

Audio Noise Suppression Techniques

Application Note AN-24



Electronic and magnetic components can generate audible signals when they are excited at frequencies in the range of human hearing. This phenomenon has been observed since the early days of electric power conversion. Transformers operating at the line frequencies of 50 and 60 Hz often produce an undesirable hum. It is well known that switching power converters operating at constant ultrasonic frequencies can produce audible noise if their loads are modulated with audio frequency components.

Audio frequency signals are usually not a concern with converters that operate at low power levels. There may be applications, however, when designers will desire to reduce the acoustic emissions from their circuits. Welding the steel laminations in 50 and 60 Hz transformers reduces the hum to acceptable levels in low power AC-DC adapters. Analogous techniques are applied to ferrite transformers in high frequency switching converters.

Sophisticated audio engineering equipment has been used to study acoustic emissions from switched mode power conversion circuits. The instruments can measure absolute sound pressure levels and spectral content with great accuracy, but human perception of sound is very subjective. It is difficult to assert how much will be audible, and even more difficult to determine how much will be perceived as unacceptable noise in a given application.

Acoustic emissions are similar to electromagnetic emissions, but there are no universal standards to provide a benchmark for acoustic compatibility. Therefore, designers may wish to follow these guidelines to reduce the acoustic emissions from their products if they have any concern about audible noise.

Capacitor Noise

All dielectric materials deform under the stress of an electric field. This electrostrictive effect is proportional to the square of the electric field intensity. Some dielectrics exhibit an additional piezoelectric effect, which is a linear displacement proportional to the electric field intensity. The piezoelectric effect is usually the dominant mechanism that produces noise from the capacitors.

The nonlinear dielectric material in ceramic capacitors typically contains a high percentage of barium titanate, which is piezoelectric at normal operating temperatures. As such, these

Quick Guide for *TinySwitch*TM Designs

The ON/OFF control used in *TinySwitch* can generate audio noise in the clamp capacitor and the transformer at certain load conditions. The following simple design steps can be taken to dramatically reduce audible noise at virtually no added cost.

1. Some types of ceramic capacitors used in primary clamp circuitry can be very noisy. Replace the ceramic capacitor with a plastic film capacitor or use a Zener clamp. Zener clamps are now comparable in cost to RCD clamps, take up much less space and also provide higher efficiency. Ceramic capacitors used in RC snubbers connected to the DRAIN rarely generate audio noise (See Figure 1).

