# Bobbin and Core Evaluations for Transformer Designs is Not For Dummies

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This article will highlight the many significant issues the magnetic design engineer must consider when selecting the best bobbin and core combination for their transformer application.

## Selecting the Optimum Bobbin and Core Combination

The bobbin or coil former is the wire winding and termination platform and represents the heart of the transformer. It supports the winding, aligns the cores, channels the winding and provides a termination and connection method. Each bobbin will have been designed for use with a specific core shape, whether that core is ferrite, iron powder, alloy powder, stacked laminations, or tape wound. Since there are so many ways an engineer can design any given transformer, it is important to understand other factors, in addition to performance demands of the application, in making the best bobbin and core combination selection. Product cost, availability, material limitations, safety agency requirements and, ease of production are all-important considerations.

## Transformer Core Development

Back in the early days for transformers, steel was stamped into thin sheets and stacked to make low frequency "lamination" transformers in E and I shapes. The E and I shapes were used because it kept stamping process material waste near zero. (figure 1) As a result, bobbins had a square or rectangular center leg. Stamped lamination transformers continue to be made and used all over the world, and are characterized in both inches and millimeters.

As the frequency of applications increased, efficiencies in performance and assembly where gained by pressing ferrite, iron and alloy powders into shape variations of the traditional lamination shape. At first these pressed powder "E" cores shapes generally had a square or rectangular center legs to match existing bobbins for stacked lamination sizes.

When it came to core and bobbins sizes, part of the world used inches while the other MM. There are some exceptions, but most inch-based cores need inch-based bobbins, and visa versa. To add to the confusion, USA and United Kingdom E-core and bobbin combinations are most often characterized by the size of the core center leg in inches,(same as the bobbin window) a convention held over from stamped laminations. European and Asian E-core and bobbin combinations use the length of the E core back leg in millimeters (mm) to characterize the size. (link to inch and mm cross reference)

Pressed powder cores allowed more shape variation than stamping two dimensional laminations. Round center legs for ease in winding, and core skirts to enhance shielding were developed.

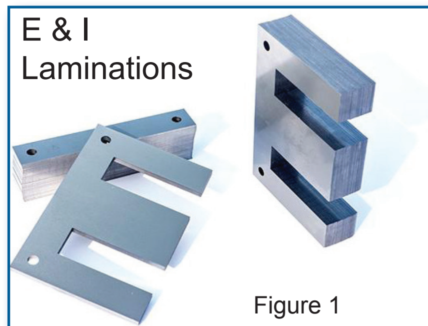



Figure 1

**Core and Bobbin Considerations**

1) Vertical or Horizontal assembly orientation,

2) Bobbins Plastic materials based on; environmental conditions, Safety Agency Insulation requirements, temperature class, flammability rating.

3) Winding Characteristics: Wire gauge, multiple windings, number of turns for each winding and how to connect the windings to the terminals and the bobbin assembly to the PCB.

4) Connection Considerations; PCB, or hard wire connection. If PCB connection, through hole, or surface mount terminals. Terminal type and spacing.

5) Safety Agency Considerations. UL1446 requirements. The need for a bobbin with separated winding sections. Barrier and insulation tape to isolate windings. Creepage and clearance requirements.

6) Availability and Production Considerations

As new shapes were developed to meet specific application requirements, new bobbins were developed to support the new cores shapes.

These new shaped cores are dimensioned in both inches and mm, but industry conventions are that they are characterized by the cores dominate dimension, generally the length of the back of the cores, in mm. In contrast to EI, EE and EF square center leg cores with their varied and confusing size conventions, the newer shapes enjoy a more universal size and shape designations.

## Core and Bobbins System Development

Electronics is a competitive market, so cost vs. performance is an important consideration. The size of the consumer electronics device is also important to success in the market, so smaller components are preferred. Inducing the same energy into smaller core and bobbin assemblies can generate more heat in the assembly. The need for ever smaller transformers is common in inductors and transformers used in lower frequency power applications, and as a result the core shapes are more open are to allow heat to escape the system.

