Practical Construction Tips For Coils Using Iron Powder Cores

Presented by

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The purpose of the following discussion is to convey practical application information for coil construction, costing, materials and product safety requirements. This paper is oriented to the design engineer to educate them about the many safety requirements and potential problems that coil winding vendors encounter while attempting to manufacture and test wound magnetic components.

Organizing Design Priorities

Cost, Size, Temperature and Safety Requirements are all interrelated and in the final analysis, cost will be the key driver in the decision process.

COST or "Total Cost" is a combination of the bill of materials, ease of manufacturing the design (or manufacturability), location in the world of the winding source especially if the design is labor intensive and the level of technical manufacturing support available on site of the winding source.

SIZE - Should be consistent with using lower cost core materials that are available. Do not design in a slightly smaller, higher cost core if an iron powder core will do the job. It is necessary to be aware of all the trade-offs in core shapes, core materials, mechanical mounting, that impact the final cost.

TEMPERATURE - The component must stay within the limits established by the safety agency for; thermal class selected, location of the part on the printed wiring board and available airflow.

SAFETY - Up-front knowledge of ALL safety requirements that pertain to the product is critical. If not properly considered, the Safety Agency Engineer will undoubtedly identify problems at the worst possible time. Usually the associated costs to fix safety related problems at this time are enormous.

Cost

CORE MATERIALS - Iron powder cores are the lowest cost cores available with the exception of "air core" parts. In today's competitive world, the cost of all electronics is driven by price and quick delivery. We have many customers that discover, after their product was already in production, the price pressure they encounter in the market is so strong it was necessary to redesign many magnetics from Ferrite and Sendust [Kool-Mu] cores to iron powder cores in order to save money and become competitive.

TOROIDS vs. E-CORES ADVANTAGES

Toroids - More compact than E-core design
Materials cost is lower due to single component
Tighter magnetic coupling - lower stray flux leakage

E-cores - Easier to automate winding process
Can be mounted by pins on the bobbins
Easier to isolate electrically multiple windings
Core can be easily gapped to extend energy storage capability

Product Safety Organizations

Be mindful of all the product safety requirements that apply to the design. Many requirements today call for a reinforced insulation system with specific creepage and clearance distance built into the design.

The most commonly specified safety requirement today for switchmode power supplies that also includes magnetics is IEC-950. Detailed information can be obtained from the UL office in Northbrook, IL. by ordering a copy of The BI-National Standard of UL1950, 3rd. Edition at approximately $175.00. [1]

Temperature Considerations

Micrometals iron powder cores do have an upper temperature limit. Please consult the factory if the application will exceed 75 degrees C for an extended period of time.
Micrometals has incorporated into our Design Software a Thermal Aging Prediction feature. The software can be downloaded from our web page at http:/www.mircometals.com

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Winding Techniques and Considerations

Toroid Cores

Toroidal cores offer a simple, compact solution for making inductors, coupled inductors and transformers. The toroidal shape provides good magnetic flux coupling and low stray flux leakage.

Another feature of the toroidal shape is the height (also referred as “thickness”) is easy to vary and requires no tooling changes. This allows the engineer to change the A_L value and cross-sectional area of the core in order to “squeeze” a part into a location that has limited board space or height.

Micrometals iron powder toroidal cores are available in a very large selection of sizes and material types. In general, most of the Micrometals toroidal core tooling allow for doubling the height (or manufacturing a thinner part than the standard) without a tooling charge. Please contact the factory if you have need for a size not listed in the catalog. The cost of tooling a toroid with special diameters is about $750.00 per inch and the lead-time runs 4-6 week’s ARO.

1. There are many ways to wind the magnet wire on toroidal cores. The most basic way is to hand wind the wire on the core applying only hand tension.

As the wire diameter increases more winding tension is required to “form the wire” to the body of the core. At this point a better method of holding the core for winding may be required. A small bench vice with “plastic faces” is one good way to hold the core in position. This works well for a wide range of toroid core sizes. The bench vise can be purchased at most electronic distributors or hobby stores and costs less than $35.00.

A simple winding tool that can be made is a “hand shuttle." The wire is first loaded on to the shuttle and then wound around the core. Shuttles are typically made from aluminum, wood or other rigid plastic material. The length and diameter of the shuttle is sized to the inside diameter of the core, wire size, and length of wire to be wound on the core.
Notches are cut into the end of the hand shuttle similar to the notch found on the “string end” of an arrow. These notches must be very smooth in order to prevent damage to the magnet wire insulation.

