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White Paper

Noise Suppression Using Toshiba SPIKE KILLER® and AMOBEADS®

Highlights

- Effective noise suppression
- High magnetic permeability
- Low hysteresis losses
- Low eddy current losses
- Minimal to zero PCB space

Switching power supplies offer a compact, high-efficiency power supply solution for electronic equipment. One of the challenges in switching power supply design is noise/ringing. Toshiba AMOBEADS and SPIKE KILLER provide a low-cost, highly effective solution for reducing that noise.

Noise generated in a switching power supply adversely effects surrounding components and circuits leaving open the possibility for operational errors and noise emission. There are various methods available to suppress noise including Ferrites and both Iron-based and Cobalt-based amorphous materials. AMOBEADS and SPIKE KILLER are made using Cobalt-based amorphous magnetic alloys. Their non-crystalline amorphous structure offers increased electrical resistance and when used as thin ribbons, results in significantly improved magnetic properties compared to ferrites, and have small eddy current losses. The chart below shows the clear advantage offered by Cobalt-based amorphous alloys:

This paper briefly describes how amorphous cores are made and describes a method of using SPIKE KILLER and AMOBEADS, small saturable inductors, to improve the recovery characteristics of a diode, which is a major source of output noise.

The manufacture of Toshiba amorphous cores is done by ultra-quenching, a process by which molten Cobalt-based alloy is poured onto the surfaces of rotating, cooling rollers. The rapid cooling prevents the alloy from acquiring a crystalline structure when it solidifies. The resulting ribbons are 12-µm to 20-µm thick.

These ribbons are cut and wound into a coil, which is used as the core of a toroidal coil. Each coil/core is packed in a protective, insulating polymer case. All of the Toshiba MS-, MT- and AB-series cores are RoHS compliant.

Small in diameter, AMOBEADS slip over a lead of a MOSFET or diode and will stop noise/ringing from propagating any further into the circuit. For higher levels of noise, SPIKE KILLER offer an even greater level of noise suppression. These are larger-diameter

Item	Magnetic Flux Density *1 Bs {T}	Coercive Force *1 Hc [A/m]	Magnetic Permeability *1 (1kHz)	Electrical Resistance p [u ohm cm]	Curie Temperature Tc [deg]
Ferrite	0.50	8	3000	1.00E+08	220
Amorphous: Fe - based	1.50	2.5	5000	130	415
Amorphous: Co - based	**0.60**	**0.4**	**50000**	**130**	**240**

amorphous cores that are wire wound and soldered into a circuit rather than sliding over the head of the MOSFET. Both AMOBEADS and Amorphous SPIKE KILLER maintain their magnetic permeability up to 120 °C.

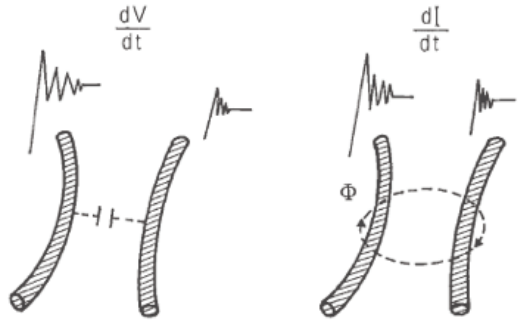
Cause of noise

Noise is generated from various sources. Spike noise, a problem in a switching power supply, is created by rapidly changing voltage or current in a switching operation and can be directly or inductively transmitted to the environment (Fig. 1). AMOBEADS and SPIKE KILLER suppress this noise by limiting rapid changes in voltage or current.