In addition to converting energy into a magnetic field, core materials are quite good an containing the magnetic field and shielding this field from adjacent components. As a result, some core shapes are designed to contain and shield the magnetic field. This is especially true in higher frequency applications where stray magnetic forces can affect frequency sensitive adjacent components.

As cores have evolved to new applications, the bobbins have evolved to match. The shape and size of the bobbins will be determined by the core set selected for a particular application. Whether the bobbins are for an application with a focus on magnetic shielding, or heat dissipation, the bobbin will be selected to match a wide variety of application attributes.

Designing a safe and cost effective inductor or transformer is not trivial, and the efficiencies in performance, manufacturability and overall cost will be tied to bobbin selection. After core shape and assembly size are determined, the designer has several other attributes to consider:

## Vertical or Horizontal Assembly Orientation

Inductor or transformer assemblies can have either a horizontal or vertical orientation and bobbins are available in both orientations. Vertical orientation with the bobbin window perpendicular to the PCB, has a smaller PCB footprint, but will usually be taller. If PCB space is at a premium, and the electronic enclosure has enough room, vertical orientation may be preferred where the bobbin widow is parallel to the PCB. If the inductor or transformer is to be surfaced mounted to the PCB, horizontal is preferred since a low center of gravity will reduce the strain on PCB solder joints.

| Core Shape Evaluation | ER | RM | EP | EFD | EPC | PQ | EE/EF | US LAM | MM LAM | EER | ETD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Magnetic Shielding | Good | Good | Great | Fair | Fair | Fair | Poor | Poor | Poor | Poor | Poor |
| Heat Dissipation | Fair | Poor | Poor | Good | Good | Good | Great | Great | Great | Great | Great |
| Winding Flexibility | Good | Good | Good | Good | Good | Good | Great | Great | Great | Great | Great |
| SMD or Through Hole | Both | Both | Both | Both | Both | TH | Both | TH | TH | TH | TH |
| Winding Cost | Moderate | Moderate | Moderate | Moderate | Moderate | Moderate | Low | Low | Low | Low | Low |
| Relative Bobbin Cost | Moderate | Moderate | Moderate | Moderate | Moderate | Moderate | Low | Low | Low | Low | Moderate |
| Ease in Gapping | Moderate | Moderate | Difficult | Moderate | Moderate | Moderate | Easy | Easy | Easy | Easy | Easy |
| Typical Applications<br>Linear Transformers<br>Communications/RF<br>Switch Mode Power<br>Current Transformer | Unlikely<br>Yes<br>Possible<br>Possible | Unlikely<br>Yes<br>Possible<br>Possible | Unlikely<br>Yes<br>Unlikely<br>Possible | Unlikely<br>Possible<br>Yes<br>Possible | Unlikely<br>Possible<br>Yes<br>Possible | Unlikely<br>Possible<br>Yes<br>Possible | Yes<br>Possible<br>Yes<br>Possible | Yes<br>Unlikely<br>Yes<br>Possible | Yes<br>Unlikely<br>Yes<br>Possible | Possible<br>Possible<br>Yes<br>Possible | Possible<br>Possible<br>Yes<br>Possible |

## Bobbins Plastic Materials

The plastic material a bobbin is molded from is important to safety agency regulations, performance, as well as cost. There are a wide variety of materials to choose from and each material will have advantages and disadvantages depending on the application. In general, the higher the temperature a material can tolerate, the more expensive a bobbin molded from that will be.

The engineer needs to understand the operational environment of the finished device to select the material that will meet safety agency requirements. There are several agency determined temperature classes that cover working environments ranging from an office, to a truck engine compartment. Each temperature class will have different performance criteria for the plastic molded bobbin. See Figure 1

In addition, the plastic needs to tolerate soldering temperatures for a brief period during the manufacturing and PCB insertion process. How much heat a plastic molded bobbin will need to tolerate is an important material consideration. (See Figure 2)

| UL Class | Max Temperature Rating |
|---|---|
| A | 105˚C (221˚F) |
| B | 130˚C (266˚F) |
| F | 155˚C (311˚F) |
| H | 180˚C (356˚F) |
| N | 200˚C (392˚F) |
| R | 220˚C (428˚F) |
| S | 240˚C (464˚F) |

Figure 2

The plastics used in bobbin molding fall into two main groups, thermoplastic and thermoset.

