TOSHIBA

APPLICATION NOTE
M-1

Magnetic Amplifier Regulation of Switch Mode Power Supplies

Introduction

The magnetic amplifier method employs saturable reactors to control electric power. A saturable reactor consists of a wire wound toroidal core with square-shaped magnetic hysteresis characteristics (i.e. Saturable Core).

Consider a saturable reactor, with a hysteresis curve as shown in Fig. 1, in a circuit with voltage applied. When the magnetization of the saturable core is in the region where the hysteresis curve inclines (i.e. unsaturated) the inductance of the reactor is very high and thus the current does not flow (OFF state). However, when it is in the nearly horizontal region (i.e. saturated) the inductance is very low and the current flows (ON state).

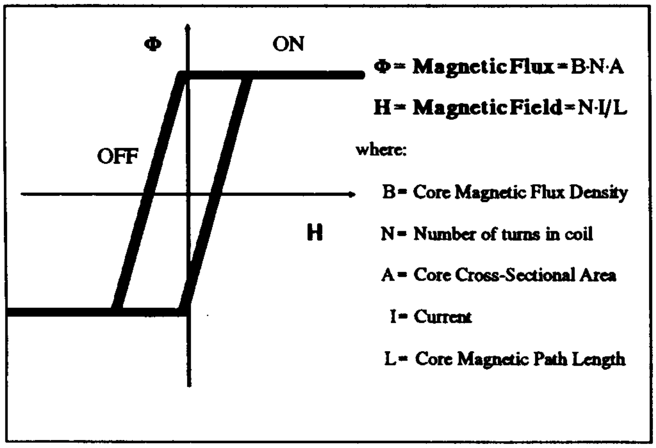

Figure 1
Magnetic Hysteresis of an Ideal Saturable Reactor

The magnetic amplifier-regulated switch mode power supply is a switching power supply that employs this magnetic switch mechanism to the PWM (Pulse Width Modulation) control element, and is therefore also known as Magnetic PWM.

Let us now suppose that a voltage pulse, X μsec wide, is applied to the saturable reactor. Consider Figure 2. Even if the pulse current is closed and opened repeatedly, the magnetized state only varies between point A (corresponding to the peak value of current) and point B (corresponding to zero current or zero magnetic field). The reactor remains in the ON state. However, when a reverse voltage is applied, a weak current flows in the reverse direction to the saturable reactor (reset current), the magnetization moves to point C, and the reactor assumes the OFF state.

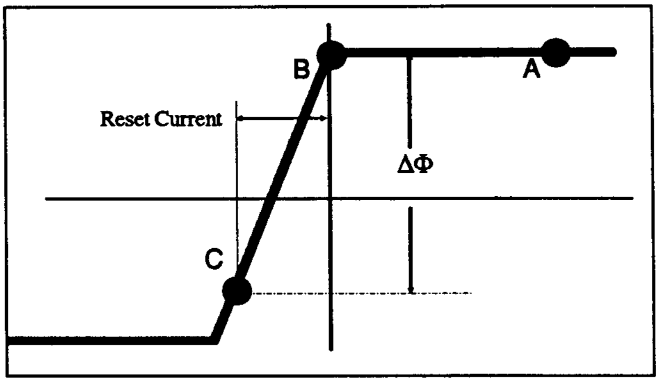

Figure 2
Operation of an Ideal Saturable Reactor

When a voltage, V, is applied to the reactor in the forward direction under this last condition, the current does not start to flow immediately. As shown in Figure 3, the rising time is delayed by ΔT through the relation:

$$\Delta T = \Delta\Phi / V$$

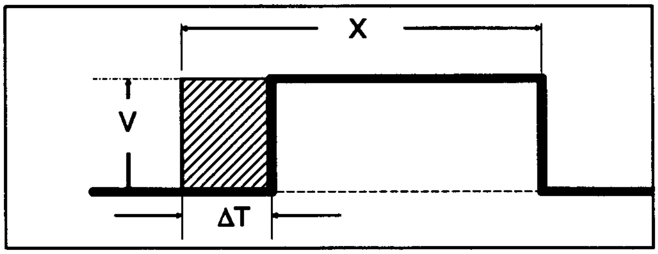

Figure 3
Delay of Voltage Rise due to ΔΦ

Thus ΔΦ, and hence ΔT, is controlled by the reset current, and PWM can be performed. If $X \leq \Delta T$, the current does not flow. Thus, ideally, PWM can be performed between 0 and 100% by controlling ΔΦ of the saturable reactor.