Figure 1. Noise transmission

a) electrostatic induction

b) electro-magnetic induction

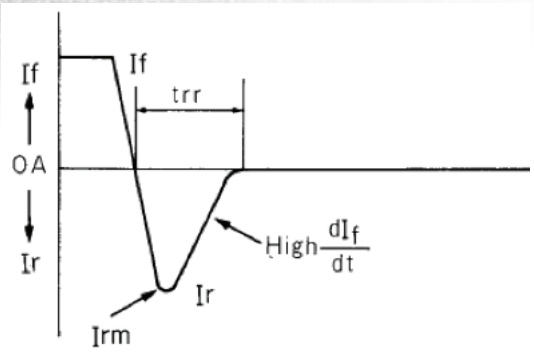


Two of the major sources of noise in a switching power supply are diodes and FETs. When a diode is reverse-biased, current flows until the carriers accumulated in PN junction in the diode disappears. This property is called the recovery characteristics of diode and the period is called reverse recovery time (trr).

Fig. 2 shows an example of diode current waveform (recovery waveform) in reverse recovery. When the diode carrier disappears, reverse recovery current (Ir) suddenly decreases creating a large current change (di/dt). This large current change is induced in the surrounding conductors via wires connected to the diode, resulting in generated noise.

Theoretically, a Schottky barrier diode (SBD) does not contain carriers so they might not demonstrate similar recovery properties. In practice, a similar waveform is observed due to the effect from junction capacity, etc. while generating noise.

Figure 2. Recovery waveform of diode



Suppression of a diode's di/dt

Generally, the recovery characteristics of a fast recovery diode (FRD) are released (for soft recovery) using an RC snubber circuit in order to reduce noise.

An RC snubber limits the switching transients and compensates for the current transient by using a condenser during diode transition from reverse conduction to cut-off condition. More effectively, a SPIKE KILLER and AMOBEADS can be connected in series with the diode or FET, this is detailed in the following paragraphs.

Using a chopper converter and forward converter, a SPIKE KILLER (SS core) was tested for the effect of improving output noise. The test results, along with the test conditions, of using the chopper converter are shown in Fig. 4 and Photo 1 on page 3. Referring to Photo 1, it is shown that the recovery waveform of the diode is improved by the SPIKE KILLER, suppressing di/dt to a lower level. It also reveals that output noise is decreased by improving the recovery characteristics of the diode.

Test results with the forward converter are shown in Fig. 6 on page 4 and Photo 2 on page 5. Like the chopper converter, the SPIKE KILLER clearly reduces output noise. In the forward converter, the transformer acts as an inductance so that noise can be effectively suppressed by using SBD. With FRD, the SPIKE KILLER is significantly more effective.

This effect might be regarded as natural because an inductance can theoretically suppress di/dt. However, its effect is not limited this much. The SPIKE KILLER provides many advantages including small core size and large L (higher permeability), saturability with smaller residual L (higher square ratio), lower core loss, etc. The SPIKE KILLER is an inductance element making utmost use of the excellent characteristics of the amorphous magnetic alloy.

AMOBEADS deliver excellent noise suppression results and are convenient to use by simply slipping over the leads of the semiconductor device. AMOBEADS are also available with a thru-hole lead and in a surface mount configuration. SPIKE KILLER, which are larger in size than AMOBEADS, most often are wire wound and are effective in minimizing higher noise levels.

Figure 3. Test circuit (chopper converter)

Test Condition

input voltage	Ein: DC15, 20, 25V
output voltage	Eo: DC 5V
output current	Io: 10A
operating frequency	f: 50kHz

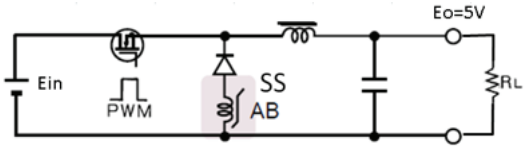
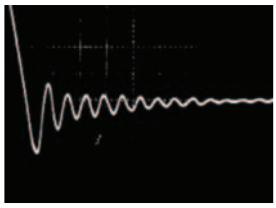
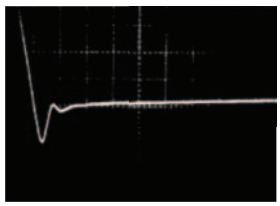