Thermoplastic materials are the most widely used in bobbin molding and are readily available. Thermoplastic bobbins are inexpensive and capable of meeting many agency heat and flammability requirements when mixed with mineral, quartz, or glass fillers.

Thermoset materials are more expensive but offer the greatest strength and temperature performance. DAP (Dially Phthalate) and Phenolic plastic are well suited for bobbin applications and are especially stable in high temperature applications.

In addition to temperature class regulations, a plastic's ability to resist burning, or its flammability rating, is also a critical factor. Safety agencies like Underwriter's Laboratory (UL) has specific flammability requirements depending on the working environment of the finished product. Referred to as UL94, this regulation classifies plastic materials on their ability to self extinguish when put in contact with, and then removed from an open flame. In most applications, the highest flammability rating of UL94VO is preferred. (See Figure 3)

Plastic molded bobbins must also meet the requirements of UL746, which requires the plastic used in molding the bobbin be traceable by

| Plastic Type | Mat'l Code | Mfg | Trade Name | UL Card No. | UL Flameability | System Class ** | RoHS Compliant |
|---|---|---|---|---|---|---|---|
| **THERMOSET** | | | | | | | |
| Phenolic | PH | Sumitomo | PM-9630 | E41429 | UL94-VO | N (200˚C) | Yes |
| Phenolic | PH2 | Sumitomo | PM-9820 | E41429 | UL94-VO | N (200˚C) | Yes |
| Phenolic | PH3 | Chang Chun | T357 / T373J / T375J | E59481 | UL94-VO | F (155˚C) | Yes |
| Dially Phthalate | DAP | Synress-Amico | 5562 | E48036 | UL94-VO | F (155˚C) | Yes |
| Dially Phthalate | DAP2 | Cosmic | D72 | E64213 | UL94-VO | F (155˚C) | Yes |
| Dially Phthalate | DAP3 | Sumitomo | 52-70-70 | E123472 | UL94-VO | F (155˚C) | Yes |
| **THERMOPLASTICS** | | | | | | | |
| Glass Filled Nylon | GFN | DuPont | FR50 | E41938 | UL94-VO | F (155˚C) | Yes |
| Glass Filled Nylon | GFN2 | DuPont | 70G33L | E41938 | UL94-HB | F (155˚C) | Yes |
| Glass Filled Nylon | GFN3 | DuPont | 132F/101L (Zytel) | E41938 | UL94-V2 | B (130˚C) | Yes |
| Glass Filled Nylon | GFN4 | RTP | RTP205FR | E84658 | UL94-VO | F (155˚C) | Yes |
| Glass Filled Nylon | GFN5 | DSM Co. | TE250F8 (Stanyl) | E172082 | UL94-VO | B (130˚C) | Yes |
| Polyethylene | PET | DuPont | FR530 (Rynite) | E41938 | UL94-VO | N (200˚C) | Yes |
| Poly Butylene | PBT | Chang Chun | 4130 | E59481 | UL94-VO | B (130˚C) | Yes |
| Polyphenylene | PPS | Phillips | R-4 (Ryton) | E54700 | UL94-VO | F (155˚C) | Yes |
| Liquid Crystal | LCP | Sumitomo | E4008 | E54705 | UL94-V0 | F (155˚C) | Yes |
| Liquid Crystal | LCP2 | DuPont | 6130L (Zenite) | E41938 | UL94-VO | N (200˚C) | Yes |
| Liquid Crystal | LCP3 | Nippon | HM402 | E91944 | UL94-VO | F (155˚C) | Yes |

**Insulation System Class Temperature is for use as mechanical support. Review specific insulation systems to determine if the material is suitable as a ground insulation or as mechanical support at a higher temperature class.

| UL94 Rating | Flammability Specifications |
|---|---|
| VO | Will support combustion for up to 10 seconds and self extinguishes when tested under specific conditions. |
| V1 & V2 | Will support combustion for up to 30 seconds and self extinguishes when tested under specific conditions. V2, dripping melted material allowed. |
| V5 | Will support combustion for up to 60 seconds after 5 test burnings of 5 seconds each and self extinguishes when tested under specific conditions. |

