TOPSwitch® Flyback Transformer Construction Guide

Application Note AN-18

Introduction

This application note is a design and construction guide for margin wound or triple insulated wire wound flyback transformers suitable for use with *TOPSwitch*. Margin wound and triple insulated wire transformer designs are derived in Appendix B for a 12 V, 15 W universal input power supply with secondary regulation, using the step-by-step procedure developed in application note AN-16. It is assumed that the reader is already familiar with *TOPSwitch* and the fundamental principles of flyback power supplies. This information can be found in the *TOPSwitch* data sheets, and application notes AN-14 and AN-16. More details on flyback transformer theory and design can be found in AN-17.

Required Reference Materials:

This application note, AN-16, and AN-17 provide the necessary techniques for design and construction of flyback transformers for *TOPSwitch* applications. In addition, the following reference materials are required to provide dimensional and electrical data for cores, bobbins, and wire. Sources for these reference materials are listed in Appendix A.

Ferrite Core Manufacturer's Catalogs

Ferrite core manufacturers publish catalogs supplying core dimensions and electrical characteristics used in transformer design. Some manufacturers also provide additional engineering information for the more popular core sizes, such as A_L vs. gap and core loss curves. The catalogs for the manufacturers listed in Appendix A supply basic electrical data for common US, Asian, and European core types. For core sizes common to several manufacturers, the electrical characteristics given by one core manufacturer can be used for a core of the same physical dimensions from another manufacturer.

Bobbin Manufacturer's Catalogs

Bobbin manufacturer's catalogs are used to provide mechanical dimensions for transformer design. The bobbin manufacturers in Appendix A offer a wide variety of bobbin styles for standard ferrite core sizes in materials suitable for high volume production. Many ferrite core manufacturers also carry bobbins for their standard core sizes.
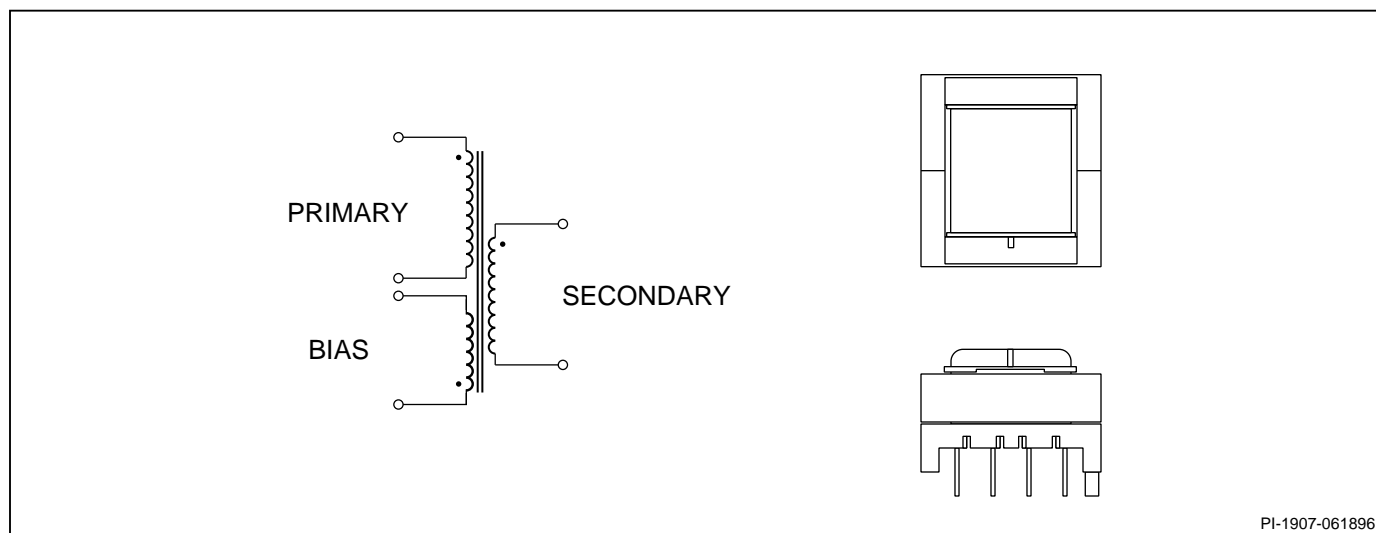

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Figure 1. Typical Flyback Transformer Using EE Core.

Wire Table

A wire table provides dimensional and electrical characteristics for magnet wire, and is used to select appropriate wire sizes for transformer design. There are three major wire sizing systems: AWG, SWG and metric. All wire sizes used in this application note are based on AWG sizing. A wire table is provided in Appendix A with data on AWG wire sizes from 18 gauge through 44 gauge. SWG and metric equivalents to AWG wire sizes are also shown. A wire table is also available in reference 5. Wire tables can be obtained from some of the magnet wire manufacturers listed in Appendix A.

Transformer Construction Materials

The following paragraphs describe the basic materials needed to construct switching power supply transformers.

Ferrite Cores

Appropriate ferrite materials for 100KHz flyback transformers are TDK PC40, Philips 3C85, Siemens N67, Thomson B2, Tokin 2500 or other similar materials. A wide variety of core shapes are available. E cores are the best choice for transformer cores for reasons of low cost, wide availability, and lower leakage inductance. Other core shapes and styles such as the ETD, EER and EI are also usable. A chart of suitable ferrite core types for various power levels and transformer construction types can be found in Appendix A.

Bobbins

Bobbins for off-line flyback transformers should be chosen with regard to the safety creepage distances required by the applicable safety regulations. Particular areas of consideration are the total creepage distance from primary pins to secondary pins through the core, and the creepage distance from primary pins to the secondary winding area. With some bobbin styles, extra insulation may be necessary to meet the creepage requirements. Bobbins should preferably be made from thermosetting materials such as phenolic resin in order to withstand soldering temperatures without deformation. Polybutylene or polyethylene terphthalate (PBT, PET) and polyphenylene sulfide (PPS) are also acceptable materials, though more sensitive to high temperatures than phenolic resins. Nylon should be avoided if possible, as it melts easily at the temperatures required to effectively terminate the transformer windings to the pins on the bobbin. If Nylon bobbins are used, they should be made with glass reinforced resin with a temperature rating of 130°C.

Insulating Materials

A common insulating material used in transformers is polyester or Mylar, available in sheet or tape form. This material is also manufactured as an adhesive tape that is particularly useful in transformer construction. US manufacturers of this tape include 3M, Tesa, and CHR. For creepage margins in transformers, it is desirable to use a thick tape so that the required build for a margin can be achieved using relatively few layers. Several manufacturers make a polyester film/mat tape that is useful for this application.

Magnet Wire

Some typical domestic manufacturers of magnet wire are Belden, Phelps Dodge, and Rea. The preferred insulation for magnet wire is a nylon/polyurethane coating. This coating burns off in contact with molten solder, allowing the transformer to be terminated by dip tinning in a solder pot. This type of insulated magnet wire is available from almost all manufacturers under various trade names: Solderon, Nyleze, Beldsol, etc. The insulating coating should be "heavy" or "double" to better withstand the stress of handling and the winding process. Ordinary enameled wire or polyimide wire insulation should not be used, as these types of insulation must be stripped mechanically or with chemical stripping agents in order to terminate the wire to the transformer pins.

Triple Insulated Wire

Triple insulated wire can be used to simplify and reduce the size of transformers where safety isolation is required. The type of triple insulated wire useful for transformer construction consists of a solid wire core with three distinct and separable layers of insulation. Three manufacturers of triple insulated wire are listed in Appendix A.