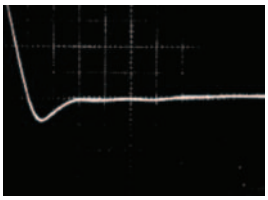
Photo 1. Recover current waveform of diode



a) without countermeasure



b) with CR snubber (0.01μF, 5.1Ω)



c) with SPIKE KILLER SS7x4x3W, 6 turn

Operation information for SPIKE KILLER

The SPIKE KILLER is a very effective element for improving di/dt when there is a large current surge. Optimum performance can be obtained by following the notes below:

1. Choice of optimum core size and number of turns

In order to improve the recovery characteristics of a diode using a SPIKE KILLER, the core saturation time (tcs) should be larger than the reverse recovery time (trr) of the diode. In addition, it should be noted that trr becomes larger by connecting a SPIKE KILLER.

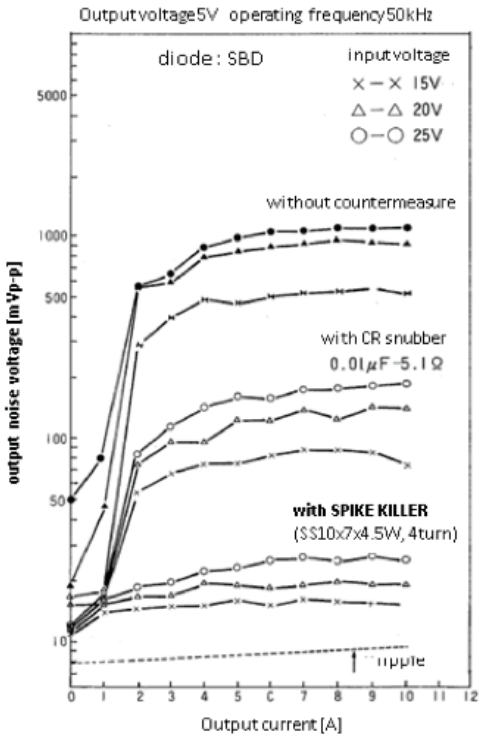
The SPIKE KILLER has an optimum core size and number of turns for a particular use. Referring to Fig. 7 on page 5, the noise reduction effect of the SPIKE KILLER is saturated beyond a certain number of turns. Conversely, the surge voltage arising in VDS of a switching FET increased with an increasing number of turns, thereby creating lower power efficiency. This makes it preferable to use the SPIKE KILLER with a minimum number of turns and minimum core size. Optimum conditions can be determined via experimentation and observing the recovery waveform.

As an example, refer to Photo 2 (b) on page 5: 2(b) shows the effect of using a only a CR snubber while (c) and (d) are completely recovered using AMOBEADS and a SPIKE KILLER respectively. When selecting the core size and the winding, selecting the smallest core that delivers the desired level of suppression will generally provide better overall results in the circuit.

2. Relation between SPIKE KILLER and diode reverse recovery time

The size of the SPIKE KILLER to be selected depends on the trr of diode as well as other circuit conditions. The use of a slow diode with a large trr results in large core and more winding. A slow trr may create a large surge voltage or reduction in power efficiency so it is generally preferable to use the highest speed diode possible.

Figure 4. Output noise characteristics



3. Joint use with CR snubber

The recovery characteristics of a diode can be sufficiently improved by using the SPIKE KILLER alone, however, certain circuit conditions may require the combination of a SPIKE KILLER and RC snubber. Fig. 8 shows various combinations together and their effect.

4. Maintain core temperature lower than 120 degrees

Extended use at temperatures greater than 120° C can deteriorate the magnetic characteristics of the amorphous magnetic alloy.

5. Conclusion

The SPIKE KILLER and AMOBEADS can suppress a current surge and reduce noise effectively by being connected in series with a diode or FET. A SPIKE KILLER or AMOBEADS used in combination with an RC snubber, can bring about the largest noise reducing effect.