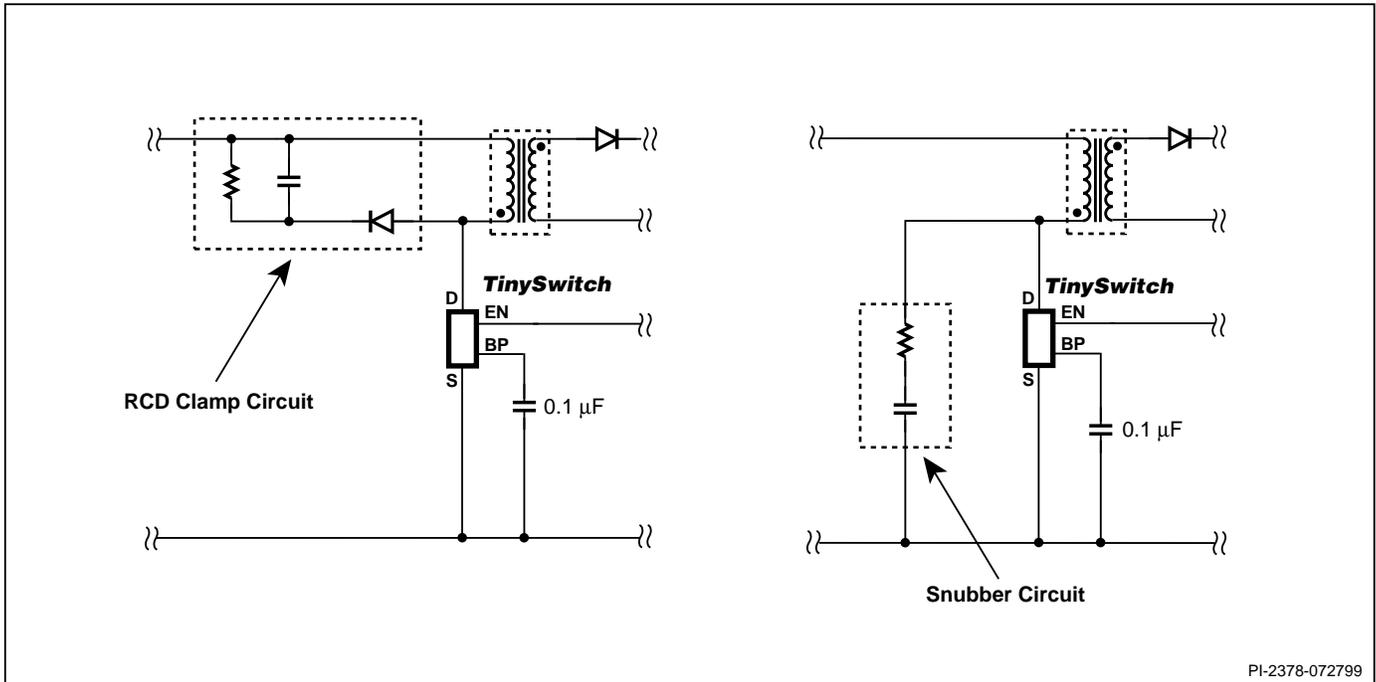
2. Construct the transformer using one of the techniques described in this application note. Gluing with glass spacer beads on all three legs is recommended because it has superior structural integrity with temperature changes, independent of the spacing between cores. This technique also eliminates the need to gap the core, saving cost. In contrast, conventional gluing (with hard glue) of center gapped cores needs to be checked over the specified temperature range for structural integrity, especially for gaps in excess of 0.1 mm. Potting is another option at a slightly higher cost.

3. If further audio noise reduction in the transformer is desired, use a lower peak flux density. Changing the peak flux density from 3000 gauss to below 2500 gauss can provide a noticeable benefit.

components tend to make more noise than capacitors with linear dielectric compositions. In switching power supplies, the capacitors in the clamp circuits that see large voltage excursions are the most likely to produce audible noise.

To determine if the ceramic capacitor is a major source of noise, replace it with one having a different dielectric. Plastic film capacitors are cost effective alternatives. Take care to be sure the replacement can withstand the repetitive peak current and voltage stress.

A cost competitive option is to replace the RCD clamp circuit (Figure 1) with a Zener clamp circuit. Zener clamps are now comparable in cost to RCD clamps. They take up much less space and also provide higher efficiency.



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Figure 1. Ceramic Capacitors Utilized in RCD Clamp Circuits can generate Significant Audio Noise while Ceramic Capacitors used in Snubber Circuits rarely generate Audio Noise.

Transformer Noise

In most flyback converter applications, the transformer is the major source of audible noise. Designers should not be alarmed if they hear noise from the first prototype transformer in their breadboard. Use of appropriate construction techniques that are well known to manufacturers will reduce the noise substantially at virtually no additional cost. Care in assembly of the prototype transformer can duplicate the performance of the production device.

Transformer noise can originate from several mechanisms. Each one produces a mechanical displacement that launches sound waves into the surrounding air. They include, but are not limited to:

- **Relative Motion** — The attractive force between two core pieces can cause them to move, compressing the material that keeps them apart.
- **Percussion** — If the faces of the core pieces can touch, they can hit or scrape together when they move in response to flux excitation.
- **Bending** — A gap in only the center leg of an EE or an EI structure can allow the core pieces to bend or flex from the attractive force between them.
- **Magnetostriction** — The core material changes dimension in response to the flux density. For common power ferrites the change is less than 1 ppm.

