

The proper size "AMOBeads™" core is selected by calculating the necessary voltage times the time in seconds (=flux). From its operating theory, there is a need to increase the voltage used in the calculation by that which develops during the reverse recovery period of diode. The multiple of the voltage and time (voltage times second) is equal to the operating flux. Therefore, the magnetization  $\Delta\phi$  ns necessary to suppress the noise is calculated by the voltage  $E_c[V]$  and time for reverse recovery of diode, that is added to "AMOBeads™"

$$\Delta\phi_{ns} [Wb] = E_c \times t_{rr} [V \times Sec]$$

A good result is achieved when the voltage  $E_c$  added to "AMOBeads™" is close to voltage added to diode. Please select the "AMOBeads™" that have a larger core magnetization  $\phi_c$  than the voltage times seconds that was calculated here. However, the actual noise suppression result for "AMOBeads™" on real circuit may differ from the calculated value due to the peculiar recovery characteristics of the diode used or the circuit structure. So please confirm the effect by performing examination. "AMOBeads™" can be also affected by things like a CR snubber, so please perform evaluation under condition without any effect of a snubber.

Since "AMOBeads™" have high circuit voltage, sometimes an insufficient result is obtained when the reverse recovery time is long and has minimal magnetization. Under this condition, please consider a wire wound type "SPIKE KILLER™"

## Example of "AMOBeads™" Selection

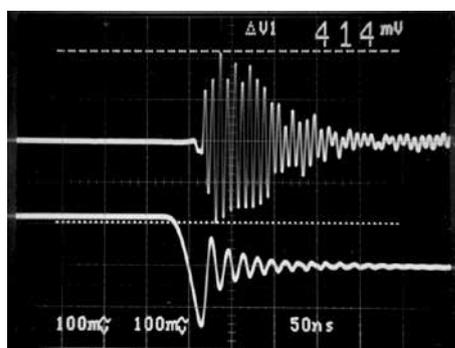
### Forward Converter

t <sub>rr</sub>	Output Voltage				
	3.3V	5V	12V	15V	24V
35nsec	AB3×2×3W	AB3×2×4.5W	AB3×2×6W	AB4×2×4.5W	AB4×2×6W
60nsec	AB3×2×4.5W	AB3×2×6W	AB4×2×4.5W	AB4×2×6W	SPIKE KILLER

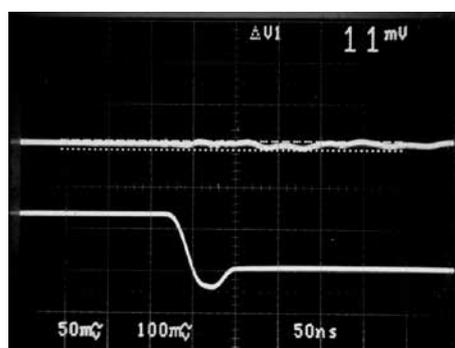
### Flyback Converter

t <sub>rr</sub>	Output Voltage				
	3.3V	5V	12V	15V	24V
35nsec	AB3×2×3W	AB3×2×3W	AB3×2×4.5W	AB3×2×6W	AB4×2×4.5W
60nsec	AB3×2×3W	AB3×2×4.5W	AB3×2×6W	AB4×2×4.5W	AB4×2×6W

## Example of Noise Reduction



Without Countermeasure



With AMOBeads  
(AB4×2×8W)

# Principle of the Noise Suppressing Device

We will explain the behavior of "AMOBeads™" when slipped over the lead of a switching power supply output diode.

## Period I, O (When Diode is On)

During period I, which is when the diode is in the "ON" condition and the forward current is running, the "AMOBeads™" are in the saturated magnetic condition "I". There will be almost no inductance under this condition. (Inductance is proportional to the slope of the B-H curve.)

