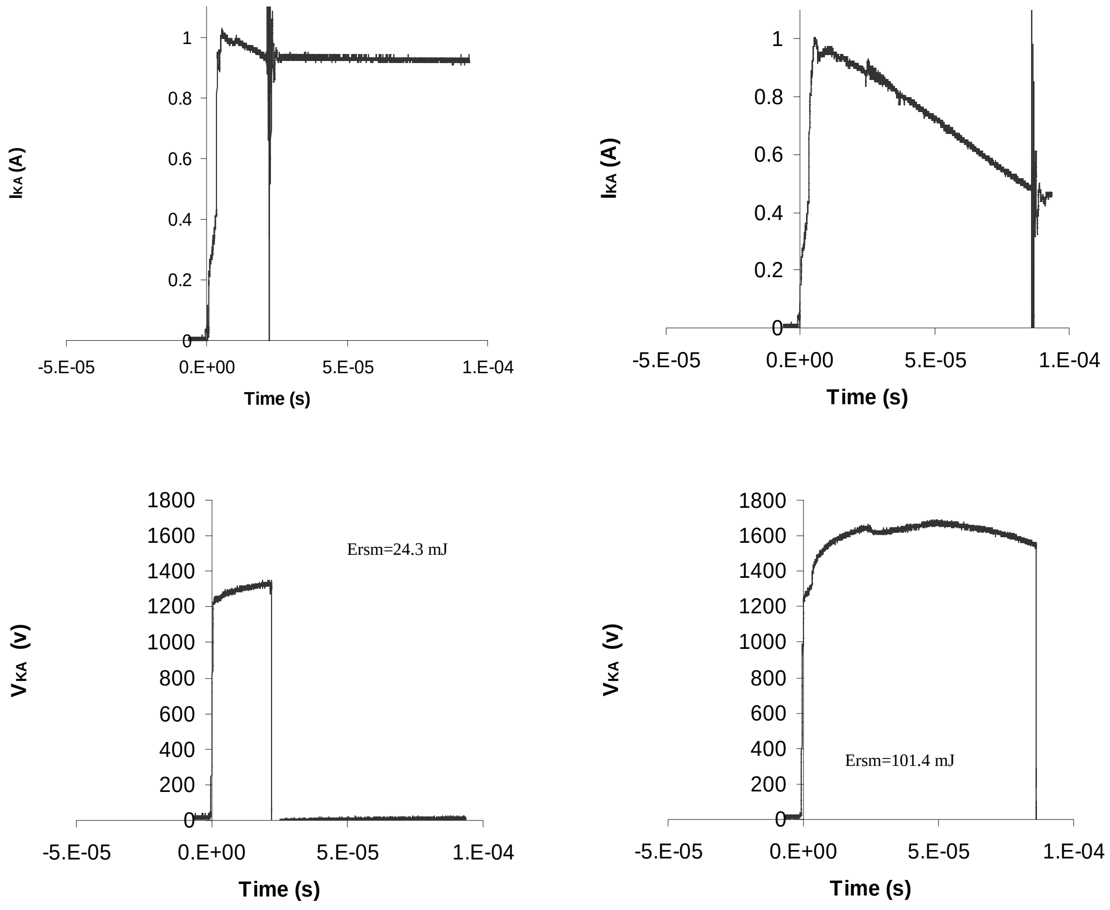


Figure 4. The voltage across (above) and the current through (below) a during the discharge of inductively stored charge. The measurements for a general purpose ultrafast rectifier (FUF4007) are shown on the left and those of the new Avalanche Rectifier design (FES1M) are shown on the right

Fagor Avalanche Diodes

Fagor have developed a range of Avalanche Rectifier diodes. Both Standard (Trr>500ns) and Ultrafast (Trr<100ns) for use in applications were the forward current prior to switching is small and large respectively.

FAMILY	PRODUCT	Ersm (mJ)	I_F	I_{FSM}	V_{RRM}	V_F(1A)	T_{RR} (ns)	OUTLINE
ULTRAFAST	FES1A	20	1	30	50	0.95	50	SMA/DO214AC
ULTRAFAST	FES1B	20	1	30	100	0.95	50	SMA/DO214AC
ULTRAFAST	FES1D	20	1	30	200	0.95	50	SMA/DO214AC
ULTRAFAST	FES1F	20	1	30	300	0.95	50	SMA/DO214AC
ULTRAFAST	FES1G	20	1	30	400	1.25	50	SMA/DO214AC
ULTRAFAST	FES1J	20	1	30	600	1.25	50	SMA/DO214AC
ULTRAFAST	FES1M	20	1	30	1000	1.5	120	SMA/DO214AC
STANDARD	FS1GE	30	1	30	400	1.1	1800	SMA/DO214AC
STANDARD	FS1JE	30	1	30	600	1.1	1800	SMA/DO214AC
STANDARD	FS1KE	30	1	30	800	1.1	1800	SMA/DO214AC
STANDARD	FS1ME	30	1	30	1000	1.1	1800	SMA/DO214AC
STANDARD	GP10AE	30	1	30	50	1.1	1800	DO41
STANDARD	GP10BE	30	1	30	100	1.1	1800	DO41
STANDARD	GP10DE	30	1	30	200	1.1	1800	DO41
STANDARD	GP10GE	30	1	30	400	1.1	1800	DO41
STANDARD	GP10JE	30	1	30	600	1.1	1800	DO41
STANDARD	GP10KE	30	1	30	800	1.1	1800	DO41
STANDARD	GP10ME	30	1	30	1000	1.1	1800	DO41

Table 1. Summary of the new Fagor range of Avalanche Diodes Fagor

Conclusions

Fagor now offers rectifiers in both standard and fast versions that are capable of operating under avalanche conditions. These devices will ensure the correct operation of applications in which the inductively stored energy would otherwise lead to destruction of the rectifier itself or some other more fragile component. These devices can easily be combined to provide the necessary protection.