- **Bobbin Motion** — Displacement of the core pieces may be transmitted and amplified through the bobbin.
- **Coil Motion** — Current in the coil produces attractive and repulsive forces that tend to move the wires.

These sources of motion act together to form a complex mechanical system that can have a strong resonance at one or more frequencies in the range of human hearing. The structures used most often in offline flyback converters below 10 watts tend to resonate between 10 kHz and 20 kHz. The motion can become audible when the fundamental frequency of the flux excitation or any of its harmonics passes through a region of mechanical resonance. Designers should vary the load over its entire range to check for audible noise, particularly if there is a dynamic load requirement.

The degree to which any of these mechanisms contributes to audible noise depends on the particular situation. Fortunately, designers may apply simple construction techniques that are very effective for reducing audible noise from multiple mechanisms.

Construction Techniques

Several methods to reduce audio noise from transformers have been investigated. All the methods require proper use of appropriate adhesives in the construction.

Evaluations by transformer manufacturers and their customers confirm that these techniques are acceptable for use in high volume consumer applications. Power Integration's Web site

at www.powerint.com gives contact information for suppliers who have demonstrated their ability to produce transformers for low audible noise. These suppliers are ready to provide samples to customers.

This document gives details of two construction techniques for reference by customers who prefer other sources of supply. Users are cautioned to perform sufficient testing to qualify all components for their intended applications.

Adhesives in Transformers

The use of adhesives in the construction of transformers is well known in the industry. Various glues, cements, coatings and potting compounds can help transformers resist mechanical shock, exclude environmental contamination, and meet safety requirements. As with each of these purposes, there are special considerations in the use of adhesives to reduce audio noise.

The adhesive should be a rigid type. The desired characteristics are most often found in hard epoxies. Soft compounds like silicone RTV are not as effective. Transformer manufacturers will often be in the best position to select an appropriate material because they usually have their own list of preferred adhesives for specific purposes that work well with their individual processes.

The chief purpose of the adhesive is to prevent relative motion between the two pieces of a magnetic core, and between the core and the bobbin. A secondary purpose is to damp mechanical resonance of the transformer structure.

Unfortunately, misapplication of adhesives can induce mechanical stresses that will fracture the core. The structural materials in transformers change dimensions by different amounts when the temperature changes. Mechanical stresses will develop if the individual pieces cannot move to compensate for these dimensional changes. Restricted motion of ferrite, bobbin, and adhesive can produce enough stress to cause the materials to fail. Also, too much or too little adhesive can result in less than optimum reduction in audio noise.

This document describes two techniques for the use of adhesives in the construction of transformers. The first method avoids the problems associated with mechanical stresses altogether. It can be used with all two-part core structures, and it offers advantages even in applications where audio noise is not a concern. The other technique is an alternative method that may be used with caution only after appropriate temperature testing of each design.

Transformers with Glass Beads

The most effective way to reduce audio noise from transformers is to glue mating surfaces of the ferrite pieces with a rigid adhesive. A uniform spacing between mating surfaces in a

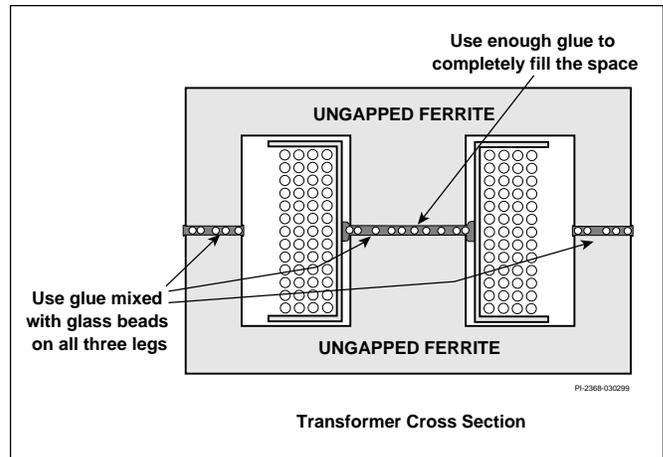


Figure 2. Construction with Glass Spacer Beads.

symmetrical structure prevents mechanical stresses because it allows the ferrite and the adhesive to change dimensions independently. One may easily achieve the desired uniformity in spacing with a mixture of adhesive and glass spacer beads.