## Period II (When Diode is Turn Off)

During period II, which is when the diode current starts to turn off and the current decreases heading towards zero, the "AMOBeads™" magnetization curve will change like "II" in a condition of almost no inductance until the current crosses zero. Since there is no inductance during this period II, the angle or slope of the diode current during turn off is constant, a unique characteristic of the "AMOBeads™". If materials such as ferrite is used, inductance will occur during this period II and the angle or slope of current during the turn off period will change and this will lead to increased diode loss.

## Period III (Reverse Recovery Period)

During period III, a reverse recovery current tries to flow in a direction opposite to the normal direction of current flow of the diode and as a result, the magnetization curve of the "AMOBeads™" change like "III" and the inductance increases rapidly. At this time, the large inductance of the "AMOBeads™" intercepts and opposes the recovery current and converts the current into a soft recovery condition. Thus by converting the sharp reverse recovery to a soft recovery condition by decreasing the rate of the current change ( $di/dt$ ), the "AMOBeads™" minimize the rapid change of current (High  $di/dt$ ) and suppress the noise in the circuit.

## Period IV (After Reverse Recovery Ends)

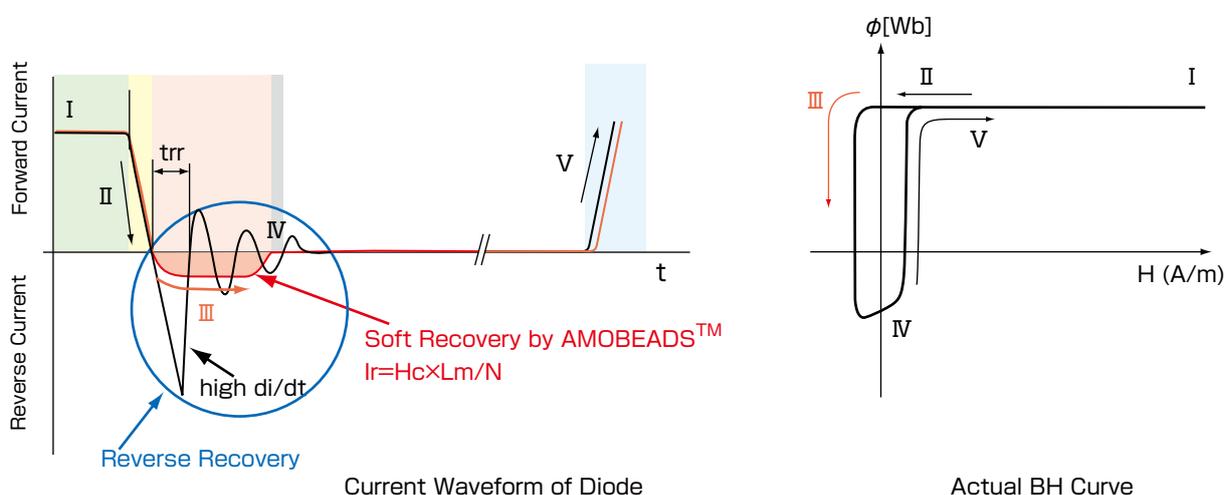
During period IV, when the reverse recovery of the diode ends, the magnetization of the "AMOBeads™" will move parallel to the vertical axis of the magnetization curve as shown in period "IV".

## Period V (When Diode is Turn On)

The "AMOBeads™" magnetization will change as shown in "V" of the magnetization curve and go back to a saturation condition. At this point, the diode will turn on and after a slight delay of the start up of current, the next current pulse will develop and the cycle described above from Period I thru V will repeat itself.

As the complete cycle repeats itself at the circuit operating frequency, the "AMOBeads™" repeatedly suppress circuit noise during period III of the cycle by eliminating the rapid change in the reverse recovery current of the diode, which is the cause of noise.

"AMOBeads™" use a cobalt based amorphous alloy with a small coercive force under frequency and this results in excellent noise suppression.



The Mag-Amp method is a switching regulation method for D.C power supply in which the magnetic switch is created through using saturated area and unsaturated area of the saturable core. Voltage regulation at the secondary side of the switching supply is realized by P.W.M. (Pulse Width Modulation).