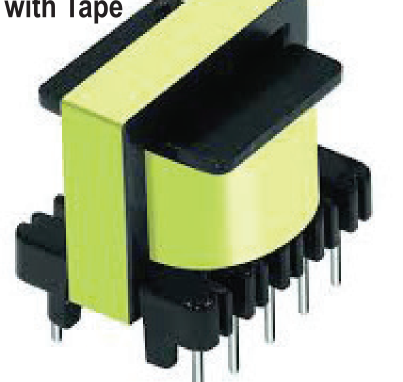
Figure 3

batch number through the molding operation back to the plastic manufacturer. This is to ensure that only the plastic material recognized by UL is actually used to make the bobbin. Often lower quality plastics with poor temperature characteristics are substituted to save cost. Saving cents on a bobbin at the risk of expensive equipment is a bad gamble. ( Link to Cost of Quality) The design engineer and the purchasing department must be confident that the source for the bobbins has the procedures and documentation in place that assures material traceability to approved plastics.

## Winding Characteristics

One of a bobbin's primary function is to hold and position the wire winding that will generate the magnetic field

Vertical EE Core, Bobbin with Tape



in the core. The number of windings, or "turns" and the characteristics of the winding will be determined by the specific application and will vary from design to design. In addition, current, capacitance and resistance considerations will influence the winding wire gauge used. The design engineer will need to choose a bobbin that will accommodate both the number of turns in the winding and the wire gauge, while providing way to connect the assembly to the rest of the circuit. Most bobbins for PCB connection will use wire gauged between 30 and 18. Heavier wire gauges often use a terminal block for hard wire connection with the heavier inductor or transformer bolted to an enclosure or chassis with mounting brackets.

## Connection Considerations

Not all bobbins will have terminals attached. Bobbins used with PCBs will have terminals to facilitate PCB insertion. Terminal size and shape will vary depending on the size and nature of the winding wire that will be used. The bobbin needs to provide input and output terminal connections for each of the windings in the assembly. Also surface mount or through-hole terminal styles must be evaluated. Practically all bobbins are available with through-hole terminals, but only selected smaller core and bobbin combinations are available in surface mount. This is primarily do to the weight of the assembly and the limitations of pick and place equipment.

Soldering is the most widely used method for connecting transformers and inductors to a PCB. Bobbin terminals will be plated with tin or tin alloys to ensure a low a resistance connection. The integrity of the solder connection will depend on the integrity of the terminal plating. A terminals "solderability" is an important quality attribute and should be verified.

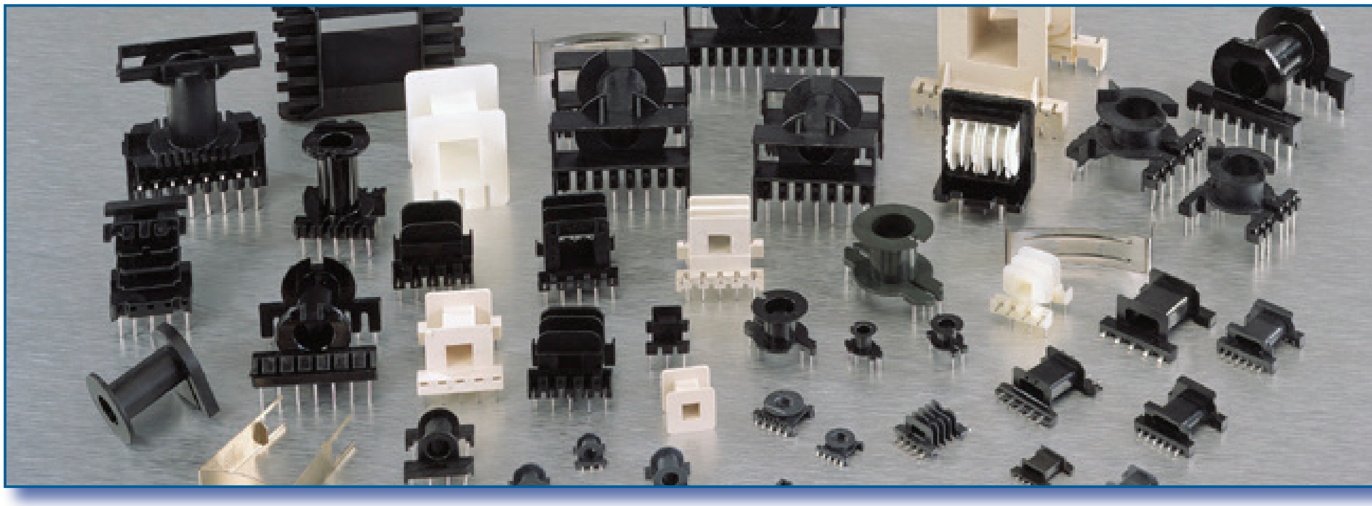
Transformers will have a least two windings, a primary and secondary, and the bobbins will provide the input and output terminal connections. Safety agencies will require these windings be isolated from each other by using insulated wire, high dielectric tape, paper, and or varnish to isolate the windings from each other. It is not unusual for a transformer bobbin assembly to have separate windings areas molded into them that isolate the windings from each other. Multi-section bobbins have molded walls or barriers that divide the winding area into two or more parts. This allows for the isolation of the windings in high voltage applications. Safety agencies may require additional winding isolation protections, so bobbins can be fitted with shrouds or covers.