Sleeving

Insulating tubing is used to insulate the start and finish leads of windings in a margin wound transformer. The tubing should be recognized by the applicable safety agencies, with a minimum wall thickness of 0.4 mm to meet thickness requirements for reinforced insulation. The tubing should also be heat resistant, so that it does not melt when exposed to the temperatures required to solder the transformer lead wires to the pins on the bobbin. Materials commonly used for sleeving include Teflon tubing or polyolefin heat shrink tubing.

Varnish

Many transformer manufacturers impregnate their finished transformers with a suitable electrical varnish. By filling the voids inside the transformer, the varnish improves heat transfer from the windings to the environment, and enhances the voltage withstand capability of the transformer insulation. It also locks the core and windings in place to help prevent audible noise and protects the finished transformer from moisture. One disadvantage of varnish impregnation is that it adds a slow extra step to transformer construction. Some manufacturers of electrical varnishes are listed in Appendix A.

Transformer Construction Methods

In order to meet international safety regulations, a transformer for use in an off-line power supply must have adequate insulation between the primary and secondary windings. For transformers using standard cores and bobbins, there are two basic transformer insulation methods: margin wound construction and triple insulated wire construction.

Margin Wound Construction

International safety regulations require the following for transformers using magnet wire:

- Reinforced insulation between primary and secondary windings.

- Guaranteed creepage distance between primary and secondary windings where reinforced insulation is not used.

A cross-section of a typical margin wound transformer designed to meet these requirements is shown in Figure 2.

The creepage distance required between primary and secondary windings by safety regulations is typically 2.5 to 3 mm for supplies with 115 VAC input, and 5 to 6 mm for 230 VAC or universal input supplies. This creepage distance is maintained by physical barriers called margins. In most practical transformer designs, these margins are built up on each side of the bobbin using electrical tape, with the windings placed between them as shown in Figure 2. The total minimum creepage distance between primary and secondary windings is equal to twice the margin width M, as shown in Figure 3. This sets the minimum margin width at one half the required creepage distance, or 1.25 to 1.5 mm for 115 VAC input supplies, and 2.5 to 3 mm for 230 VAC or universal input supplies.

The necessary reinforced insulation between primary and secondary windings is provided using three layers of electrical tape, any two of which can withstand the full safety test voltage, which is 2000 VRMS for 115 VAC input supplies, and 3000
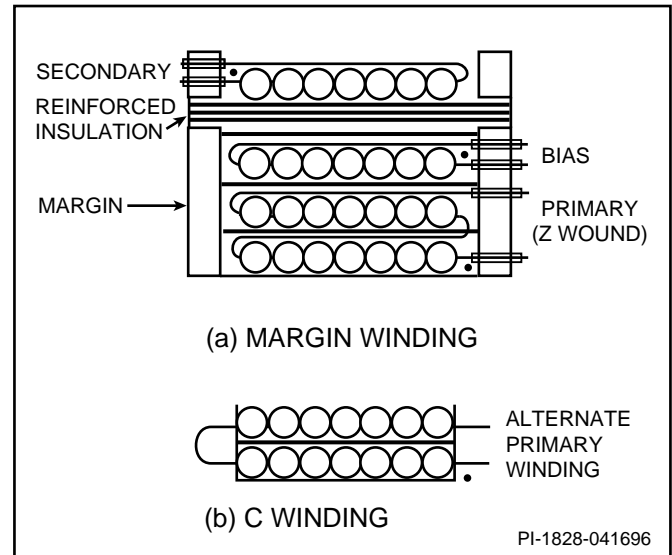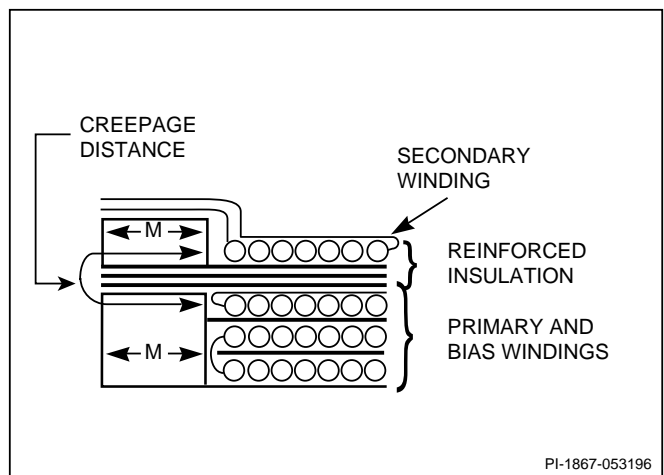
Figure 2. Margin Wound Transformer Cross Section.

Figure 3. Interwinding Creepage Distance for Margin Wound Transformers.

VRMS for 230 VAC input supplies. The tape layers should cover the entire width of the bobbin from flange to flange, as shown in Figure 2. A polyester film tape with a base film thickness of at least 0.025mm is sufficient for use in this application. The secondary windings are effectively "boxed in" by the margins and the reinforced insulation, isolating them from the primary. Since the start and finish leads of each winding pass through the margins to reach the transformer pins, they may require extra insulation to maintain the integrity of the margin insulation. Insulating tubing with a wall thickness of at least 0.4 mm is used to cover all start and finish leads of a margin wound transformer to meet this requirement. This insulation should extend from the transformer pin to inside of the margin barrier, as shown in Figure 4.

Use of margin winding techniques allows the construction of a transformer with ordinary magnet wire and readily available insulating materials. However, the necessity for margins, start and finish sleeving, and reinforced insulation results in a complex and labor-intensive transformer. The margins waste space inside the transformer, making it necessary to use a much larger core and bobbin size than could be used if the margins were not required. One alternative to margin wound construction is the use of triple insulated wire.

Triple Insulated Wire Construction

Triple insulated wire (Figure 5) has three separate layers of insulation, any two of which can withstand a safety hipot test voltage of 3000 VRMS. Triple insulated wire thus satisfies the requirements for a reinforced insulation per VDE/IEC regulations, and can be used to construct a transformer without the creepage margins required in a design using conventional magnet wire. A cross-section of a triple insulated wire transformer design is shown in Figure 6. The triple insulated wire design uses magnet wire for primary and bias windings, with a triple insulated secondary. This is generally the most cost effective and space-efficient way to utilize the benefits of triple insulated wire, as it is larger in diameter and more costly
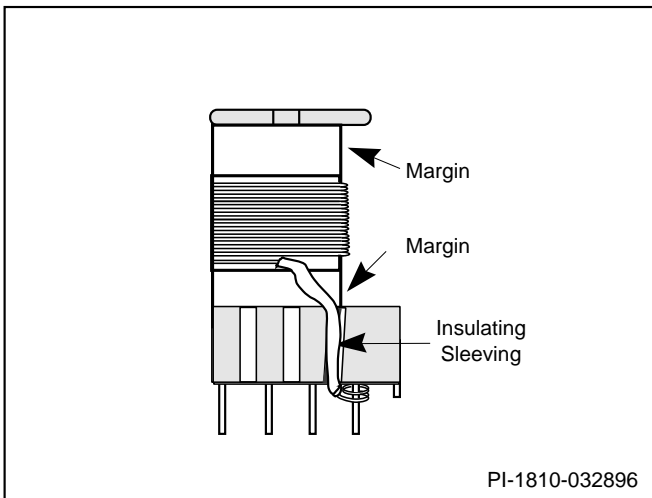

Figure 4. Use of Insulating Sleeving.

than the equivalent size of magnet wire. The secondary winding will usually require fewer turns of larger diameter wire than the primary, so the cost and space impact of the triple insulated wire is minimized. In a triple insulated wire design, the full width of the transformer bobbin is usable, due to the reinforced insulation provided by the triple insulated wire. A transformer using a triple insulated wire design will generally be 1/2 to 2/3 of the size of a transformer of the same power capability using a magnet wire design. Leakage inductance varies inversely with the width of the transformer windings, so leakage inductance for a triple insulated wire transformer will usually be less than that of an equivalent margin wound design, due to more efficient use of space on the transformer bobbin.