**Period I (Pulse is on)**  
 When the "ON" pulse is from the main transformer, the flux changes as "I" on the actual magnetization curve. At this time, the saturable core has very high inductance because the core's magnetization is in an unsaturated area. When voltage is added, it is handled at both ends of the coil and the current does not flow toward the side with the current load. During Period "I", the voltage is blocked with the switch OFF, and the pulse width modulation is done.

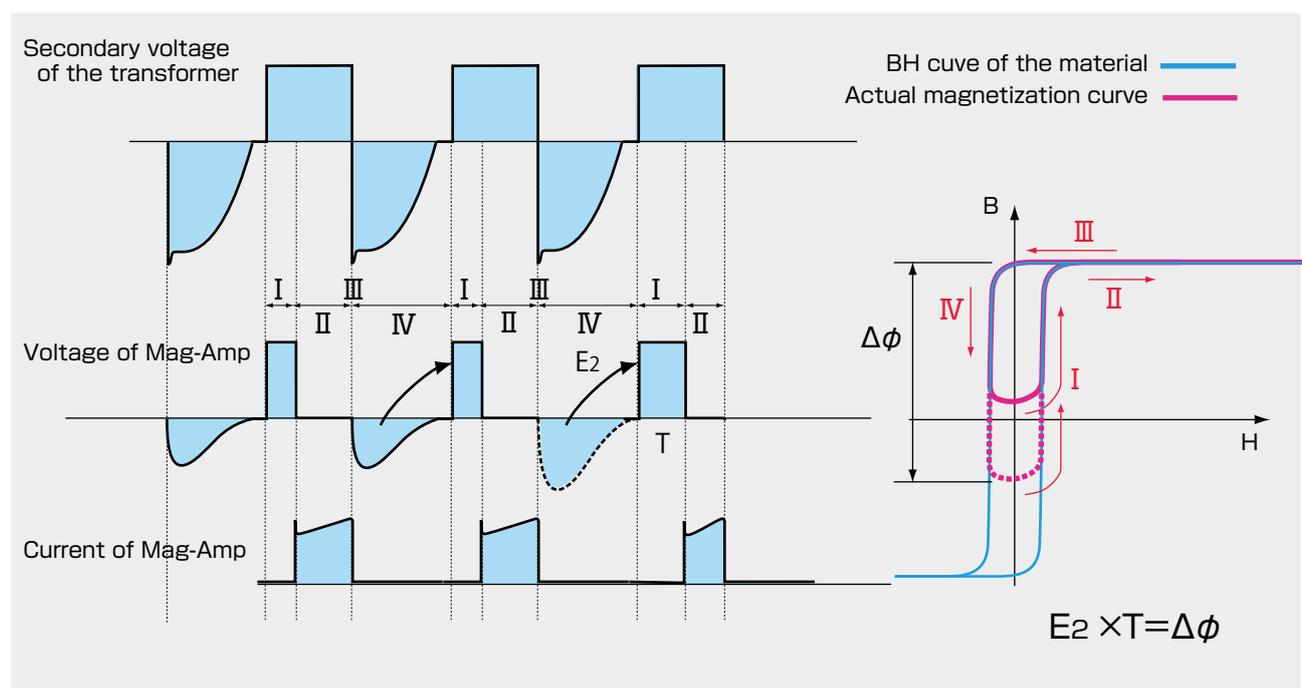
**Period II (Mag-amp is saturation)**  
 After some time at Period I, the saturable core becomes saturated "II" and the inductance rapidly decreases to a minimum and the current is supplied toward the load side. The switch is ON in Period II.

**Period III (Pulse is off)**  
 When the pulse from the main transformer is OFF (Period III), the magnetic curve of the saturable core changes as in III. It rises over the magnetization axis from the effects of the reverse recovery current and leaked current of the output diode.

**Period IV (Reset)**  
 While the polarity of the pulse voltage is reversed (Period IV), there is voltage control which corresponds with the preset output voltage by the Mag-amp control circuit. The saturable core's magnetization changes (resets) itself as in "IV".