Considerable mechanical advantages are gained when using a hand shuttle since it is easier to put tension on the wire. The shuttle also stores the wire neatly during winding which helps prevent nicks and kinks as it is being wound around the core as well as speeding up the process for long wire lengths.

With any winding method selected it is important not to apply too much pressure since the magnet wire can stretch, break or crack the core. A broken wire or core is easy to detect, but *stretching the wire* is a little subtler. It can lead to insulation failure and higher than expected winding resistance [direct current resistance] since the wire has been reduced in diameter.

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Iron powder cores, by nature, are both electrically and mechanically *robust* to external forces. Winding stress on iron powder cores is only a problem *if* the core breaks and comes apart. Only a small change with initial permeability is noticeable [up to 5%] when a core has a crack. Ferrite cores will change dramatically if cracked and a 50% decrease in initial permeability or more is not uncommon.

Ferrite cores and tape wound cores are susceptible to changes in initial permeability and core loss due to external mechanical force. These forces include winding pressure, potting or encapsulation pressure and mechanical pressure from mounting or clamping the core and coil assembly together.

To obtain the best coupling between the winding and the core, evenly space or position the turns around the core. Be careful not to "bunch up" the windings since the *apparent inductance* will increase by both the self-capacitance and leakage inductance. As the operating frequency increases above 1 kHz, the winding distribution about the core becomes more important. With lower permeability Iron Powder materials, poor magnetic coupling can result in a 2 to 1 difference in inductance between the calculated and measured value.

The application of low perm toroidal cores with a single turn straight through the hole may yield inductance values as low as 50% of the catalog specification due to poor coupling. It is important to be aware of this up front in your design effort.

Composite cores such as the Micrometals "ST" series are composed of a ferrite core and iron powder core bonded together as a single unit. The design engineer needs to apply the precautions listed above due to the ferrite core.

Core problems are detected by visual, mechanical and electrical limits established by the design engineer.

2. Be cautious of winding a single, large diameter wire on a physically small core. The winding pressure can break the core. Also, large wire may not conform well to the vertical walls of the core. Consider using 2 smaller wires in parallel for this application. The completed coil will be smaller in size and exhibit better magnetic coupling to the core.

Other winding methods should also be considered based on the number of turns, wire size and desired electrical results. Some of these methods include but are not limited to a single continuous winding where the wire has been wound around the core in more than 1 pass provided winding capacitance is not critical. Bank winding or Progressive winding is used where the wire is wound in less than 1 pass on the core and a physical gap is left between the start and finish of the winding. This method reduces the capacitance between the ends of the winding for improved high frequency operation (increases the SRF).

3. Prepping a toroid core with Mylar tape [like 3M #56 or equivalent] before winding will reduce the capacitance and increase the dielectric strength between the winding and core. A low cost solution to increase the voltage rating is to apply a double thick coating of Polyester paint. This is only an option for core sizes equal to or greater than Micrometals part prefix “T25”. Contact the Anaheim, California office for details. [9]

4. A quick and easy way to mechanically separate the start lead from the finish lead is to apply a tie wrap around the core or use electrical crepe tape [like 3M #38 or equal.]. This method works well for separating two or more windings. Just add additional mechanical barriers to the core prior to winding. [9]

5. When winding solderable film wire on toroid cores be aware that stripping and tinning the lead ends in one operation *close to the core* can be very damaging to the wire's insulation and finish on the core. Shorts can occur either turn-to-turn or turn-to-core if not performed properly. Solder splash and solder

balls will often end up deposited on the core and within the windings. The foreign material can come off the part at a later time and cause electrical problems in the printed wiring board [PWB] or circuit card assembly [CCA]. The solution is to “rotary strip” or mechanically strip the insulation from the wire to the desired strip gap length, flux the bare ends, and then use a 450 to 550 degree F solder pot in which to tin the leads.

A simple coil guard to keep solder balls or solder splash out of the windings can be made out of 0.010 inch thick Nomex paper that has one or more holes in it. Start by placing the leads through the Nomex paper and then into the flux and solder pot for tinning.

6. A simple solution to meet IEC-950 winding isolation is to use triple insulated wire of Kapton film or Teflon for this application.