Transformer Construction Techniques

Figure 7 shows four styles of transformer construction for both primary and secondary regulated flyback power supplies, using margin wound and triple insulated wire techniques. These four styles are sufficient for almost all switching power supply requirements. The following paragraphs describe the considerations involved in selecting a particular construction style for an application, as well as additional considerations for reducing EMI, stray capacitance, and leakage inductance.

Winding Sequence

Figure 7 shows optimum winding sequencing for transformers for primary and secondary regulation schemes using margin wound and triple insulated wire construction. The factors involved in determining optimum winding sequencing and insulation placement are discussed below.
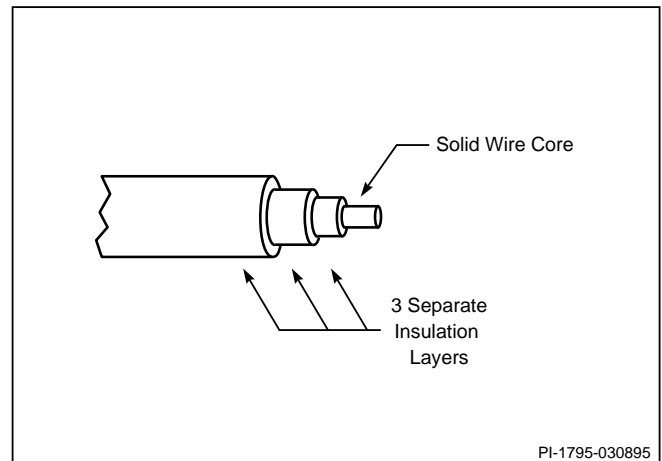

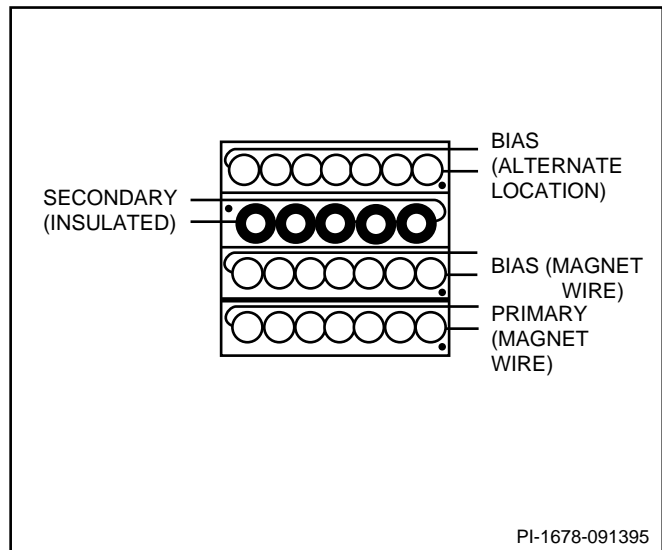*Figure 5. Triple Insulated Wire.*

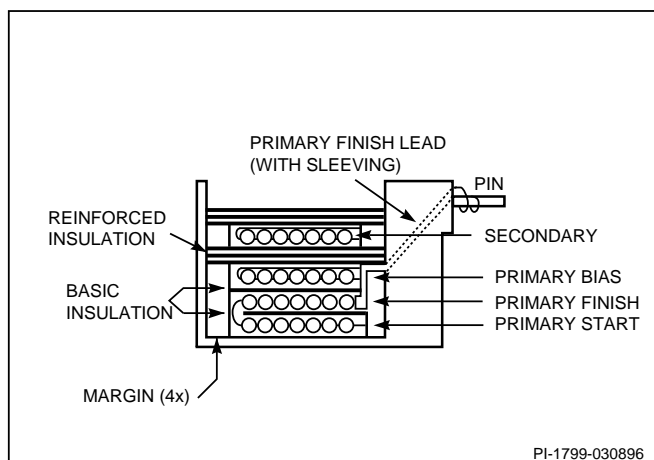*Figure 6. Triple Insulated Wire Wound Transformer Cross Section.*

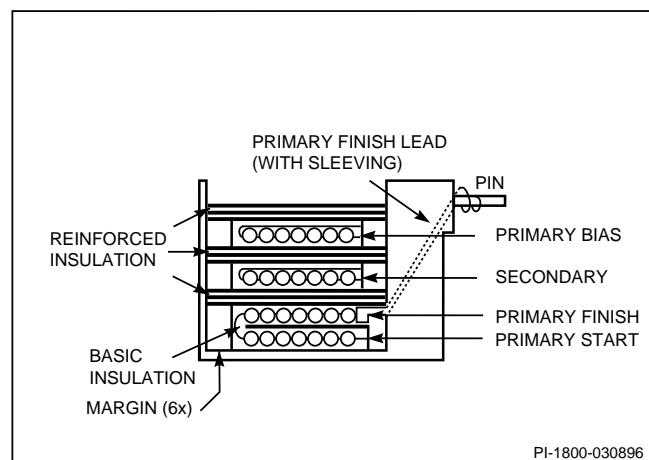Figure 7A. Margin Wound Secondary Regulated Transformer.

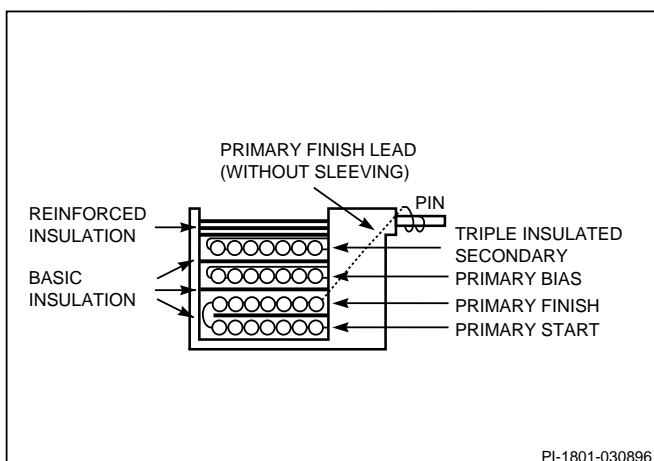Figure 7B. Margin Wound Primary Regulated Transformer.

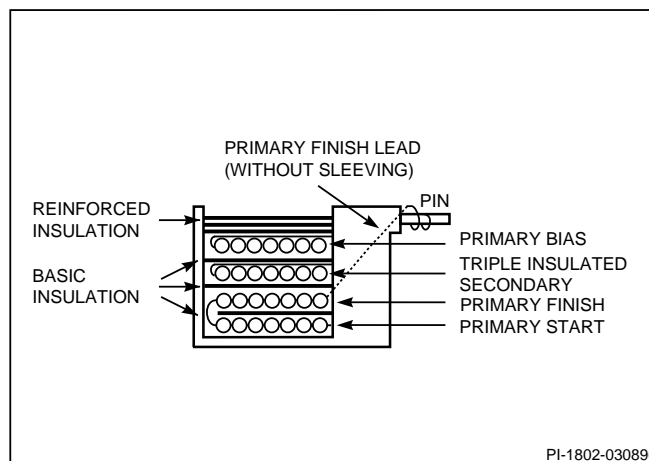Figure 7C. Triple Insulated Secondary Regulated Transformer.

Figure 7D. Triple Insulated Primary Regulated Transformer.