Period I~Period IV is operated repeatedly through the operated frequency and the voltage is regulated.

The reset area at Period IV and the area at Period I is equal. Therefore, by changing the reset amount at Period IV, the blocked area at Period I can be changed, and it becomes possible to regulate voltage by magnetic P.W.M.



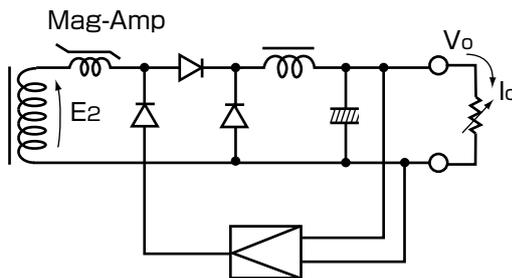
# Mag-Amp Design (Forward Converter)

The standard methodology for designing and selecting the proper size mag-amp is to first determine the product of the secondary voltage of the transformer and the "on duty" time, measured in seconds. The proper size mag-amp can then be selected by determining which mag-amp core can adequately handle the highest product of this secondary voltage and "on duty" time, otherwise known as core flux. All calculations must be made on the condition that this on-pulse product of voltage and time is at its maximum.

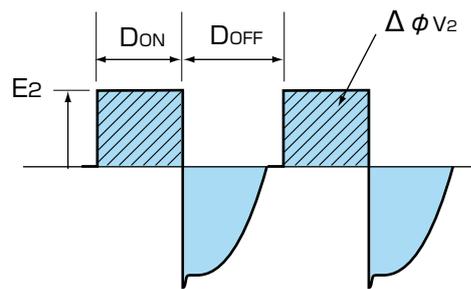
## ☆ On-pulse maximum product of time

The on-pulse maximum product of time  $\Delta \phi v_2$  is calculated from the secondary voltage of the transformer ( $=E_2$ ) [V] and the maximum on time duty period ( $=D_{ON}$ ) and operating frequency ( $=f$ ) [Hz]. For cross-regulation type circuits, the on-duty values for the main circuit at maximum load current are usually used.

$$\Delta \phi v_2 \text{ [Wb]} = E_2 \times D_{ON} / f \text{ [V} \times \text{Sec]}$$



Mag-Amp circuit of the secondary side



Transformer voltage of the secondary side

## ☆ Flux needed for mag-amp control

The calculation of the Voltage-time product ( $=$ Magnetic Flux)  $\Delta \phi_{mag}$  differs between when the mag-amp is used for voltage regulation only and when the mag-amp is also used to protect against over currents.

### (1) Voltage regulation

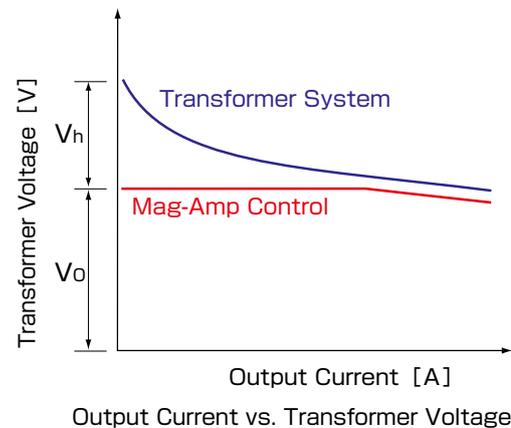
The mag-amp is designed with the standard of no load, because the flux deviation is usually largest when there is no load. The coefficient for the incremental increase in voltage at no load ( $K_v$ ) is used. ( $K_v < 1$ )

$$\Delta \phi_{mag} = \Delta \phi v_2 \times K_v \text{ [Wb]} \quad \left[ K_v = \frac{V_h}{V_o} \text{ see right figure} \right]$$

### (2) Protection of over currents

When the mag-amp is also used to protect against over-currents, the on-pulse maximum voltage-time product  $\Delta \phi v_2$  must be handled by the mag-amp. Therefore, the following calculation is applied.