The thinnest wall insulation we are aware of is “half lapped” Kapton film, type FN fluorocarbon sealed by heat. It increases the OD of the wire by approximately 0.006 inch's total. The cost per foot for AWG-24 is approx. $0.08 [2]

The next smallest finished OD triple insulated wire is Teflon FEP. Each layer is approximately 0.003 inches thick. It increases the OD of the wire by approximately 0.018 inch’s total. The cost per foot for AWG-24 is approx. $0.08 [3, 3-1]

7. For most applications that need to meet UL, CSA or IEC commercial thermal requirements, Class 130C magnet wire would be the best choice for use. Some magnet wire manufactures carry a dual Class 130/155C rating per MW80. This insulation is also considered to be a “solderable film." [4]

8. Toroids can be mechanically mounted by various means ranging from the self-leads of the coil to using toroid mounts or headers. Silicone rubber adhesive or epoxy adhesive is also recommended to mechanically bond the coil to a toroid mount or header.

Some parts are partially potted in a plastic cup in which the leads pass through the case wall. The case or cup may also have inserts installed for additional mechanical strength. [5]

9. A simple wound toroid may need to be varnished or encapsulated. Several factors should be considered ranging from the expected humidity to how fragile the coil is from a mechanical or vibration standpoint during all processing as well as use in the end product.

If the part needs to be completely encapsulated or molded for severe environmental conditions, the coil may need to be protected from the stress of the encapsulation material especially if you are using a ferrite core or composite core. Some of the protective methods for consideration includes mummy wrapping the coil with Teflon tape or dipping it in RTV that has been thinned down prior to use and then allowed to dry.

The encapsulation material usually is a “filled” resin. It should have a thermal coefficient of expansion that is close to the core and copper coefficients in order to minimize the stress on the component once the resin has cured. [6]

E-Cores

In today’s world, low total cost for magnetics is very important. The best starting point is to design around standard catalog cores and not custom shapes unless the quantity is very large or nothing else will fit in the space available. The main reason for this statement is that bobbins and other associated hardware already exists which will help to reduce the bill of material as there is no additional tooling charge. If on the other hand, you need a special size, the cost for tooling Micrometals E-cores is about $1000 per inch of the longest dimension and the lead-time runs about 4-6 week's ARO.

A unique characteristic of iron powder cores is that E-core can be manufactured with a center leg gap as opposed to a secondary operation, which includes machining a gap after the core has been pressed. It is less expensive to press a core with a gap, however it is possible that new tooling will be required. The break-even point on machining a gap in iron powder E-cores vs. pressing a core with a gap (if new tooling is required) is roughly 5,000 to 10,000 pieces.

1. For ease of manufacturing, it’s best not to exceed 80% of the *minimum* core window space available. This rule can be modified by up to 5% if the wire lies very flat on the bobbin or if you incorporate a coil squaring or sizing sequence that flattens and shapes the coil. Sizing can be done at various steps during the winding operation and after the last winding has been applied.

For a single, continuous winding, coil sizing would be done as the last step before the core is assembled into the coil.

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A word of caution is due since the coils can short out internally if excessive pressure is used during sizing. Be extra careful when using this technique.

Be aware that the coil will “swell up or expand” physically after it warms up. If the coil clearance between the outer legs of the “E” core is insufficient, the core outer legs can possibly break. This is caused by the coil expanding and exerting enough pressure on the core to crack it.

Having the core leg(s) crack is a very serious problem with ferrite cores due to its higher initial perm, which range from a low of around 1800 to a high of over 10,000. Ferrite cores will change dramatically if cracked and a 50% decrease or more in initial permeability is not uncommon.

Iron powder cores by nature are both electrically and mechanically *robust* to external forces. Winding stress on iron powder cores is only a problem *if* the core breaks and comes apart. The initial perm is generally less than 85, and a crack of one or both legs is much less of a problem because of the distributed air gap construction. The initial permeability might drop up to 5% due to a crack.

2. Pay close attention to the dimensional tolerances of the core(s) selected. Do not use the nominal core dimensions when calculating % window fill, but use the minimum window height and width after applying the manufacture’s mechanical tolerances.

3. Use the maximum OD for magnet wire with Heavy insulation in your calculations for turns per layer and winding build-up. Engineers sometimes overlook this point and wonder why the coil was larger than they had calculated.

It’s also not worth the risk of shorted turns by specifying single coated magnet wire. The mechanical and electrical safety margin is not there for off-line switchmode magnetics.

4. Lead exits should always have a “cross over pad” of either tape or sheet insulation placed between the winding directly over the turns that the lead would cross. The exit lead and insulation are then secured to the coil with electrical tape. This will prevent the possibility of shorts in this area.