Figure 2 illustrates the use of glass spacer beads in the construction of a transformer with two identical E-cores. Glass spheres in the adhesive maintain uniform spacing between the pieces in each leg. This spacing maintains the appropriate nonmagnetic path length to obtain the desired inductance. The adhesive and the ferrite can expand independently by different amounts while remaining securely bonded together.

The Figure also shows that a small amount of adhesive from the gap in the center leg bonds the bobbin. It is important that the bobbin does not bond along its entire length. The construction must allow the bobbin and the core to change their dimensions independently in response to changes in temperature.

This same technique works well for EI structures also. As with the EE structure, each leg is the same length. Grinding is not required to make a gap in any leg. The glass beads in the adhesive maintain the required spacing to determine the inductance.

The procedure for design and construction of transformers with glass spacer beads is simple, straightforward and economical. The next section addresses these topics.

Design and Construction with Glass Beads

The use of glass spacer beads to define bond lines is a common industrial practice. Several manufacturers provide the materials in a variety of sizes and dimensional tolerances. The Appendix of this document gives information on common sizes and known sources of supply. While the products are likely to be screened with the same standard meshes and sieves, some suppliers may have better quality control or tighter tolerances in their products. Users are advised to check the specifications before selecting a supplier.

How to Choose the Proper Size Glass Bead

Calculations of air gap dimensions often use ideal models that assume all the flux is confined to the core. Such calculations are seldom accurate because there is always some flux that escapes from the core. Therefore, designers use the computed value of A_L (inductance per squared turn) rather than a physical dimension as a design parameter for a given core size. In Power Integrations' transformer design spreadsheet (see AN-18) this parameter is called A_{LG} .

The design procedure with glass beads is the same as for cores with center gap when only standard gap lengths are available. To design a transformer for construction with glass beads, one needs to know the A_{LG} for each core and glass bead size under consideration. The Appendix of this document gives approximate A_{LG} values for selected cores with 15 common sizes of glass beads. The transformer designer simply adjusts parameters to produce a computed A_{LG} that matches one in the table.

For experimentation, users should have sizes that are adjacent to any value they select from the table in the Appendix. Differences in processes, procedures and core composition may alter the values in the table sufficiently to require a different size bead for optimal design. Therefore, designers may wish to make their own table of A_{LG} values that are refined to match their particular process.

Assembling Transformers with Glass Beads

The best method for assembly of transformers with glass spacer beads will depend on the particular circumstances of production. For example, the optimal method for large volume production on a highly automated production line is not likely to be the best way to produce smaller quantities where most of the work is performed by hand. The major differences between the two operations are likely to be in the selection of the type of adhesive, and in the details of the mixing.

High volume automation is likely to use a two-part adhesive that cures quickly at a moderate temperature. The details of mixing the glass beads with the adhesive will depend on the characteristics of the machinery.

Lower volume production will likely use a single part adhesive with a curing schedule of about one hour at a temperature over 100° C. The glass beads may be mixed with the adhesive just prior to use, or a suitable mixture may be purchased from the adhesive supplier.

The adhesive should be a compound of high enough viscosity to keep the glass beads in a uniformly distributed suspension. The Appendix lists some examples that are known to work well for laboratory use and for production in medium volumes. Fast curing and low viscosity adhesives like cyanoacrylate are not appropriate. The adhesive must also be rated for use at the

temperature extremes of the application.