$$\Delta \phi_{mag} = \Delta \phi v_2 \text{ [Wb]}$$



Output Current vs. Transformer Voltage

## ☆ Selection of core size

The core size is selected based on the flux needed to control the mag-amp,  $\Delta \phi_{mag}$ . The following simplified calculation is used to select core size.

$$\phi C \cdot A_w \geq \Delta \phi_{mag} \times I_o / (K_f \times J) / K_t \text{ [Wb} \cdot \text{mm}^2]$$

Here,  $\phi C$  is the total flux of the core and  $A_w$  is the core winding area. The values for  $\phi C \cdot A_w$  are found in the standard specification chart.  $K_t$  is the design safety coefficient;  $K_f$  is the coefficient for wire winding, and  $J$  is the current density.

## ☆ Calculation of Number of Turn

The number of turns ( $N$ ) is calculated by the following equation, where  $N$  is an integer.

$$N \geq \Delta \phi_{mag} / \phi C_{min} / K_t \text{ [turn]}$$

## ☆ Calculation of Diameter of the Wire

From the equation for current density  $J$  [A/mm<sup>2</sup>], wire diameter  $d$  [mm], output current  $I_o$  [A],

$$I_o = (d/2)^2 \times \pi \times J \text{ [A]} \rightarrow d = 2 \times \sqrt{I_o / (\pi \times J)} \text{ [mm]}$$

Please always confirm operation on the actual circuit after design.

## Examples of the Design

Here, we show a design example when regulating a 5V-10A circuit using a forward converter with an operating frequency of 150kHz.

### ☆On-pulse maximum voltage-time product

The  $E_2$  on the secondary side of the main transformer and the maximum on duty cycle are assumed to be  $E_2=15[V]$  and  $D_{on}=0.4$ .

$$\begin{aligned}\Delta \phi_{v2} &= E_2 \times D_{on} / f \text{ [V} \times \text{Sec]} = \text{[Wb]} \\ &= 15 \times 0.4 / 150000 \\ &= 40 \text{ [}\mu\text{Wb]}\end{aligned}$$

When using a Mag-amp to also protect against over currents,  $\Delta \phi_{mag} = \Delta \phi_{v2}$ . Here, we assume that the mag-amp only regulates voltage and set the incremental increase at the time of no current load as  $K_v=0.6$ .

$$\Delta \phi_{mag} = \Delta \phi_{v2} \times K_v = 40 \times 0.6 = 24 \text{ [}\mu\text{Wb]}$$

### ☆Choice of core size

The wire winding coefficient,  $K_f$ , is the coefficient that it is possible to wind on the inside of a toroidal core. Usually,  $K_f=0.4$  is used. The current density  $J$  is usually set as  $J=5 \sim 10 \text{ [A/mm}^2\text{]}$ . Here, we assume  $J=8 \text{ [A/mm}^2\text{]}$ .

If the mag-amp's maximum operating temperature is assumed to be  $120^\circ\text{C}$ , we assume that the flux density of the core decreases to 80%. We also allow flux design space to be 70%.

$$\begin{aligned}\phi_c \cdot A_w &\geq \Delta \phi_{mag} \times I_o / (K_f \times J) / K_t \\ &\geq 24 \times 10 / (0.4 \times 8) / (0.8 \times 0.7) \\ &\geq 133.9 \text{ [}\mu\text{Wb} \cdot \text{mm}^2\text{]}\end{aligned}$$

From the standard specification table, MT12X8X4.5W is chosen.

### ☆Number of wire winding

$$\begin{aligned}N &\geq \Delta \phi_{mag} / \phi_{Cmin} / K_t \text{ [turn]} \\ &\geq 24 / 6.31 / (0.8 \times 0.7) = 6.8 \\ &= 7 \text{ [turn]}\end{aligned}$$

### ☆Wire diameter

When the wire diameter is over  $\phi 1.0\text{mm}$ , there is difficulty in the actual wire winding of the toroidal cores. Therefore, when the output current  $I_o$  is over 5[A], parallel winding is used. Here, since  $I_o=10\text{[A]}$ , two parallel wires are used.

$$\begin{aligned}d &= 2 \times \sqrt{I_o / 2 / (\pi \times J)} \text{ [mm]} \\ &= 2 \times \sqrt{10 / 2 / (\pi \times 8)} = 0.89 \text{ [mm]}\end{aligned}$$

As a result, 2 parallel  $\phi 0.9\text{mm}$  wires are wound.