Primary Winding

In all the transformer construction styles depicted in Figure 7, the primary winding (or a portion of it) is always the first or innermost winding on the bobbin. This keeps the mean length of wire per turn as short as possible, reducing the primary winding parasitic capacitance. Also, if the primary winding is the innermost winding on the transformer, it will be shielded by the other transformer windings, helping to reduce noise coupling from the primary winding to adjacent components. The driven end of the primary winding (the end connected to the *TOPSwitch* drain) should be at the start of the winding. This allows the half of the primary winding with the largest voltage excursion to be shielded by other windings or by the second half of the primary winding, reducing EMI coupled from the primary side of the transformer to other parts of the supply. The primary winding should be designed for two winding layers or less. This minimizes the primary winding capacitance and the leakage inductance of the transformer. Adding a layer of tape between primary layers can reduce the primary winding capacitance by

a factor of four. This is especially important for low power applications using TOP200 and TOP210 to prevent spurious triggering of the *TOPSwitch* current limit by the initial current spike generated when *TOPSwitch* turns on and discharges the transformer winding capacitance.

Primary Bias Winding

The optimum placement of the primary bias winding will depend on whether the power supply uses a primary referenced or secondary referenced regulation scheme. If the power supply is regulated from the secondary side, the bias winding should be placed between the primary and secondary, as shown in Figures 7A and 7 C. When placed between the primary and secondary, the bias winding acts as an EMI shield connected to the primary return, reducing the conducted EMI generated by the power supply. In margin wound designs for secondary regulated supplies, placing the primary bias winding between the primary and secondary also minimizes the number of margins and reinforced insulation layers in the transformer.

For power supplies using a primary regulation scheme, the bias winding should be the outermost winding on the transformer, as shown in Figures 7B and 7D. This maximizes the coupling of the primary bias winding with the secondary, and minimizes coupling to the primary, improving the output regulation of the supply in two ways. With better coupling to the secondary, the bias winding responds more accurately to output voltage changes, improving regulation. Also, the resultant poor coupling of the bias winding to the primary helps to improve regulation by reducing peak charging of the bias output due to the primary leakage spike. If the bias winding is only loosely coupled to the primary, the leakage spike can be filtered by using a small resistor in series with the primary bias winding, improving the load regulation of the supply. This is discussed in greater detail in design note DN-8.

The primary bias winding should ideally form one complete layer across the width of the bobbin. If the bias winding has relatively few turns, this can be accomplished by increasing the size of the wire used in the bias winding, or using multiple parallel strands of wire. Increasing the fill factor of the bias winding in this manner improves the shielding capability of the winding in the case of the secondary regulated supply, and improves the secondary to bias coupling in the case of the primary regulated supply.

Secondary Windings

If a transformer has multiple secondary windings, the highest power secondary should be the closest to the primary of the transformer, in order to reduce leakage inductance. If a secondary winding has relatively few turns, the turns should be spaced so that they traverse the entire width of the winding area, for improved coupling. Using multiple parallel strands of wire will also help to increase the fill factor and coupling for secondaries with few turns. For multiple output secondary regulated supplies, auxiliary outputs with tight regulation requirements should be wound directly on top of the regulated secondary to improve coupling.

Multiple Output Winding Techniques

Instead of providing separate windings for each output in a multiple output supply, a common technique for winding multiple output secondaries with the same polarity sharing a common return is to stack the secondaries, as shown in Figure 8. This arrangement will improve the load regulation of the auxiliary outputs in a multiple output supply, and reduce the total number of secondary turns. The windings for the lowest voltage output provide the return and part of the winding turns for the next higher voltage output. The turns of both the lowest output and the next higher output provide turns for succeeding outputs. For the two output stacked winding example shown in Figure 8, the relation between output voltages V_1 and V_2 is given below:

$$V_2 = \left((V_1 + V_{D1}) \times \left(\frac{N_1 + N_2}{N_1} \right) \right) - V_{D2}$$

V_{D1} and V_{D2} are the rectifier forward voltage drops for D_1 and D_2, respectively. N_1 and N_2 are the winding turns for the V_1 and V_2 outputs.

The wire for each output must be sized to accommodate its output current plus the sum of the output currents of all the outputs stacked on top of it.

Insulation Requirements

Figure 7, in addition to showing optimum winding sequencing, also shows placement of basic and reinforced insulation to meet safety requirements and to improve consistency of the finished transformer.

For the margin wound secondary regulated transformer (Figure 7A), basic insulation (1 layer of electrical tape) is used between primary layers and between the primary and the bias winding. A layer of tape can also be useful between secondary windings to provide a smooth winding surface from one winding layer to the next. Reinforced insulation (three layers of tape) is used between the primary bias winding and the secondary. A three layer finish wrap completes the reinforced insulation for the secondary. There are four margins in this transformer: two for the primary and bias windings, and two for the secondary windings. Insulating sleeving is used on the start and finish leads of all windings. In Figures 7A and 7B sleeving is shown only on the primary finish lead for purposes of clarity. In practice, sleeving is used on the start and finish leads of all windings. The sleeving should extend as shown from the inside edge of the margin to the transformer pin.

For the margin wound primary regulated transformer (Figure 7B), basic insulation is used between primary winding layers. As in the secondary regulated transformer, a layer of tape can be used between secondary windings to smooth the winding surface. Reinforced insulation is required between the primary and secondary windings, between the secondary and primary bias windings, and as a finish wrap on top of the primary bias winding. In this transformer, there are three pairs of margins: one pair for the primary winding, one pair for the secondary winding, and one pair for the bias winding. Start and finish of each winding are sleeved as described above.

For the triple insulated secondary regulated transformer (Figure 7C), basic insulation is used between primary layers, between primary and bias, and between bias and secondary. The insulation reduces the capacitance of the primary winding
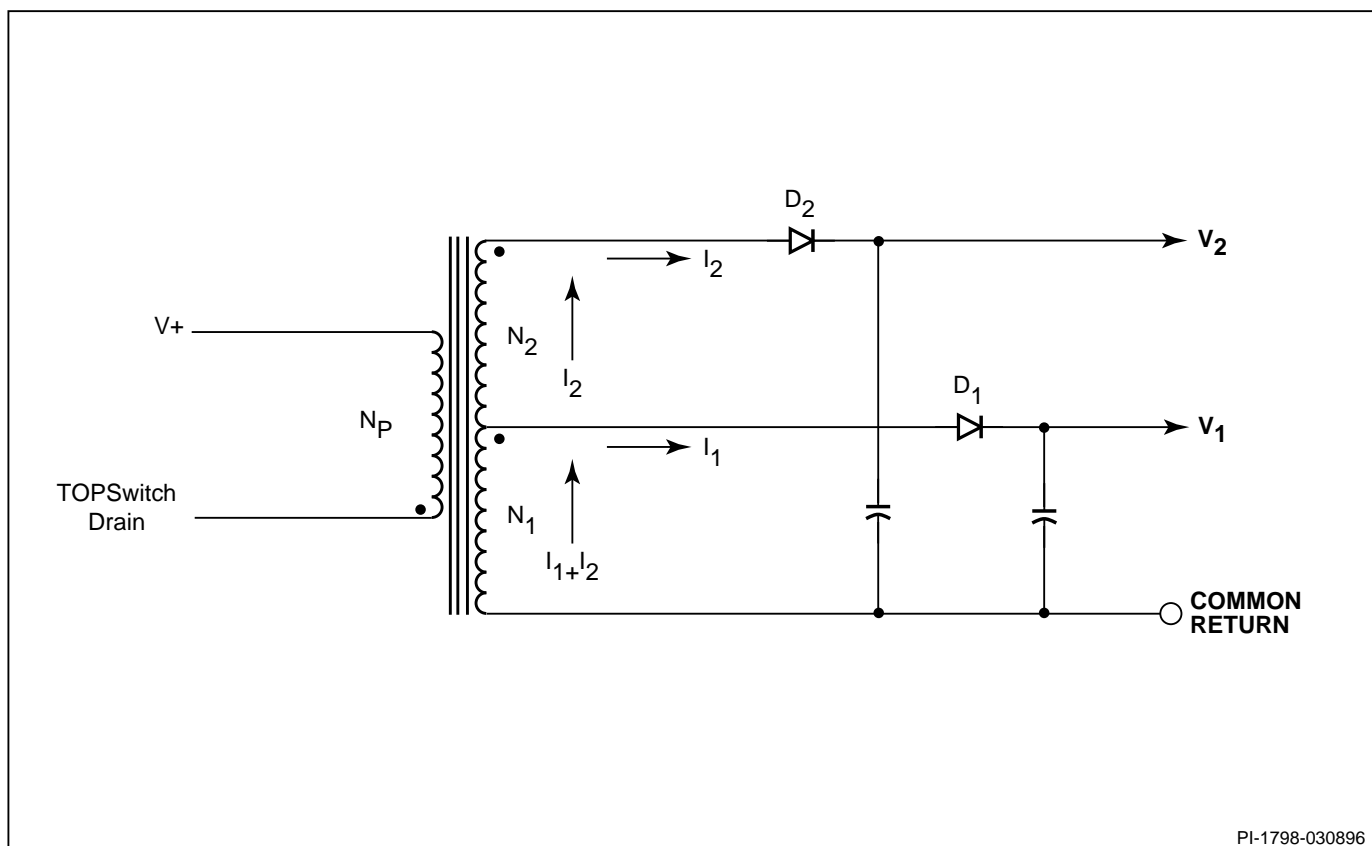
Figure 8. Stacked Secondary Windings for Multiple Outputs.