A mixture of about 10% glass beads by weight of appropriate adhesive gives good performance for most applications. Although in theory there needs to be only one bead in each leg to maintain the required spacing, there should be a sufficient number of beads in each leg to keep the mating surfaces parallel while the adhesive cures. Evaluations have shown that mixtures of less than 5% glass are likely to leave some legs without beads. More than 20% can make the mixture too stiff for reliable application and adhesion. These results may vary with adhesives that have different characteristics.

The cost of the glass beads in a transformer is negligible. An EE16 transformer needs about 20 milligrams of glue and glass mixture. If 10% of the mixture is glass, an EE16 transformer needs about 2 milligrams of glass. Assuming a worst case cost of \$100 per pound (\$0.22 per gram), the cost of glass beads in one transformer would be \$0.00044, or 0.044 cents.

Construction Hints

There are many ways to assemble transformers with glass spacer beads. This section offers suggestions that are applicable to laboratory prototypes and small production runs.

- Make a fixture with permanent magnets to hold the transformers for gluing and curing. Start with a steel sheet or tray that will fit the curing oven. Glue button magnets to the tray in a suitably spaced array. Alternate the north-south orientations of the magnets to obtain the strongest magnetic field.
- Place one ferrite E-piece on each magnet with the legs upward. Apply a mixture of adhesive and glass beads to each leg. A disposable plastic syringe (sometimes called a transfer pipette) makes a good dispenser when constructing many transformers at one sitting.
- There must be enough adhesive in each location to completely fill the space between the two mating surfaces. Voids will allow the transformer to produce more audio noise. Be careful not to apply too much to the center leg. There should be enough extra to bind to the bobbin only at its center.
- Put the bobbin on the E-piece that has the glue. Then mate the second ferrite piece (E or I) to the first. Press the top ferrite with enough force to guarantee that only one layer of glass beads determines the separation between the two pieces.
- Place the tray with the assembled transformers in the curing oven. It is not necessary use tape or clamps. The magnets provide sufficient force to hold the pieces together.



The inductance of the transformer is likely to change while the glue cures, particularly in designs that use the smaller diameters of glass beads. The amount of change one should expect depends on the process, but the results will be consistent if the process is well controlled. The particular glue, mixture, assembly technique and clamping method can influence the final inductance after curing.

The usual 25% variation in permeability of the ferrite material can change the inductance by as much as 6% for the smallest cores and glass bead diameters. Designs with larger cores and larger diameter glass beads are less sensitive to changes in permeability. Designers should confirm that the inductance is within the desired limits after curing. A final inductance measurement will also catch the rare case where an outer leg has no beads.

Transformers with Center Gap Glue

While the use of glass spacer beads is superior to other constructions in many respects, some manufacturers may elect to use adhesives with the traditional center leg gap construction. **This alternative technique can be quite effective to reduce the generation of audio noise, but users should test each design to confirm that mechanical stresses under expected temperature extremes do not cause structural failures in the application.**

It is important that users have confidence in their source of ferrite material because the strength of ferrite cores can vary greatly among suppliers. The cores in each unit must be strong enough to endure the mechanical stresses that are unavoidable with the center leg gap construction.

Qualification of each design should include thermal stress testing that covers all the requirements of the end product as well as transportation of the transformers themselves. For example, the end product may be required to operate at a minimum temperature of only 0° C, but shipment of the product or the transformers by air will expose them to temperatures of -40° C.

It is common for products such as battery chargers and AC adapters for portable equipment to have the requirement of a thermal shock test for qualification. A typical specification calls for 32 thermal cycles that go between -40° C to 85° C. In each cycle the units spend one hour at each extreme with a transition between the two in less than 15 seconds. Some applications call for transitions between the extremes of -40° C and 100° C.