## Safety Agency Requirements

In addition to regulations concerning the bobbin material, additional safety agency requirements cover the construction of the entire transformer or inductor. There are several agencies with responsibilities that cover a variety of applications, market segments, and geographic areas. These regulations are concerned with insulation and spacing to protect against an electrical short in the winding over time and with thermal aging. UL 1446 regarding motor, transformer and coil insulation is the primary specification in the United States that governs the insulation requirements of these products. UL 510 is another important regulation for electronic tape flammability, which will often be part of a transformer or inductor design.

## Availability Considerations

Bobbin and core availability is also a critical issue. With product design cycles getting shorter, it is important that the product is available to meet production deadlines. Checking with core manufacturers, distributors and bobbin manufacturers, will give you a good indication on available stock and lead times for bobbin and core combinations.



While several bobbin molders will make bobbins for a standard ferrite or lamination size, they may all have slight differences. The most common differences include; wire slots and flange shape, locator marks or notches, standoffs, material, terminal shape and terminal style. When evaluating bobbins, it is recommended that the design engineer request a sample from the bobbin molder.

## Production Considerations

Production consideration is another key factor in bobbin and core selection. The winding method, the wire size to be used, bobbin capacity, and assembly techniques must be carefully reviewed to make sure they are compatible with production capabilities.

Bobbin and core combinations with round center legs are well suited for machine winding. Where as in square leg E-cores and bobbin combinations, the wire will not lay flat as it is wound around the bobbin corner and creates loops and gaps between the wire and the bobbin. This increases leakage inductance and can hurt the performance of the transformer.

Bobbin capacity or fill should be calculated so that approximately 90% of the bobbin's capacity is filled with magnet wire. This will optimize the assembly by achieving maximum magnetic coupling.

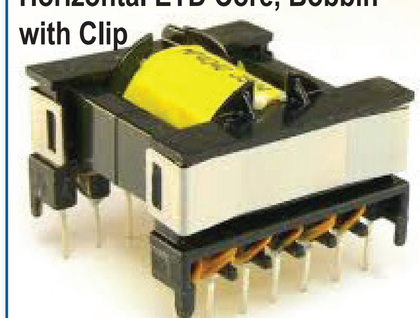
In most bobbin and core assembly, the two parts of the core material must be joined through the bobbin. It is important that the cores are firmly pressed together to assure consistency in performance. Some cores are glued together, others are taped, and others have spring metal clipping devices designed for that core and bobbin combination. Each bobbin and core assembly option should be considered to determine which is best for your assembly capabilities.

Depending on the number of "turns" and wire gauged used in the primary, and possible secondary winding, this wire is added to the bobbin by hand, or with the aid of a machine. The tension of the winding turns and how each layer is applied compared to the previous turn has an impact on performance and efficiency of the assembly.