and smooths the surface between windings. The finish wrap of three layers is more for cosmetic reasons than for safety. There are no margins and no sleeving.

In the triple insulated primary regulated transformer (Figure 7D), basic insulation is used between primary layers, between primary and secondary, and between secondary and bias. A three layer outer wrap is required on the outside for reinforced insulation. Again, no margins or sleeving are required.

Reducing Leakage Inductance

The winding order in a transformer has a large effect on the leakage inductance. Transformer windings should be arranged in concentric fashion for minimum leakage inductance. Offset or split bobbin construction (shown in Figure 9) should be avoided, as these techniques will result in high leakage inductance and unacceptable primary clamp circuit dissipation.

In a multiple output transformer, the secondary with the highest output power should be placed closest to the primary for the best coupling and lowest leakage. For higher power applications (40 watts and above), a split primary "sandwich" construction is recommended to minimize leakage inductance. Using a split primary will in general cut the leakage inductance to half that of a transformer with a single primary winding. Split primary construction for secondary regulated transformers is shown for the margin wound and triple insulated case in Figures 10A and 10B. A split winding construction is not recommended for primary regulated designs, as it will result in poor load regulation.

High power secondary windings consisting of only a few turns should be spaced across the width of the bobbin window instead of being bunched together, in order to maximize coupling to the primary. Using multiple parallel strands of wire is an additional technique of increasing the fill factor and coupling of a winding with few turns. In such cases, the wire size may be determined more by the requirement for a good fill factor rather than the RMS current rating of the wire. Where cost permits, using foil windings is also a good way of increasing coupling, although this method is usually practical only for low voltage, high current secondary windings.
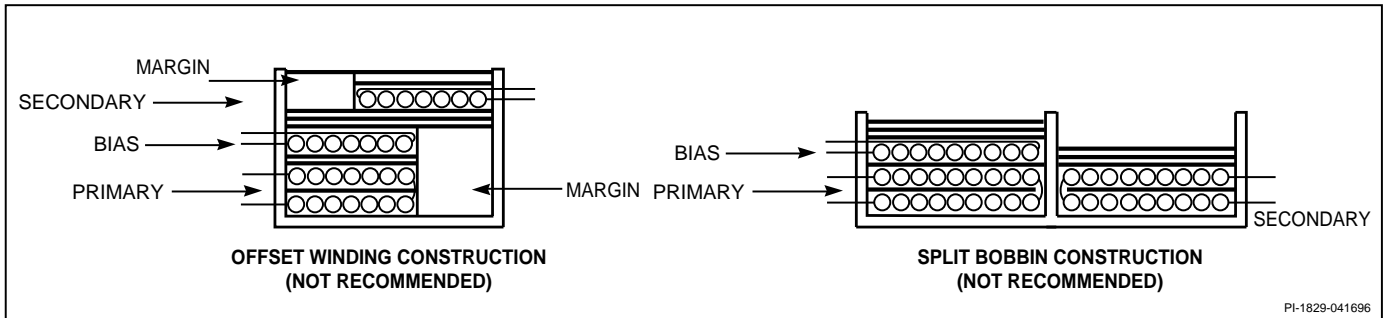
Figure 9. Offset and Split Bobbin Construction Techniques (Not Recommended).

EMI Reduction Techniques

The following transformer construction techniques help to reduce EMI:

- Make the primary winding the innermost winding on the bobbin.

- The start of the primary winding should be connected to the *TOPSwitch* drain.

- For a secondary regulated transformer design, place the bias winding between primary and secondary to act as a shield.

Additional EMI/RFI reduction techniques include shielding between primary and secondary windings, and the addition of a "flux band" to reduce the stray field around the transformer.

Shields are placed between the primary and secondary of a transformer to reduce the capacitive coupling of common mode noise between primary and secondary. The shield can be referenced either to the primary high voltage supply or to the primary return. Typical shielded transformer constructions are shown in Figure 11. The most economical form of shield is a wire shield. This type of shield can be added to the transformer with very few extra steps, since it consists of a winding traversing the full width of the bobbin. One end of the shield winding is terminated to the primary return or primary V+ supply, while the other end of the winding is left floating, insulated with tape, and buried inside the transformer instead of being terminated to a pin. The wire size used for a wire shield is a compromise between a large size to minimize the number of shield turns, and a relatively small wire size for ease of termination. 24-27 AWG wire is a reasonable compromise for small to medium size transformers.

In some cases, the stray magnetic field around a switching power supply transformer can interfere with adjacent circuitry and contribute to EMI. To reduce this stray field, a copper "flux
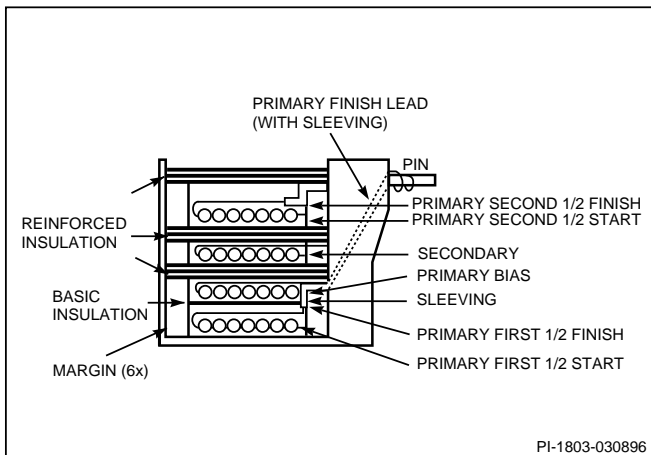

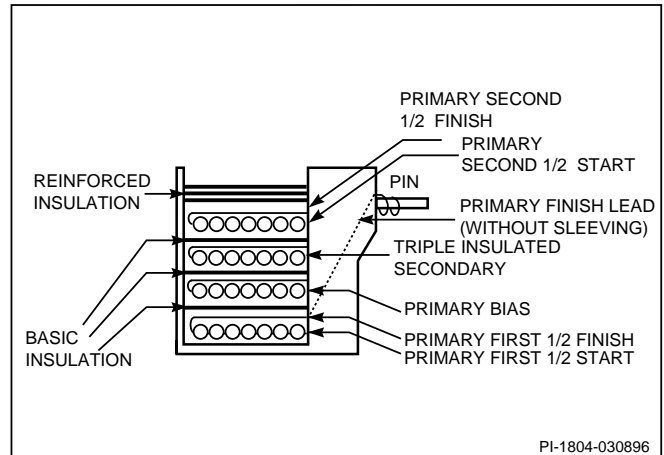*Figure 10A. Margin Wound Secondary Regulated Transformer with Split Primary.*