Users are advised to understand their applications thoroughly so that they can determine proper test conditions. Thermal shock testing has been performed on hundreds of transformers of different designs to the specifications described in the

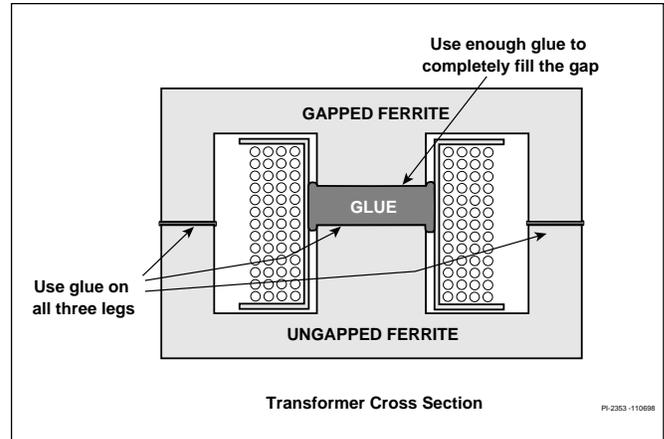


Figure 3. Construction with Gap in Center Leg.

previous paragraph. Many failures have been observed in transformers that have a center gap filled with hard glue, especially with gaps of greater than 0.1 mm. In contrast, no failures have been observed in the recommended construction with glass spacer beads.

A marginal design may have a small but still unacceptable failure rate in high volume production. Therefore, the qualification procedure for large volume production should include environmental testing of several hundred units to increase the likelihood of detection.

Failed units may be obvious from external cracks. Visual inspection will not detect internal failures. Those will be evident from increased audio noise in operation.

The risk appears to be low for center gaps less than 0.1 mm with a suitable hard glue. Hard glues with excessively high coefficients of thermal expansion will crack cores that have smaller gaps. Soft glue does not show the cracking problem because the mechanical stresses are much lower than with hard glue, but soft glue is much less effective in the reduction of audio noise.

Construction with Center Gap Gluing

Figure 3 shows a cross section of a transformer with the usual gap in the center leg. The two E pieces are bonded together with an adhesive in each leg. In EE core structures with a center leg gap it is most important that the **center gap be completely filled with adhesive**, and that the material forms a strong bond over the entire surface on opposing faces of each leg.

The Figure also shows that a small amount of adhesive from the gap in the center leg bonds the bobbin. As with the glass bead construction, it is important that the bobbin does not bond along its entire length. The construction must allow the bobbin and the core to change their dimensions independently in response to changes in temperature.

Gluing Procedures

The procedure for application and curing of the adhesive is very important. This is especially true in the fabrication of prototype transformers for the breadboard, where the process is neither automated nor refined.

Although transformer suppliers may be familiar with the use of a particular material in their manufacturing process, it is essential that they understand the purpose of the procedure, and that they consistently use enough glue. Incomplete gluing may be adequate to hold the pieces together, but it will not give the expected reduction in noise. Consistency in the gluing process is necessary to produce a high yield of quiet transformers.

The same construction techniques described earlier for glass spacer beads apply to assembly of transformers with the center gap.

The addition of an adhesive between mating surfaces may reduce the inductance of the transformer due to expansion of the glue while curing, particularly if the original gap is small. Designers should confirm that the inductance is within the desired limits after curing. It may be necessary to start with a smaller gap in the center leg to compensate for the thickness of the glue in the outer legs.

If a prototype transformer is still noisy after gluing, cut away the bobbin to inspect the glue in the center leg. In most cases of noisy transformers, the gap will not be filled completely. If the glue in the center leg has no voids, separate the core pieces to expose the mating surfaces of the outer legs. Check for a good bond over the entire surface.

The adhesives listed in the Appendix are suitable for use with center leg gaps as well as glass spacer beads. Prototype units for thermal testing must use the same adhesive that will be used in production because the characteristics of the glue determine the mechanical stresses in the ferrite.

Other Construction Techniques

Applications that need fully encapsulated (potted) magnetic components usually require no additional procedures to reduce audible noise. Manufacturers sometimes use potting to address special environmental conditions, or to meet electrical insulation requirements where space is at a premium. If desired, potting can be used just for noise reduction at slightly higher cost than the other techniques.