Once the bobbin is wound, the winding leads need to be terminated. If the bobbin has terminals, the wire leads need to be soldered to those terminals. Care must be taken at his stage not to damage the bobbin with the heat of the soldering process. The melting point of Thermoplastics is in the same temperature range as typical solder operations. The metal terminals will transfer the solder heat to the plastic surrounding and supporting the terminal. If the solder heat is applied for more that a few seconds, the plastic will soften too much and the terminal may "float" or move out of alignment, making PCB insertion difficult. With thermoplastic bobbins, careful hand solder techniques or quick dips in a solder pot can solder the lead to the terminal without damaging the plastic. 130° C polynylese solder strippable magnet wire is commonly used to either solder dip or mechanical strip the insulation from the magnet wire close to termination pin, then wrap 1 to 2 turns minimum around the terminal. Hand solder at approximately 525°F (288°C) for five seconds with environmentally friendly 100% tin solder. Careful soldering technique will be important so termination to the bobbin terminal do not re-flow when soldered to the PCB.

Bobbins molded from Thermoset plastics have melting points that are higher than the solder melting point and tolerate higher solder temperatures. Another method when using polynylese magnet wire is to wrap the unstripped wire around the terminal and elevate

**Horizontal ETD Core, Bobbin with Clip**



the solder pot temperature to around 700° F (371°C) using 100% tin solder. The bobbin terminals are dipped into the solder and allowed to soak for two seconds. This will strip and solder the wire to the terminal in one step.

Once the winding leads have been soldered to the bobbin's terminals, the bobbin will be soldered in a PCB. An important factor is whether the heat applied to the terminal while soldering the terminal to the PCB will reflow and weaken the winding lead to terminal solder connection accomplished earlier in the process. One method for avoiding this problem is to use a higher melting point solder to connect the leads to the bobbin terminals, then use a lower temperature solder to make the PCB connection.

**Horizontal EER Core, Bobbin Solder Terminated Winding**

## Core and Bobbin Combination and their Advantages

Core and Bobbin combinations can be divided into two groups, depending on whether they are used in telecommunication or power conversion applications. Lower power and low heat dissipation, but high-shielding requirements characterizes the telecommunication group. Higher power and heat dissipation and energy storage requirements characterize the power group.

The telecommunications group of core and bobbin combinations includes Pot Cores, RM cores and EP cores. These assemblies were designed to use smaller magnet wire in a more closed structure to provide excellent magnetic shielding.

### Higher Frequency Group

### Pot Cores

• Pot cores were introduced in the early 1960's and are the oldest of the group. They were used primarily in oscillators, tone generators and coupling transformers. Many core manufacturers are discontinuing some pot core sizes due to declining popularity. Pot core sizes 22/13, 26/16, and 30/19 are still being designed in power converters, although the newer RM core has become a more popular alternative.

• Core Materials: Available in ferrite, iron powder and alloy powder.

• Core cost: Pot core costs are moderate to high due to lower production volumes and a more complicated shape.

• Bobbins: Low cost glass filled thermoplastic bobbins with through hole terminals are most common, but few surface mount bobbins are available The bobbin cost is relatively low.

**RM Cores**; Sizes RM4 RM6, RM8, RM10, RM12, RM14

• RM cores offer a larger wire egress slots than a pot core and can accommodate larger magnet wire. They also take up less PCB space than pot cores.

• Core Materials: Usually ferrite material.

• Core Cost: RM cores are relatively low in cost.

• Bobbins: There are many through hole bobbin options available in both thermoset and thermoplastic materials. Some surface mount versions are available. The bobbin cost is relatively low.

**EP Cores**; Sizes EP 7 EP 10, EP13, EP17, EP 20.

• EP Cores have been popularity with design engineers. They provide very good magnetic coupling in a compact space.

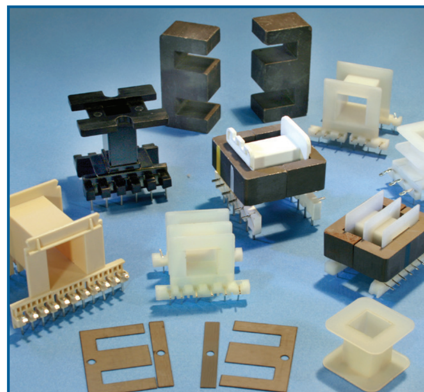
• Core Materials: Usually ferrite material.