5. It is prudent to use a “pre-approved” insulation system if you intend to obtain UL, CSA, IEC or other safety agency approval. The varnish or epoxy and insulation manufacturers offer these systems at no charge if you ask. [7]

6. This leads into the typical materials used in the construction of the magnetics. The normal thermal or temperature class for switchmode magnetics is Class B or so called Class 130 that meets 130 C operation. The magnet wire is usually Heavy grade, solderable film. [4]

IEC-950 Isolation for 1 or 2 windings can be met by using triple insulated wire of Kapton film, Teflon or Tex-E wound without any additional supplemental insulation or setback. This works well for coupled inductors, transformers and pulse transformers. [2,3, 3-1]

Windings can be made by using copper foil of different thickness and widths. Foil can either be purchased bare or with insulation applied [electrical tape or enamel film].
The best copper alloys to specify for high conductivity is #102 [99.96%] or #110 [99.9%]. [8]

The biggest single problem with copper foil is the tendency to short turn-to-turn through thin film or paper insulation caused by burrs on the edge(s). A solder "spike" created when making the solder joint on the foil can cause a short too.

A good solution to this problem is to specify burrless copper. If the foil is less than 0.011 inch's thick, the foil should be 1/2 hard and if it's more than 0.011 inch's thick, specify soft or annealed copper. This rule makes it easier to slit the copper without burrs. Any soldering must be smooth and free of sharp spikes. Do not leave any foreign material between the copper foil and the insulation layer to prevent shorts layer-to-layer.

The electrical tapes used are Mylar film, polyester film, composite film, filament reinforced, glass cloth, acetate cloth and paper. This wide selection is due in large part to the wide range in power and physical sizes encountered by the designer. [9]

The most common wire sleeving used is Acrylic, PVC shrink tube, Silicone rubber, Teflon or Vinyl. [10]

The bobbins are molded out of Delrin, Liquid Crystal Polymer, 6/6 Nylon, Glass filled Nylon, Rynite or Ryton. Please note that not all these materials meet UL94V-O. It is necessary to know which degree of flammability the magnetics must meet prior to selecting the material. Also, some bobbins are "plain" and some contain "pins" for terminating the windings. The bobbins with pins often allow for mechanical mounting to a printed wiring board [PWB] or circuit card assembly [CCA]. [11]

Coil forms or start tubes can be made from Paper Phenolic, Fish paper [105 C], Glass Epoxy, Mylar composites [130 C to 150 C] and Nomex [220 C]. [12]

E-core, U-core and HS-core Banding, Strapping and Mounting Precautions

Iron powder cores are manufactured with a distributed air gap structure. This type of structure is susceptible to changes in performance if a ferrous material is wrapped around it. The gap structure on the outer surface is essentially "shorted-out" by the ferrous material resulting in a decrease of the "Q" for the coil. When this occurs, the core loss will increase which reduces the overall efficiency and increases the core temperature rise. It is also possible that this could cause the inductor to exceed a safe operating temperature. The best nonferrous materials to use in securing this family of cores together are: Phosphor bronze or nonmagnetic stainless steel banding material, brass hardware, various electrical tapes, and tie wraps.

Mounting the wound coil for the next assembly can be a problem for bobbins without pins as part of the design. There are various mounting bases tooled to meet some of the more common core sizes and those can be a good low cost solution. Otherwise, the design engineer is faced with designing custom brackets or devising some other means by which to secure the part at the next assembly. [13]

The varnish or epoxy resin selected should be based considering the following factors:
a. Temperature class for maximum continuous operation including internal temperature rise.
b. UL, CSA or IEC requirement for the magnetics and end product.
c. Oven cure or room temperature cure material.
d. Filled or unfilled material and the viscosity.
e. Hardness of the material [flexible, semi-flexible or a hard product] considering the fragility of the parts being impregnated or encapsulated.
f. The environmental conditions for expected operation, i.e., moisture, grease, dust, etc.
g. Pot life, tank life and the working time once you mix and start to use the product.
h. Consider the shelf life of the product and any associated costs when old material needs to be disposed of while meeting local, state and EPA rules. [14]

8. The following suggestions are some of the methods used to meet the requirements for reinforced insulation or a double insulation system:

a. One easy way to set winding margins of 2.0mm to 6.0mm wide is by placing tape that has been pre-slit to the desired width on the bobbin or coil form before starting the winding.