Figure 10B. Triple Insulated Secondary Regulated Transformer with Split Primary.
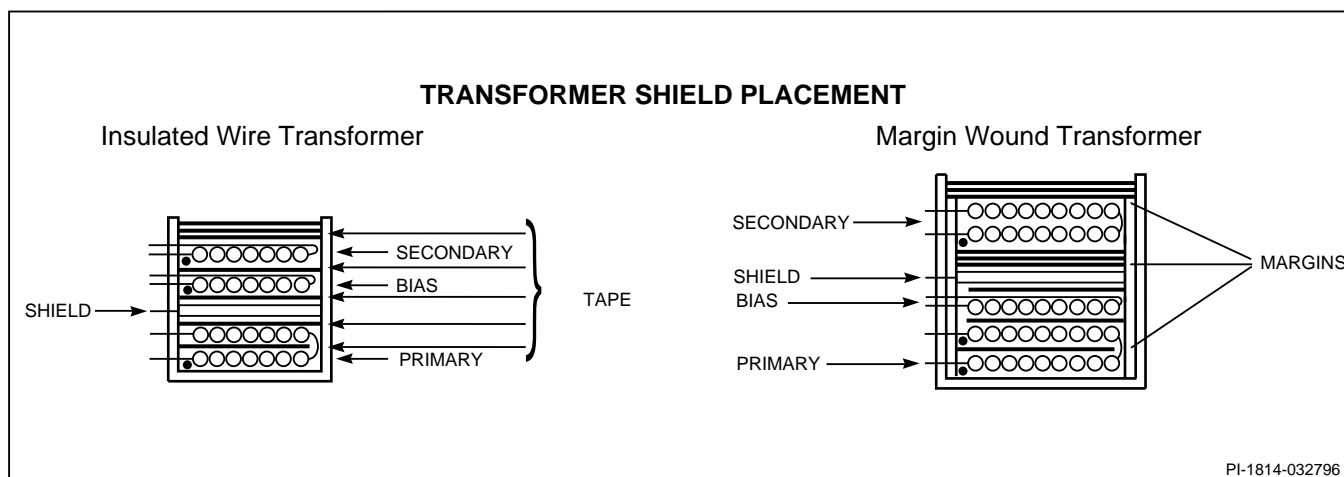
Figure 11. Transformer Shield Placement.

band" can be added around the outside of the transformer, as shown in Figure 12. The "flux band" acts as a shorted turn for stray flux outside the magnetic circuit formed by the transformer windings and core. Opposing currents are induced in the flux band by the stray fields, partially canceling their influence. If necessary, the flux band can also be connected to primary return to help reduce electrostatically coupled interference. If a flux band is used, care must be taken to make sure that there is sufficient total creepage distance from the primary pins to the secondary pins through the flux band. Refer to AN-15 for more information on EMI reduction techniques.

Transformer Construction

Two transformer design and construction examples are shown in Appendix B for margin wound and triple insulated transformers for use with *TOPSwitch*. The design procedure for the two examples utilizes computer spreadsheet techniques described in application notes AN-16 and AN-17. The detailed step-by-step flyback power supply design procedure for using the spreadsheet is shown in AN-16, while the spreadsheet itself is described in detail in AN-17. The paragraphs below describe the procedures needed to apply the information generated by the power supply design spreadsheet to a practical transformer design. These procedures are used to complete the two design examples in Appendix B. In this application note, two completed spreadsheet design examples are presented. Information derived from these spreadsheets is used in the construction examples.

Spreadsheet Parameters Used for Transformer Specification

Once a power supply design spreadsheet has been completed and optimized, information from the spreadsheet can be used to complete a specification for transformer construction. Much of

the information required to specify a transformer can be read directly from the completed spreadsheet. Other parameters must be calculated using numbers from the spreadsheet and information from other sources, such as a wire table. The spreadsheet parameters listed below provide information used to specify a transformer. The number in parentheses indicates the cell location in the spreadsheet.

- Core Type (B23)
- Bobbin Physical Winding Width (BW) (B27)
- Safety Margin Width (M) (B28)
- Number of Primary Layers (L) (B29)
- Number of Secondary Turns (N_S) (B30)
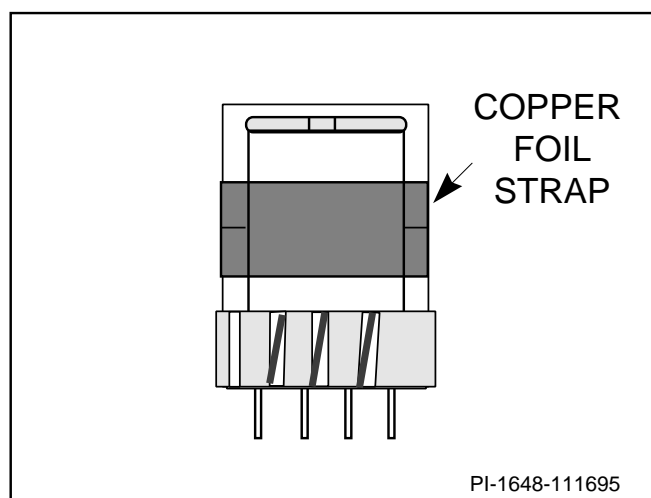- Primary Inductance (L_P) (D44)
- Primary Number of Turns (N_P) (D45)

Figure 12. Transformer Flux Band.

• Bias Winding Turns (N_B) (D46)
• Gapped Core Inductance Coefficient (A_{LG}) (C47)
• Primary Wire Gauge (AWG) (D56)
• Primary Winding Current Capacity (CMA) (D58)
• Secondary Circular Mils (CMS) (C66)
• Secondary RMS Current (I_{SRMS}) (D62)
• Secondary Wire Gauge (AWG_S) (D67)

Transformer Construction Steps

Once the transformer parameters have been determined from a spreadsheet design, the following steps are required to determine the remaining information needed for transformer construction:

• Calculate and select wire sizes using spreadsheet information and wire table
• Pick transformer construction style
• Determine insulating tape sizes
• Determine insulating sleeving size
• Choose method of core gapping

Wire Sizes

Wire sizes for the primary, secondary, and bias windings are determined from the information provided by the power supply design spreadsheet. Some extra steps may be necessary to determine the wire size for a given winding. The wire size selection process is described below.

Primary Wire Size
The power supply design spreadsheet calculates the insulated wire diameter for the primary based on the number of primary turns, the number of winding layers, and the available winding space on the bobbin. The calculated maximum insulated wire diameter is shown in cell (D53) of the spreadsheet. The spreadsheet uses this value to choose an AWG wire size that comes closest to fitting the bobbin. If the wire size falls between two standard AWG wire gauges, the spreadsheet will automatically round down the primary wire size to the next smaller wire gauge. The resulting primary AWG wire size is displayed in cell (D56) of the spreadsheet. The spreadsheet calculates the current capacity of the primary wire (CMA) in circular mils per ampere and displays the result in cell (D58). The CMA value should be between 200 to 500 circular mils per ampere for a practical design. If the CMA is not within these limits, the design should be adjusted to bring the primary CMA within limits.

Wire Size vs. Frequency
In some cases, the wire size determined by the spreadsheet will be too large for use at 100KHz. The wire size that can be effectively used in a power transformer depends on the operating frequency. High frequency currents tend to flow close to the surface of a conductor rather than its interior. This phenomenon is called the skin effect. The penetration of AC current into a

conductor varies as the square root of the frequency, so for a higher frequency, currents will flow closer to the surface of the conductor and leave the interior relatively unutilized. The result is a higher effective resistance for AC current versus DC current. To minimize the AC copper losses in a transformer, no conductor should be used that has a thickness greater than 2 times the skin depth at the operating frequency of the supply. A graph of usable wire gauge as a function of frequency is shown in Figure 13. At 100 KHz, the nominal operating frequency of *TOPSwitch*, 26 AWG is the largest wire size that allows full utilization of the cross-section of the wire. High current windings at 100 KHz should be constructed using several strands of 26 AWG or smaller wire rather one large diameter conductor, in order to allow full utilization of the conductor. This is usually more of a concern for selecting the wire size for a secondary output winding than for a primary winding.