Noise generated by a switching power supply should be comprehensively analyzed and then reduced by various methods that include the suppression of external or back noise using a noise filter, the reduction of voltage spikes using an RC snubber or surge absorber, prevention of voltage spike transmission using electrostatic shield or bypass condenser, etc. Of course, using only the SPIKE KILLER will not completely prevent noise. However, the SPIKE KILLER can easily reduce current spikes, which can be generated by switching power supplies.

6. Number of windings

The number of windings applying to SPIKE KILLER are obtained by the following equation.

$$N = 3 \times trr \times Ec / \phi c \ [turn]$$

N[turn]: number of windings
trr[sec]: diode revers recovery time
Ec[V]: additional voltage of diode
ϕc[uWb]: total flux of core

7. Precautions

(1) The voltage across the switching transistor at primary side might become higher when using the SPIKE KILLER. Care should be taken to avoid this condition.

(2) The temperature rise at the core may become large during operation of the SPIKE KILLER, if this occurs, reduce the number of windings.

Figure 5. Test circuit (forward converter)

Test Condition

input voltage	Ein: AC100V
output voltage	Eo: DC 5V
output current	Io: 8A
operating frequency	f: 150kHz

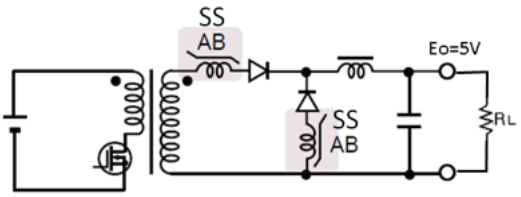
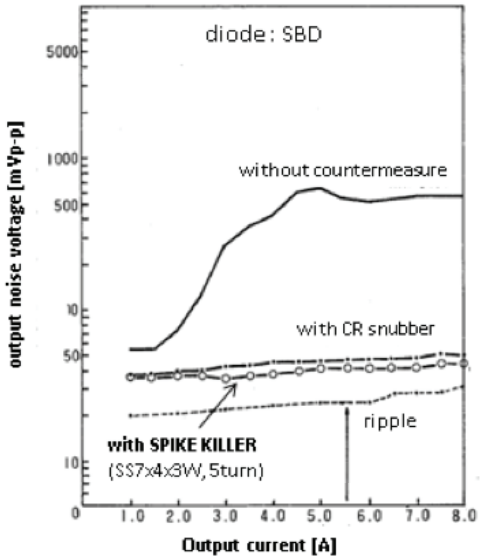
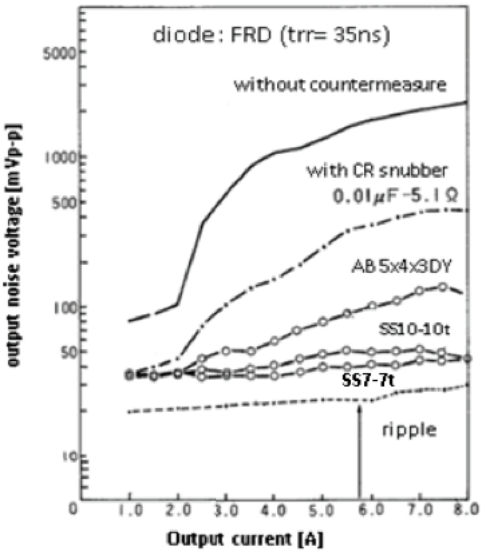


Figure 6. Output noise characteristics (Forward converter)