The tape thickness used is a function of the wire diameter. Mylar tape can be used for small diameter wires and crepe tape for larger diameter wire. Also multiple layers of tape can be used to increase the height as needed. [9]

The purpose of this tape is to establish a physical space that the winding must not cross over to prevent violating the minimum creepage distance requirement.

b. Normally, the enamel or insulation coating on the magnet wire is not considered to be sufficient protection for leads exiting a coil assembly. These leads need to be sleeved from the terminal pin to inside the coil by 3.0mm minimum. The sleeving must be continuous and not have any damage or breaks. This too must be secured by tape or some other means so it cannot be moved. In addition, the winding needs to have the outer turns secured with tape or some other means to prevent displacement of the windings that would violate the creepage requirement. [9,15]

c. The overwinding insulation that is used to separate the low voltage output(s) from the high voltage input can vary from tapes to films or sheet insulation. The thickness and number of layers are dependent on the voltage levels. As an example, the switchmode isolation transformers used in most computer related applications requires 2 or 3 layer's minimum of insulation between primary and secondary. The hi-pot test voltage is 3000V_{RMS} to 3750V_{RMS} for 60 second's duration primary to secondary, 2000 V_{RMS} primary to core and 500V_{RMS} secondary to core.

The design engineer needs to establish a derating factor for the materials selected so there will not be production hi-pot failures and the cost of materials is not excessive. As an example, do not specify Kapton film if Type EL Mylar film will do the job. [9,16]

9. Since we have addressed the product safety needs, attention is now directed to the electrical performance details such as leakage inductance and interwinding capacitance.

When the safety margins are used, the net effect is to shorten the distance over which the windings are wound across the center leg of the core. This causes the *leakage inductance* to increase but also lowers the *winding capacitance* since the winding is now narrower and taller. The window utilization of the actual winding space available has been reduced by 20% or more as a result of the winding setback margins and additional overwinding insulation required to meet the hipot voltage levels.

There are many layering schemes that have been used to solve high leakage inductance caused by a narrower winding. The most common technique is to split the primary winding around the secondary winding(s). This is done by winding an inside primary followed by the secondary winding(s) followed by the outside primary.

The primary can be either series or parallel connected based on the number of turns, wire gauge and overall performance of the winding scheme. Note that with a parallel primary or secondary, the turns must be exact otherwise the core flux is unbalanced.

If reduced capacitance between the primary and secondary is required because of a conducted noise problem or performance problem, shielding can be added with a single turn of .001 to .005 inch thick copper foil. This shielding is called a Faraday shield.

The shield drain wire should be soldered at the 1/2 turn point for maximum effect. Again, pay attention to solder spikes that can short out the winding. The finish should overlap the start by 3/16 inch and insulation must be inserted to prevent a shorted turn. Use Mylar tape or equivalent to secure the shield in place so it will not move around.

If you have designed a split primary winding, then two shields are required for maximum effect.

The drain wire is often terminated to the primary circuit return, however the engineer needs to experiment as to which location in the circuit gives the best result in noise reduction.

10. Radiated magnetic flux can be reduced by placing a “Belly Band” made of .005 to .010 inch thick copper foil around the periphery of the coil assembly [after the core has been assembled to the coil]. The copper shield needs to be soldered together after forming it to the shape of the core and coil. To avoid thermal damage to the coil, make the solder connection on the outer core leg location. A layer of tape will keep the shield from moving until the part has been impregnated with epoxy or varnish.

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Be aware that placing a “Belly Band” around a coil with mechanical gap in the outside core legs will have some effect by shorting or shunting the gap. The inductance will increase when this occurs. To avoid this problem, consider the use of a “center leg gap” in the core.

11. There is a wide selection of materials and methods from which to choose in securing the cores together. They range from epoxy to tie wraps to tape placed around the periphery of the core. [15]

Unless you are using a very high perm core, we recommend bonding the three core faces together to reduce the possibility of core hum or buzzing especially if the device is subjected to 60 Hz or a pulsed condition that is in the audible frequency range. The adhesive layer helps to prevent core noise caused by magnetostriction.

Philips undertook an in depth study of 17 adhesives used to glue ferrite cores together in 1995. Most of the materials tested will also work in bonding iron powder E-cores. You need to be aware of the maximum gap the bonding agent needs to fill as part of your selection process. [17]

Testing Considerations

The testing of coupled inductors and transformers for correct turn's ratio with lower perm or large gapped core structures can lead to *apparent* turn’s count errors. This is caused by the test equipment source not being capable of providing enough current to excite the core for accurate measurements. The simplest solution is to substitute a higher perm ungapped core for the turn’s ratio test and then install the lower perm core to complete the inductance testing, hi-pot, etc.