### ☆Results of design (Operating Frequency 150kHz, 5V-10A, Voltage Regulation)

MT12X8X4.5W,  $\phi 0.9\text{mm}$ , 2 parallel windings, 7[turn]

Please always confirm operation on the actual circuit after design. Since the mag-amp is a passive part, it becomes susceptible to effects from the waves of the transformer, and actual operating tests are necessary.

Design Example ( Forward Converter, 150kHz operating)

Current Voltage	Voltage Control (at $K_v=0.6$ )			Over Current Protection (at $E_2 \times D_{on} = 1.2V_o$ )		
	6A ( $\phi 1.0\text{mm}$ )	10A ( $\phi 0.9\text{mm} \times 2\text{p.}$ )	15A ( $\phi 0.9\text{mm} \times 3\text{p.}$ )	6A ( $\phi 1.0\text{mm}$ )	10A ( $\phi 0.9\text{mm} \times 2\text{p.}$ )	15A ( $\phi 0.9\text{mm} \times 3\text{p.}$ )
3.3V	MT12S115	MT12S208	MT12 : 5turn	MT12S115	MT12S208	MT15:7turn
5V	MT12S115	MT12S208	MT15 : 6turn	MT12S115	MT15S214	MT16:6turn
12V	MT15S125	MT15S214	MT18S311	MT15S125	MT18S222	MT21:16turn
15V	MT15S125	MT18S222	MT18 : 14turn	MT18S130	MT21S222	MT21:20turn
24V	MT18S130	MT18S222	MT21 : 19turn	MT21S134	MT21:32turn	MS26:18turn

Note) Operating flux is influenced by the main transformer of the circuit, and the value shown in the table is not necessarily applied as it is.

# Evaluation of the Mag-Amp Circuit Unit

## 1) At no-Load

Generally, the range of the flux becomes large at no, or small current load. There is a possibility that the mag-amp may not be able to control the output voltage because there is a shortage of core flux. This problem occurs because the large range of the flux density causes saturating on the other side and there is not enough ability to control the voltage-time product. In order to set the allowances for design, the wire winding for the Mag-amp is reduced and the operating range is confirmed.

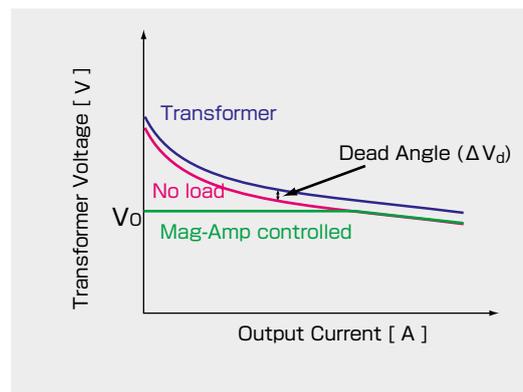
However, the core flux necessary at the time of no current load is largely influenced by such factors as the dummy current value. Therefore, when the core flux is large at no current load, such factors as the dummy current value must be adjusted, taking efficiency into account.

## 2) At Full-Load

Generally, the mag-amp's flux range becomes small at the full current load. There is the possibility that output voltage cannot be regulated because it is not possible to make the range any smaller. This problem is called the dead angle.

The allowances for design at full current load are confirmed by increasing the number of wire windings.

However, the dead angle value is influenced not only by the core characteristics, but also by the reverse recovery current of the output diode and leaked currents. Please select output diodes with fast recovery times. Also, when using SBD (Schottky Barrier Diode), please use one with small current leaks and stable temperature characteristics.