Audio measurements have shown that potting can be just as effective as glass beads and center gap gluing to reduce audio noise. Manufacturers should be aware that noise reduction is a goal of the construction to assure consistent results in production. It is possible to build potted transformers that consistently meet

all conventional environmental requirements, but yet show large variations in audio noise.

Some manufacturers have very effective proprietary techniques to reduce audio noise. These, as well as other alternatives, should be tested over the expected temperature range as part of the product qualification.

Varnish is often used in the manufacture of transformers to improve reliability. It keeps out moisture and adds durability to fine wires. While varnish can be beneficial to reduce audible noise, designers should use caution with varnish impregnation.

Although it is unrelated to audio noise, the users should be aware that varnish with a high dielectric constant can raise the capacitance of the primary winding. Increased primary capacitance will lower the self resonant frequency of the transformer, increase the peak current of the power switch at turn-on, and reduce the efficiency of the power supply.

Transformer Design Considerations

Lower peak flux density produces less noise. If further reduction in audible noise is desired for a given transformer construction, the designer can reduce the peak flux density. For a transformer with no adhesive between the core pieces, a reduction in peak flux density from 3000 gauss to 2000 gauss can lower the audible emissions by 10 to 15 dB. The reduction will be about 5 dB for the same transformer that is properly glued. It is generally accepted that humans perceive a 10 dB change in sound pressure level as a factor of 2 in loudness.

Note that a design for lower peak flux density will require more turns and a larger gap to achieve the same output power with a given core. More turns will lead to more leakage inductance, which may require changes in circuit component values to stay within device limits and to meet product specifications.

The magnitude of audible noise depends on the flux duration as well as the peak flux density. For a given peak flux density, less time to go from zero to the peak and back to zero produces less noise. Transformers designed for operation at higher frequencies will tend to produce less noise when they are excited by audio frequency signals in the power converter.

Circuit Packaging Considerations

Designers should consider the packaging of their product when making decisions related to audible noise. Any enclosure can make a dramatic reduction in the transmission of audible noise from the circuit card. An ordinary unventilated plastic case can attenuate the sound by about 20 dB. The customer should evaluate the effect of the enclosure on the thermal characteristics of all components in the circuit.



Perspective on Audible Noise

Acoustic emissions from switched mode power converters are analogous to electromagnetic emissions. In each case, designers need to overcome a small inconvenience to benefit from a superior technology. Unlike electromagnetic emissions, however, there are no universal standards for low levels of acoustic emissions to tell the designer what is acceptable in his application. Power Integrations will continue to assist designers with audible noise updates on our Web site, www.powerint.com, as more information becomes available.

Appendix A

SOURCES OF GLASS SPACER BEADS			
Potters Industries Inc. Southpoint Corporate Headquarters P.O. Box 840 Valley Forge, PA 19482-0840 USA <i>www.pottersbeads.com</i> Tel: +1-610-651-4700 Fax: +1-610-251-9139		MO-SCI Corporation 4000 Enterprise Drive P.O. Box 2 Rolla, MO 65401 USA <i>www.mo-sci.com</i> Tel: +1-573-364-2338 Fax: +1-573-364-9589	
Potters Industries Inc. Spacer Application Glass Beads		MO-SCI Corporation Class V Precision Glass Spheres:	
Maximum Diameter (mm)	Maximum Diameter (inches)	Maximum Diameter (mm)	Maximum Diameter (inches)
0.594	0.0234	0.600	0.0236
		0.500	0.0197
0.419	0.0165	0.425	0.0167
		0.355	0.0140
0.297	0.0117	0.300	0.0118
0.249	0.0098	0.250	0.0098
		0.212	0.0083
0.178	0.0070	0.180	0.0071
		0.150	0.0059
0.124	0.0049	0.125	0.0049
0.104	0.0041	0.106	0.0042
0.089	0.0035	0.090	0.0035
0.074	0.0029	0.075	0.0030
0.064	0.0025	0.063	0.0025
0.053	0.0021	0.053	0.0021
Prices are between \$50 and \$95 per pound (\$110-209 per kg) as of June 1999. Contact manufacturers for current pricing. An EE16 transformer takes about 2 milligrams of glass beads.			