Fig. 4 shows the hysteresis curve of an actual saturable core. B_m denotes the maximum magnetic flux density, B_r the residual magnetic flux density, and H_c the coercive force. B_r / B_m is defined as the squareness ratio.

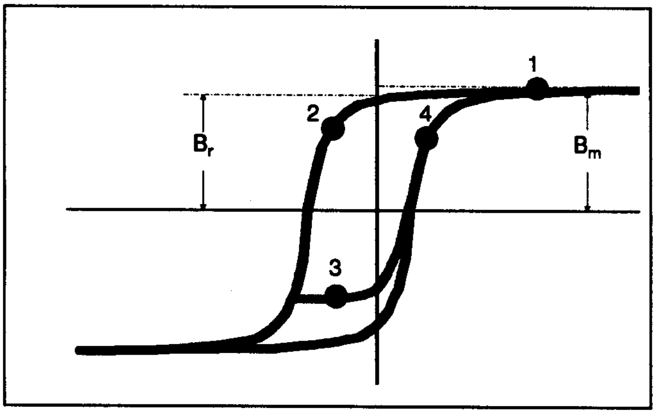

Figure 4
Magnetic Hysteresis of a Real Saturable Core

Since the values of B_m and B_r are not equal in actual cores, even if the reset is not applied, the magnetic flux changes by the difference between B_m and B_r (i.e. $B_m - B_r$), which causes a delay in the rise time as shown in Fig. 5. This so-called dead angle refers to uncontrollability. (For frequencies greater than 50 kHz, the dead angle is significantly influenced by the recovery characteristics of the rectifier.) In order to decrease the dead angle it is necessary to enhance the squareness ratio and to select a high speed rectifier (i.e. short recovery time).

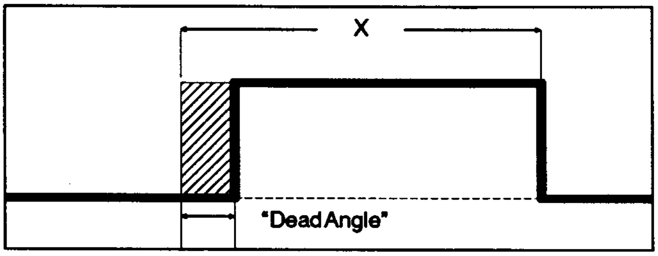

Figure 5
Dead Angle

If the coercive force is small, the reset current will be small. In addition, when this core undergoes a magnetic flux density change ΔB, it repeats the locus of points 1 ⇒ 2 → 3 ⇒ 4 ⇒ 1 (see Fig. 4). The area enclosed by these points indicates the core loss (iron loss) which leads to heat generation and/or a power supply efficiency drop. The coercive force should therefore be as small as possible to minimize core loss.

In summary, the ideal core for a magnetic-amplifier should have a high squareness ratio and a low coercive force. **Toshiba MS series Amorphous Saturable cores outperform 80 Ni Permalloy cores in both characteristics.**

Advantages of Mag-Amps

With a Magnetic-Amplifier (magnetic PWM system), unlike semiconductor PWM systems, regulation takes place at the secondary side of the output transformer. This makes it suitable for regulating each circuit of a multiple output power supply.

There are other secondary side regulation systems (e.g. Buck Converter, 3-terminal regulator, etc.) but unlike these, magnetic amplifiers offer the following advantages:

- ☐ **High Efficiency** -- The regulation circuit is simple, there is little resistive loss and little electric power is required for control which provides high efficiency.
- ☐ **High Reliability** -- Because it regulates by coils, there is no damage from instantaneous overload. Circuit design can be based upon average electric power, even for cases of large load variation, which leads to a more efficient design.
- ☐ **Low Noise and Diode Protection** -- The Saturable reactors act as Noise Suppressors by decreasing the dI/dt of reverse recovery current as well as current and voltage spikes. In this way they also protect the diodes.

In Touch with Tomorrow
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