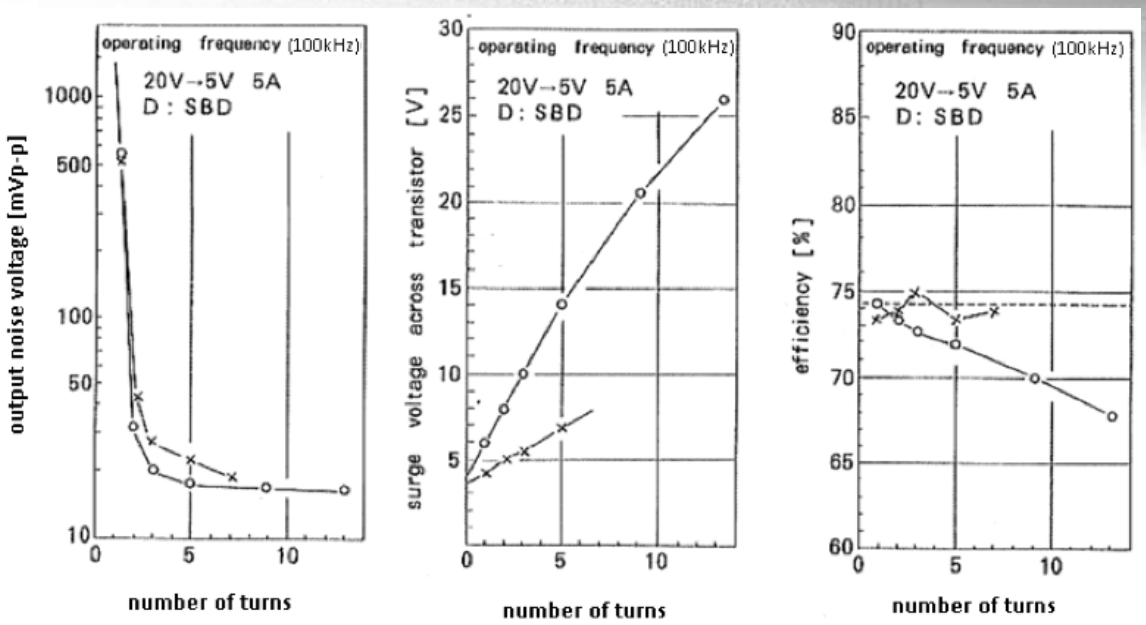
6-1) Schottky barrier diode



6-2) Fast recovery diode

Figure 7. Variation of some characteristics with number of turns

Chopper converter (Ein=20V, Eo=5V, Io=5A) • SS7x4x3W ×AB5x4x3DY



7-1) Output noise 7-2) Surge voltage 7-3) Efficiency

Photo 2. Recovery current waveform of diode (Forward converter I : 0.5A/div t : 50nsec/div)