• Core Cost: EP core costs are moderate.

• Bobbins: Surface mount and through hole bobbins are available. The surface mount bobbins are more popular in thermoplastic LCP while the through hole versions are popular in thermoset plastic. The bobbin cost is moderate.

### Power Group

The power groups designed primarily for power switching transformers include the E cores, ETD cores, PQ cores and EFD cores. The ferrite material composition used on this group provides lower core loss at elevated temperature and higher frequency power switching.



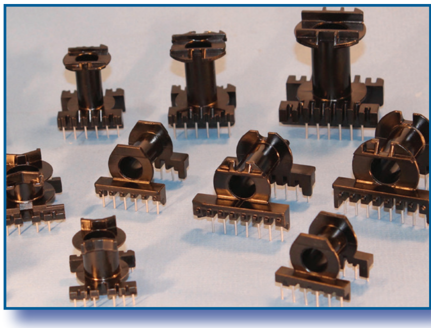
**LAMINATIONS, E, EI and EF Cores:** Sizes EE10 through EI200.

• This is the largest selection available of any power ferrite shapes. However, due to the square or rectangular center leg, the ferrite shapes are limited to low frequency switching under 150 kHz because winding inefficiencies causing high leakage inductance. Due to the more open shape of E-cores, shielding the core with copper foil recommended for EMI suppression.

• Core Materials: Steel laminations, ferrite, iron powder and alloy powder material.

•Core Cost: Laminations and E core costs are relatively low.

•Bobbins for this group are readily available in many configurations. The selection includes vertical or horizontal, surface mount and through hole, thermoset and thermoplastic, and multi-section. The bobbin cost is relatively low



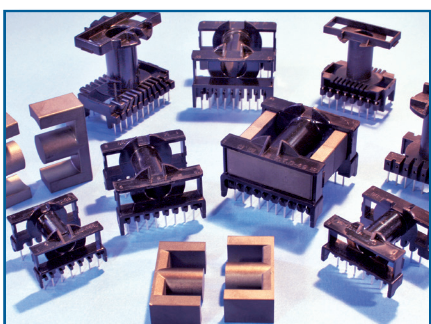
**EER Cores;** Sizes EER2818, EER2824, EER2828, EER2834, EER3541, EER4045, EER4249, EER4955

• Similar to ETD cores, these cores have a round center post which makes the winding of magnet wire or foil easy. They are most often used in high power switching frequency to 600 kHz. This shape is good for improved magnetic coupling.

• Core Materials: Usually ferrite material, but powder shapes possible.

• Core Cost: EER cores cost are moderate.

• Bobbins are readily available in vertical or horizontal orientations with through holes. They are also available in both thermoset and thermoplastic materials. Surface mount is generally not available. Multi-section bobbins are available. Bobbins usually have moderate sized terminals to facilitate connection of larger magnetic wire. The bobbins are easy to use and the costs are moderate.



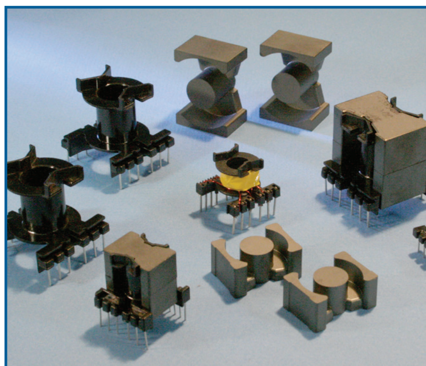
**ETD Cores;** Sizes ETD 29, ETD 34, ETD 39, ETD 44 ETD 49, ETD 59.

• Similar to EER Cores these cores have a round center post which makes the winding of magnet wire or foil easy. They are most often used in high power switching frequency to 600 kHz. This shape is good for improved magnetic coupling.

• Core Materials: Usually ferrite material.

• Core Cost: ETD cores cost are moderate to high.