Secondary Wire Size
The minimum secondary bare wire cross-sectional area is determined by the spreadsheet from the secondary RMS current, and is sized for the same current capacity (CMA) as the primary winding. The resulting minimum wire area (in circular mils) is displayed in cell (C66) of the spreadsheet, and is used by the spreadsheet to calculate a secondary wire size. If the secondary wire size falls between two standard AWG sizes, the spreadsheet will automatically round the wire size up to the next larger AWG size. The resulting secondary AWG wire size is displayed in cell (D67) of the spreadsheet. In many cases, the wire size picked by the spreadsheet will be too large to satisfy the size requirements for 100 KHz operation described above. In these cases, it will be necessary to use several parallel strands of
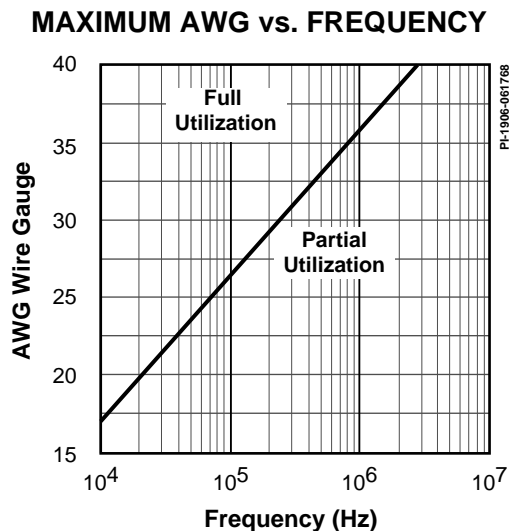
MAXIMUM AWG vs. FREQUENCY

Figure 13. Skin Depth vs. Frequency.

26 AWG or smaller wire to construct a secondary winding that satisfies both the CM_S requirement and the 100KHz maximum wire size requirement. The total bare area of the paralleled secondary conductors should be close to the CM_S value calculated by the spreadsheet in cell (C66). If the total bare area is greater than or equal to the calculated value, the wire size for the paralleled secondary winding can be used without further checking. If the total bare area is less than the calculated value from cell (C66), the current capacity should be checked to make sure that it remains within the design limits. The current capacity of the paralleled wires can be calculated from the formula:

$$CMA_S = \frac{N \times CM}{I_{SRMS}}$$

CMA_S is the current capacity of the parallel secondary winding in circular mils per ampere, N is the number of strands in the secondary winding, CM is the bare area of a single secondary conductor in circular mils (from the wire table in Appendix A), and I_{SRMS} is the secondary RMS current from cell (D62) of the spreadsheet.

Bias Winding Design

The wire size for the bias winding will be determined mainly by space-filling considerations rather than current capacity, as described in the previous sections on transformer construction. The wire size of the bias winding should be selected to form as complete a layer as possible. Usually, it will be necessary to use a parallel bifilar winding in order to fill the largest possible space with a manageable wire size. In the Appendix A wire table, turns per centimeter (TC) values are given for AWG wire sizes. This data can be used to select a bias winding wire size for a bifilar winding for a given number of turns and available bobbin width. The required TC value can be calculated from the equation:

$$TC = \frac{2 \times N_B \times 10}{BW - (2 \times M)}$$

TC is the turns per centimeter capability of the bias winding. N_B is the number of bias turns from cell (D46) of the spreadsheet, BW is the bobbin physical winding width in mm from cell (B27) of the spreadsheet, and M is the margin width in mm from cell (B28). Once the required TC is calculated, a wire size is selected from the Appendix A wire table with a TC greater than or equal to the calculated value. The largest recommended wire size is 24 AWG, for ease of winding and termination. If the wire size used does not form one complete layer, the winding turns should be wound evenly across the width of the bobbin winding area.

Choosing a Transformer Construction Type

The transformer construction types shown in Figures 7 and 10 are optimized for margin wound and triple insulated wire transformer designs for both secondary and primary regulated power supply designs. These construction types are suitable for the majority of *TOPSwitch* flyback supply applications. These figures should be used as examples for specifying the order of the transformer windings and the placement of the margins and insulating sleeving (if used), and insulating tape. The construction type is chosen on the basis of the supply regulation scheme (primary or secondary) and insulation type (margin wound or triple insulated wire). Applications requiring the lowest transformer cost but not the smallest possible transformer size can use a margin wound transformer. Applications requiring the smallest possible transformer size should use a triple insulated wire design.

The construction types shown in Figure 10 are low-leakage split primary designs, and should be used if the output power of the supply is greater than 40W. These designs can also be used to increase efficiency for a lower power supply, but will be higher cost than a design with a one piece primary winding.

Choosing Insulation Tape Width

For a margin wound transformer construction, three different insulation tape widths are required. A tape width equal to the width of the bobbin from flange to flange (BW) is required for reinforced insulation. This information can be read directly from cell (B27) of the spreadsheet. A tape width equal to the width of the bobbin minus the width of the margins is needed for basic insulation between winding layers and adjacent primary or secondary windings. This width can be calculated with the equation:

$$W_{TB} = BW - (2 \times M)$$

W_{TB} is the width of the basic insulation tape, BW is the width of the bobbin from cell (B27) of the spreadsheet, and M is the margin width from cell (B28). The third tape width required is for the margin layers on each side of the bobbin. The width of this tape is picked to satisfy applicable safety regulations and entered in cell (B28). Triple insulated wire transformers require one size of tape for basic insulation, with a width equal to BW.

Insulating Sleeving

In margin wound transformer designs, insulating sleeving is required on all winding start and finish leads, so that the primary to secondary isolation provided by the margins is preserved. The sleeving should have a wall thickness of at least 0.4 mm. Sleeving for this purpose can be obtained in sizes equivalent to AWG wire sizes. Usually one size of sleeving, equal to the

largest wire size, is sufficient for a transformer design. This size of sleeving can then be used for all other wire sizes in the transformer. Sleeving is not required for triple insulated wire designs.

Transformer Gapping, Primary Inductance Tolerance

In standard practice, transformer cores for flyback transformer applications are gapped to a specified value of A_{LG} rather than a precise gap length. The center value of A_{LG} can be read from cell (C47) of the spreadsheet. A_{LG} is customarily specified to a tolerance of +/- 5-6%. The gap length shown in cell (D 51) of the spreadsheet is useful mainly for checking transformer peak flux density and for determining the practicality of the design, and should not be used in a transformer specification. Transformer gaps smaller than 0.051 mm (0.002 in) should be avoided, as it is difficult to maintain tolerance on this small a gap. Transformer primary inductance tolerance should be specified at +/- 10% to +/- 15%. Tighter tolerances offer no performance advantages, and can be unnecessarily costly.

For high volume transformer applications, the transformer core is commonly gapped by grinding down the center leg of one of the ferrite core halves to introduce a single air gap in the magnetic path of the core. An alternate technique for small production runs and prototypes is to use non-conducting spacers between the core halves. If spacers are chosen rather than grinding the core center leg, the spacer thickness should be half the value used for the center leg gap, as the magnetic path is divided twice by the spacers: once at the core center leg, and once at the core outer legs.