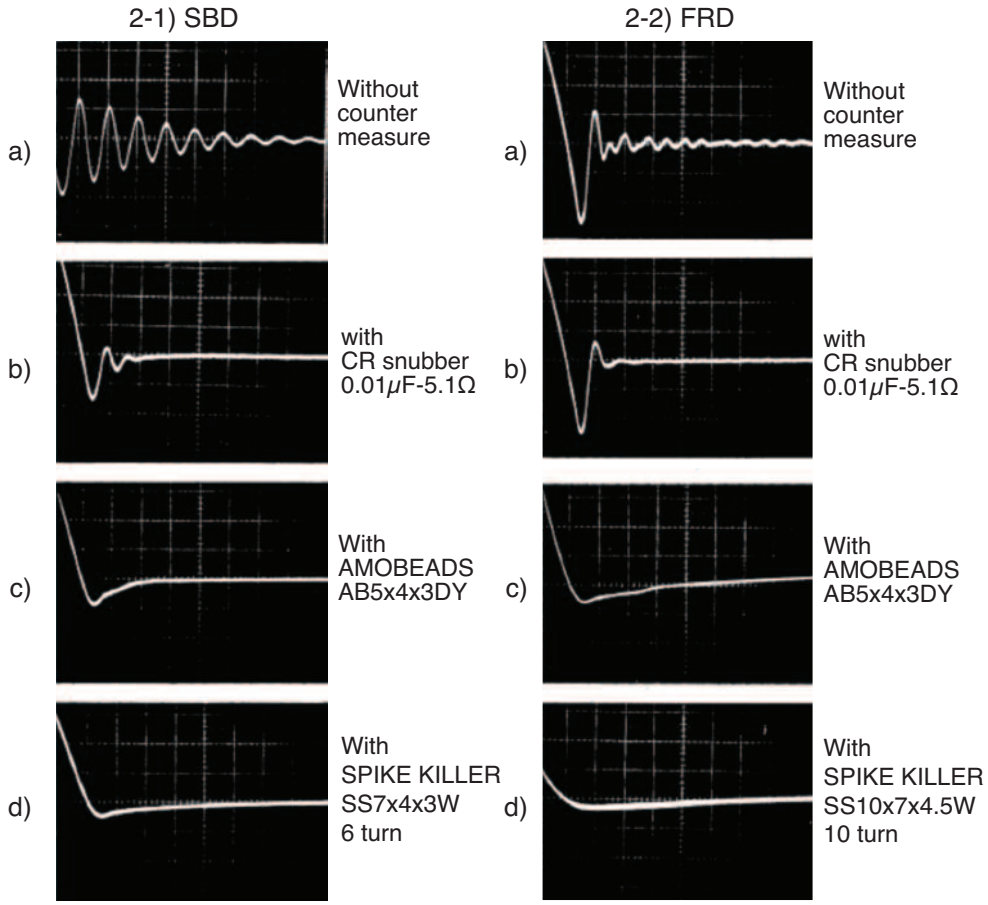


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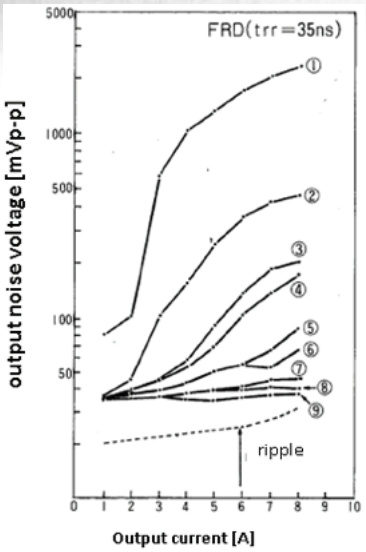
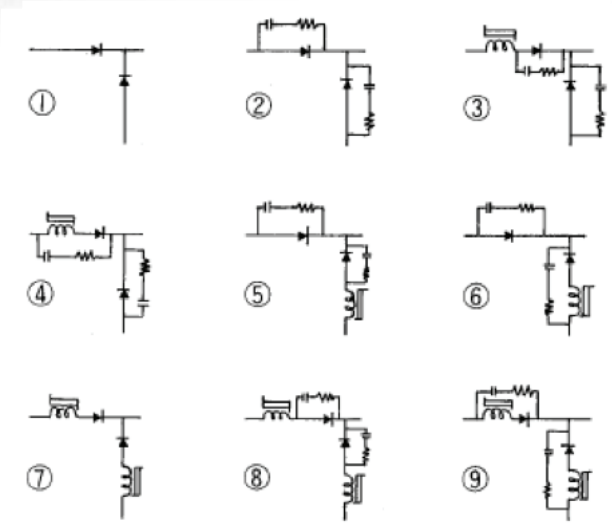
Figure 8. Combination effect of SPIKE KILLER and CR snubber forward converter (Ein=20V, Eo=5V, f=150kHz)



8-1) Output Noise



8-2) Combination Of SPIKE KILLER and CR snubber.

Applications for AMOBEADS and SPIKE KILLER

- SMPS (switch mode power supply) inverters
- UPS (uninterruptable power supply)
- Motor control circuits
- Semiconductor device protection
- Miniature common mode filters
- Consumer electronics