• Bobbins are readily available in vertical or horizontal orientations with through holes. They are also available in both thermoset and thermoplastic materials. Surface mount is generally not available. Multi-section bobbins are available. Bobbins usually have moderate sized terminals to facilitate connection of larger magnetic wire. The bobbins usually include a metal clip, so the costs are moderate to high.



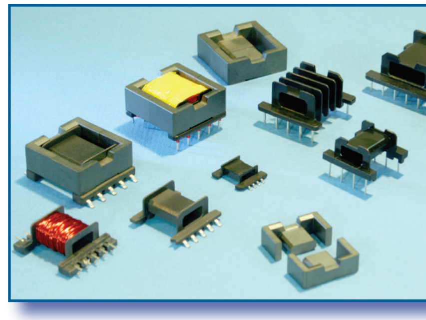
**PQ Cores;** Sizes PQ2016, PQ2020, PQ2610, PQ2614, PQ2620, PQ2625, PQ3214, PQ3220, PQ3230, PQ3535, PQ4040.

• PQ cores have round center posts and this circular geometry makes these cores very popular. They also provide excellent shielding, good magnetic coupling, ease of winding and ease of assembly.

• Core Materials: Ferrite, iron powder and alloy powder material.

• Core Cost: PQ core cost is moderate.

• Bobbins; PQ bobbins are readily available in the horizontal orientation with through holes. They are also available in both thermoset and thermoplastic materials. Surface mount is generally not available. Bobbins usually have moderate sized terminals to facilitate connection of larger magnetic wire. The bobbin is easy to use and the costs are low to moderate.



**EFD Cores;** Sizes EFD 10, EFD 15, EFD 20, EFD 25, EFD 30.

• These cores are low profile, with a high effective area, (Ae). This makes EFD cores desirable for lower power switching transformers. EFD cores provide good coupling and shielding.

• Core Materials: Usually ferrite material but powder cores are available.

• Core cost is moderate.

• Bobbins: Excellent bobbins are readily available in the horizontal orientation with through holes and surface mount terminals. They are also available in both thermoset and thermoplastic materials. Bobbin cost is moderate.

Ask Lodestone Pacific about custom bobbin and terminal configurations.

## Conclusion

When designing and specifying a bobbin and core combination, attention is initially paid to the performance of the core. The designer must realize that the bobbin, and not the core, will have the greatest impact on the nature and ease of the winding operation, the winding lead termination, safety regulations and PCB insertion. The bobbin will have a larger impact on the cost of manufacturing the assembly than the core. Moreover, the bobbins will be at least as important as the core to the long-term success of the transformer or inductor in operation. When the transformer is properly designed assembled, finished and tested it will be one of the last components to fail in any system.

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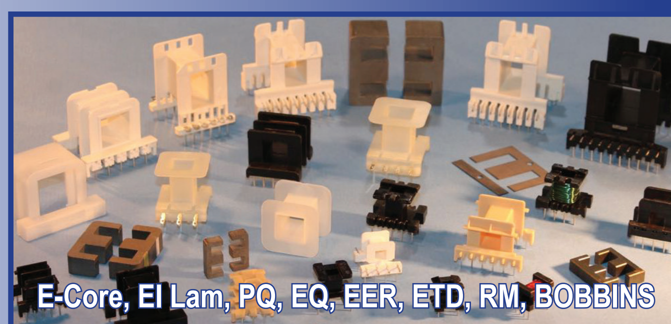
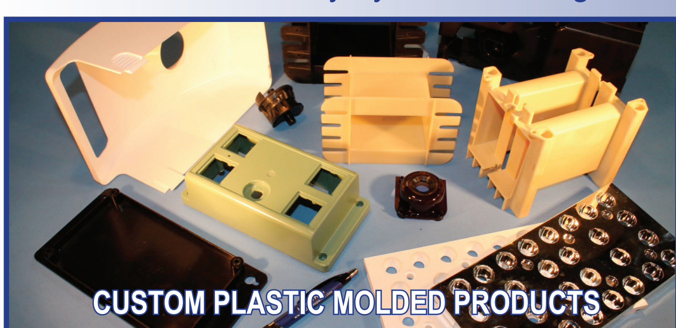
- World Class Quality Systems and Logistics





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