Table 1. Sources of Glass Spacer Beads.



APPROXIMATE A_{LG} VALUES FOR COMMON CORES								
BEAD DIAMETER		A_{LG}						
		EE13	EE16	EEL16	EF16	EE19	EEL19	EF20
mm	Mils	nH / N ²						
0.053	2.1	203	220	215	245	258	244	341
0.064	2.5	179	194	192	215	228	220	304
0.074	2.9	160	174	174	193	204	201	274
0.089	3.5	139	151	153	167	177	178	240
0.104	4.1	123	134	136	148	157	160	214
0.124	4.9	108	117	120	129	137	141	187
0.150	5.9	94	102	105	112	119	124	162
0.178	7.0	83	90	93	99	104	110	142
0.212	8.3	74	80	82	88	92	97	125
0.249	9.8	66	71	73	78	82	86	110
0.297	11.7	58	63	65	69	72	77	97
0.355	14.0	51	56	58	61	64	68	85
0.419	16.5	46	50	52	55	58	62	76
0.500	19.7	41	44	47	49	52	56	68
0.594	23.4	37	39	44	44	48	52	62

Notes:

1. All values are computed from inductance measurements on a single sample with 100 turns on an appropriate bobbin, using an uncured mixture of adhesive and glass beads.
2. Adhesive is Eporite 2095 epoxy. Glass bead content is 10% by weight for diameters 0.053 mm through 0.419 mm, and 15% for diameters 0.500 mm and 0.594 mm.
3. EE and EEL cores are NC-2H equivalent material. EF cores are 3C85 material.
4. Results for finished transformers may differ from these values because of differences in materials, handling operations, or curing techniques. Users may find it necessary to adjust these values for a particular manufacturing process.

Table 2. Approximate A_{LG} Values for Common Transformers with Glass Spacer Beads.



EXAMPLES OF ADHESIVES USED IN THE CONSTRUCTION OF TRANSFORMERS			
Manufacturer	Product	Description	Application
EPOLAB Chemical Industries, Inc. 11, Ho-Jung N. Rd. Chungli Industrial Park Chungli, Taiwan Tel: +886-3-4521501 Fax: +886-3-4529318	EPORITE 2066	Single Component Epoxy; Cure at 130° C for 2 hours or 150° C for 1 hour	<ul style="list-style-type: none"> • Ungapped cores with Glass Spacer Beads • Center leg of center gapped transformer* • All three legs of center gapped transformer*
	EPORITE 2089		
	EPORITE 2095		
Jungdo Chemical Company, Ltd. South Korea Tel: +82-2-856-0391 Fax: +82-2-867-1685	JAC-133	Single Component Epoxy; Cure at 120° C for 1 hour	<ul style="list-style-type: none"> • Ungapped cores with Glass Spacer Beads • Center leg of center gapped transformer* • All three legs of center gapped transformer*
Loctite Corporation 1001 Trout Brook Crossing Rocky Hill, CT 06067-3910 Tel: +1-860-571-5100 Fax: +1-860-571-5465 www.loctite.com	Product 638	Single Component Anaerobic Adhesive; Room Temperature Cure	<ul style="list-style-type: none"> • Outer legs of center gapped transformer

*These designs should be tested to confirm that temperature changes do not cause structural failures in applications.

Table 3. Examples of Adhesives Used in the Construction of Transformers.



Revision	Notes	Date
A	-	7/99
B	Figure 1 added.	8/99
C	Appendix A, Table 2 revised to reflect additional data.	9/99

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