## 3) Temperature Rise

The temperature rise from no current load to full current load should be confirmed. Since the upper limit temperature for continuous use of our mag-amp saturable cores is  $120^{\circ}\text{C}$ , the mag-amp should be designed so that the sum of the surrounding temperature and core temperature rise does not exceed  $120^{\circ}\text{C}$ . Please measure core temperature rise under the condition of natural air-cooling (Without cooling fan). Generally, the mag-amp is designed calculating the temperature rise at  $\Delta T=30^{\circ}\text{C}\sim 40^{\circ}\text{C}$ .

With forward converters, the temperature rise at no current load is especially high. When this occurs, the wire winding should be increased and the operating flux density reduced. When the temperature rise is too high at full current load, the wire winding should be reduced and the operating magnetic field reduced.

## 4) Output voltage precision

It is necessary to confirm the voltage regulation characteristics (specifications) from no current load to full current load conditions. When there is a mismatch between the gain of the mag-amp and the gain of the regulated circuit, the circuit vibrates abnormally. Especially when there are sounds from the mag-amp circuit, there is a high possibility that the regulated circuit is abnormally vibrating.

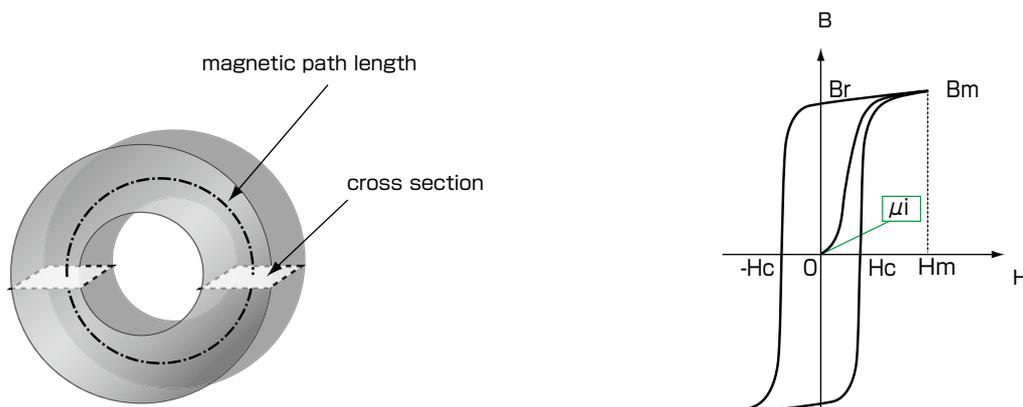
## 5) Protection from Over currents

When protecting for over currents, the range of operating flux for the mag-amp becomes large. Please set the maximum flux range to be 70% of the core flux, similar to when there is no current load.

## Technical Terms

Saturable Core	A magnetic core can be able to saturate. These cores have a high square shape ratio, and it can use magnetic saturation and magnetic being un-saturated.
Toroidal Core	Magnetic core which has doughnut shape.
Cross Section	Effective core cross section area :Ae, $A_e [m^2] = ((OD[m] - ID[m]) \times \text{height } HT[m] / 2) \times pf$
Packing Factor pf	The ratio of the absolute area of magnetic material to its geometrical area .
Magnetic Path Length Lm	Length of the magnetic circuit. In the case of the toroidal core, magnetic mean path length Lm is adopted. $L_m [m] = (OD[m] + ID[m]) \times \pi / 2$
Magnetic Flux Density B	Magnetic flux strength of the material, which is perpendicular magnetic flux of the unit area. $B[T] = \phi[Wb] / A_e [m^2]$
Magnetic Flux $\phi$	$\phi[Wb] = V \cdot \text{sec} = B[T] \times A_e [m^2]$
Magnetic Field Strength H	$H[A/m] = I [A] / L_m [m]$
Permeability $\mu$	$\mu = B / H$ . Inductance L is proportional to permeability $\mu$ .
Initial Permeability $\mu_i^{*1}$	First inclination of the initial growth of magnetic flux density B (see the illustration below)
Maximum Flux Density Bm	In this booklet, Bm is defined as the flux density at the magnetic field Hm. (see the illustration below)
Residual Magnetic Flux Density Br	Br is the flux density at the time the magnetic field return to H = 0 (see the illustration below)
Total Magnetic Flux $\phi_c$	Total magnetic flux of the core. In this booklet, total magnetic flux $\phi_c$ is defined as the following equation. $\phi_c [Wb] = 2 \times B_m [T] \times A_e [m^2]$
Rectangular Ratio Br / Bm	The ratio of the Bm and Br. Greater the rectangular ratio, the more superior the magnetic saturability. $Br / B_m = Br [T] / B_m [T]$
Coercive Force Hc	Hc is the cross point of the BH curve and X axis. Smaller the Hc, the less the loss and the more superior the Hc. (see the illustration below)