Please note that Micrometals tests all E-Cores for inductance using a 100-turn coil, 10 kHz, and the peak AC flux density is 10 gauss. Measurements made under other conditions will produce results in accordance with the curves for Percentage Initial Permeability Vs Peak AC Flux Density and Effective Permeability Vs Frequency as shown in Micrometals Power Conversion Catalog.

Winding Credits for Slide Presentation:

Toroids: Corona Magnetics 201 Corporate Terrace Corona, CA 91719 909-735-7558	E-Cores: Frost Magnetics 49643 Hartwell Road Oakhurst, CA 93644 559-642-2536

Mounting Hardware:
Lodestone Pacific
4769 Wesley Dr.
Anaheim, CA 92807

714-970-0900

Referenced Sources

[1] IEC 1950 Specifications:
UL Technical Publications Dept.
800-704-4050

[2] IEC Kapton Suggested Sources:
Virginia Insulated Products
703-496-5136

Quirk Wire Co., Inc.
d.b.a. Wirecraft Products
508-867-7767

[3] IEC Teflon Suggested Source:
Rubadue Wire Co., Inc.
714-693-5512

Kerrigan Lewis
312-772-7208

[3-1] Solderable Triple Insulated Wire:
Furukawa (Tex-E Wire)
770-487-1234

[4] Magnet Wire Suggested Sources:
Rea Magnet Wire Division
800-732-9437

Essex Wire Corporation
800-348-0857

Phelps Dodge Magnet Wire Co.
800-255-2542

[5] Mounting Hardware Suggested Source:
Lodestone Pacific
714-970-0900

[6] Varnish Epoxy Suggested Sources:

John C. Dolph
908-329-2333

Epoxylite/Ripley Resin Co.
714-951-3231

3M
Electrical Specialties Div.
800-328-1368

ResTech Resin Co.
800-992-9799

Schenectady Chemical Co.
518-370-4200

[7] Pre-approved UL Systems:

E.I. Du Pont & Co.
302-999-3705

Epoxylite/Ripley Resin Co.
714-951-3231

John C. Dolph
908-329-2333

ResTech Resin Co.
800-992-9799

Schenectady Chemical Co.
518-370-4200

[8] Copper Foil Suggested Sources:

E. Jordan Brookes Co., Inc.
510-770-1500

A.J. Oster Co.
800-321-9750

[9] Electrical Tape Suggested Sources:

3M
Electrical Specialties Div.
800-328-1368

Permacel
Electrical Tape Products
714-523-7113

Tesa Tape Inc.
Electrical Tapes
704-554-0707

[10] Electrical Sleeving/Shrink Tube Suggested Sources:

Markel Corp.
215-272-8960

Bentley Harris Mfg. Co.
800-926-2472

Zeus Industrial Products, Inc.
800-526-3842

Raychem Corp.
800-272-9243

[11] Bobbin Suggested Sources:

Lodestone Pacific
714-970-0900

Plastron-Yarbrough-Timco
630-595-2212

Cosmo Corp.
216-498-7500

[12] Coil Forms Suggested Sources:

Lodestone Pacific
714-970-0900

Paramount Tube Div.
219-484-4111

Dorco Electronics
213-636-9146

Precision Fiberglass Products
310-539-7470

[13] Bobbins with Pins Suggested Sources:

Plastron-Yarbrough-Timco
630-595-2212

Mc Elroy Electronics Corp.
508-425-4055

Lodestone Pacific
714-970-0900

[14] Varnish/Epoxy Suggested Sources:

John C. Dolph
908-329-2333

Epoxylite/Ripley Resin Co.
949-951-3231

3M
Electrical Specialties Div.
800-328-1368

ResTech Resin Co.
800-992-9799

Schenectady Chemical Co.
518-370-4200

[15] Adhesives Suggested Sources:

Loctite Corp.
Industrial Group
800-243-4874

3M
Electrical Specialties Div.
800-328-1368

[16] Sheet Film/Insulation Suggested Source:

E.I. Du Pont & Co.
302-999-3705

[17] Adhesive Study Reference:

Philips Components
Report #9398-083-20011
1-800-223-3850 (Eastern Components)