\*1 Initial permeability is out of control in the case of saturable cores, because it is unrelated to the Mag-Amp.



# Notices on Handle, Maintenance and Discontinue List

<p>Notices of the amorphous magnetic parts on handle</p> <p>Detail information are described on the technical data sheet or the specification for supply.</p>	
Maximum Operating Temperature	120°C (include temperature rising by self-heating, under natural air cooling) (except FS series which is 85°C)
Wire Winding	Be careful at wire winding or lead insertion. Damage or deformation of the core or insulating cover has a harmful influence. Be careful to the rare short circuit.
Mounting	Make sure not to apply any stresses which will lead to deformation of the core exterior. If the product is to be impregnated, bonded, cleaned or otherwise treated, confirm that such treatment will not adversely affect the magnetic characteristics. When impregnating the core, be sure that the magnetic properties will not be influenced. Prevent radiation and conduction from high temperature components from reaching the core. Be sure to consider vibration and shock when installing these parts.
Soldering	When soldering be sure that the core exterior will not be deformed by heat conducted through the lead wire. Do not subject parts to re-flow or flow soldering. (Except the surface mounting type)
Circuit Design	Be careful, of input voltage, rated current, ambient temperature and temperature rise. When revising the circuit, please recheck the core temperature rise. Recheck the maximum temperature or maximum loads.
Transport and Storage	Do not drop the parts. Protect the parts from water.

## Discontinued List

Discontinued Type No.	Substitution (recommend)
FS10X4X1	(FS12X8X4.5W)
MA7X6X4.5X	(MS10X7X4.5W)
MA8X6X4.5X	(MS10X7X4.5W)
MA10X6X4.5X	(MS10X7X4.5W)
MA14X8X4.5X	MS14X8X4.5W
MA18X12X4.5X	MS18X12X4.5W
MA22X14X4.5W	(MS26X16X4.5W)
MA26X16X4.5W	MS26X16X4.5W
MB8X7X4.5	(MS10X7X4.5W)
MB9X7X4.5	(MS10X7X4.5W)
MB10X7X4.5	MS10X7X4.5W
MB12X8X4.5	MS12X8X4.5W
MB14X8X4.5	MS14X8X4.5W

Discontinued Type No.	Substitution (recommend)
MB15X10X4.5	MS15X10X4.5W
MB18X12X4.5	MS18X12X4.5W
MB21X14X4.5	MS21X14X4.5W
MS8X7X4.5W	(MS10X7X4.5W)
MS9X7X4.5W	(MS10X7X4.5W)
MS10X6X4.5W	(MS10X7X4.5W)
MT10X6.5W	MT10X7X4.5W
SA4.5X4X3	AB5x4x3DY
SA5X4X3	AB5x4x3DY
SA7X6X4.5	(SS7X4X3W)
SA8X6X4.5	(SS10X7X4.5W)
SA10X6X4.5	(SS10X7X4.5W)
SA14X8X4.5	SS14X8X4.5W

### Attention :

Same or similar core size items are listed up for substitution. Magnetic or electric characteristics are changeable. Please test substitution parts before replacing to ensure performance.  
Wired parts made by these cores are also discontinued items.