Completion of Transformer Specification

Once the above information has been determined, there is sufficient information to complete a specification for construction of the transformer. The specification should contain the following information:

• Transformer schematic, showing all windings, order of windings, pin assignments, dots indicating winding starts, turns of each winding, and wire types and sizes

• Transformer parts list, including:

    Core part number and A_{LG}
    Bobbin part number
    All wire types and sizes used
    All insulating tape types and widths
    Insulating sleeving type and size (if used)
    Varnish type (if used)

• Transformer specifications:

    Primary inductance and tolerance
    Primary leakage inductance and tolerance (determined from prototype)
    Applicable safety standards, or hipot test voltage and minimum creepage distances

• Detailed construction drawing and instructions (optional)

Design Summary

1) Load Design Spreadsheet with Application Variables and *TOPSwitch* Variables per instructions in AN-16.

2) Choose a core from Appendix A, and determine core and bobbin parameters needed for spreadsheet from manufacturer's catalog data. Load these values into the spreadsheet.

3) Complete spreadsheet per AN-16 procedure and iterate until all parameters meet recommended design limits.

4) From spreadsheet values and Appendix A wire table, calculate primary, secondary, and bias wire sizes.

5) Pick a transformer construction style depending on supply regulation scheme (primary or secondary) and insulation type (margin wound or triple insulated).

6) Calculate tape widths needed for transformer insulation.

7) Pick insulation sleeving size (if necessary).

8) Complete transformer specification using spreadsheet values and information from steps 4-7.

Appendix A

Appendix A contains a wire table (Table 1) and a table of suggested core sizes (Table 2) for use in the flyback transformer design and construction procedures described in this document. Also included is a list of manufacturers for transformer construction materials. Electrical and mechanical data on the cores listed in Table 2 can be obtained from the ferrite core manufacturers listed in this appendix. These manufacturers also carry a selection of bobbins for their more popular core sizes. Additional sources for transformer bobbins are also listed in this appendix.

AWG Wire Size	SWG Wire Size	Metric Size (mm)	Bare Wire Cross-Sectional Area (CM)		TC	
			cm²10⁻³	CIR-MIL	Turns/cm	Turns/Inch
18	19	1.00	8.228	1624	9.13	23.2
19	20	0.900	6.531	1289	10.19	25.9
20	21	0.800	5.188	1024	11.37	28.9
21		0.750	4.116	812.3	12.75	32.4
22	22	0.700	3.243	640.1	14.25	36.2
23	23	0.600	2.588	510.8	15.82	40.2
24	24	0.550	2.047	404.0	17.63	44.8
25		0.450	1.623	320.4	19.80	50.3
26	28	0.400	1.280	252.8	22.12	56.2
27	29	0.350	1.021	201.6	24.44	62.1
28	30	0.320	0.8046	158.8	27.32	69.4
29		0.280	0.6470	127.7	30.27	76.9
30	33	0.250	0.5067	100.0	33.93	86.2
31		0.220	0.4013	79.21	37.48	95.2
32		0.200	0.3242	64.00	41.45	105.3
33		0.180	0.2554	50.41	46.33	117.7
34		0.160	0.2011	39.69	52.48	133.3
35		0.140	0.1589	31.36	58.77	149.3
36	39	0.130	0.1266	25.00	65.62	166.7
37	41	0.110	0.1026	20.25	71.57	181.8
38	42	0.100	0.08107	16.00	80.35	204.1
39	43	0.090	0.06207	12.25	91.57	232.6
40	44	0.080	0.04869	9.61	103.6	263.2
41	45	0.070	0.03972	7.84	115.7	294.1
42	46	0.060	0.03166	6.25	131.2	333.3
43			0.02452	4.84	145.8	370.4
44			0.0202	4.00	157.4	400.0

Table 1 Wire Table.

Output Power	FERRITE CORES	
	Triple Insulated Wire Construction	**Margin Wound Construction**
0-10W	EPC17	EEL16
	EFD15	EF20
	EE16 or EI16	EEL19
	EF16	EPC25
	E187	EFD25
	EE19 or EI19	
10-20W	EE19 or EI19	EEL19
	EPC19	EPC25
	EF20	EFD25
	EFD20	EF25
	EE22 or EI22	
20-30W	EPC25	EPC30
	EFD25	EFD30
	E24/25	EF30
	EI25	EI30
	EF25	ETD29
	EI28	EER28
30-50W	EI28	EI30
	EF30	ETD29
	EI30	EER28
	ETD29	EER28L
	EER28	EER35
50-70W	EER28L	EER28L
	ETD34	ETD34
	EI35	EER35
	EER35	ETD39
70-100W	ETD34	EER35
	EI35	ETD39
	EER35	EER40
	E21	E21

Table 2 Ferrite Core Selection Table for Transformer Construction.

Transformer Material Vendors

The contact numbers below are listed for information purposes only. Please refer to local authorized representatives and distributors for pricing and ordering information.

Ferrite Cores

TDK Corporation, of America, 1600 Feehanville Dr. Mount Prospect IL 60056 (847) 803-6100 (847) 803-6296 (FAX)

Siemens Matsushita Components, Special Products Division, 186 Wood Ave, South Iselin, NJ 08830 (908) 906-4300 (908) 632-2830 (FAX)

Philips Components, Discrete Products Division, Magnetic Products, 1033 Kings Highway, Saugerties, NY 12477 (914) 246-2811 (914) 246-0486 (FAX)

Tokin America, Inc.,155 Nicholson Lane, San Jose, CA 95134 (408) 432-8020 (408) 434-0375 (FAX)

Thomson Passive Components Corporation, 2211-H Distribution Center Drive, Charlotte, NC 28269 (704) 597-0766 (704) 597-0553 (FAX)

Bobbins

Many of the ferrite core vendors above offer compatible bobbins for their cores. Additional bobbin suppliers are listed below:

Yih Hwa Enterprises Co., Ltd., 2 Floor, No. 2, Alley 4, Lane 222 Lien Cheng Rd. Chung Ho City, Taipei, Taiwan, R.O.C. 886-2-2483366 886-2-2406919 (FAX)

Taiwan Shu Lin Enterprise Co., Ltd., 760 Chung Cheng Road, Chung Ho City, Taipei Tsien, Taiwan, R.O.C. 886 2 2231500 886 2 2224646 (FAX)

B&B Products Corp., 2190 Ironwood Crest Dr., Tucson, AZ 85745 (520) 743-3389 (520) 743-8000 (FAX)

Miles-Platts, Inc. 901 Touhy Av., Elk Grove Village, IL 60007 (847) 364-0363 (847) 364-0614 (FAX)

Insulating Materials

3M Electrical Specialties Division, Bldg. 130-4N-40, 3M Austin Center, P.O. Box 2963, Austin TX 78769 (800) 364-3577 (800) 713-6329

CHR/Furon, 407 East St., P.O. Box 1911, New Haven, CT 06509 (203) 777-3631 (203) 787-1725 (FAX)

EIS, 41444 Christy Street, Fremont, CA 94538 (510) 490-5855 (510) 490-2956 (FAX)

Tesa Tape Inc. 5825 Carnegie Bl., Charlotte, NC 28209 (704) 554-0707 (800) 852-8831 (FAX)

Magnet Wire

Belden Wire and Cable Company, P.O. Box 1980, Richmond, IN 47375 (317) 983-5200 (317) 983-5656 (FAX)

MWS Wire Industries 31200 Cedar Valley Dr., Westlake Village, CA 90404 (818) 991-8553 (818) 706-0911 (FAX)

Phelps Dodge Magnet Wire, 2131 S. Coliseum Blvd. Fort Wayne, IN 46803 (219) 421-5400 (219) 421-5564 (FAX)

Rea Magnet Wire Co., Inc. 3600 E. Pontiac St. Fort Wayne, IN 46896 (219) 424-4252 (219) 421-7349 (FAX)

Triple Insulated Wire

Furukawa Electric America, Inc. 200 Westpark Drive, Suite 190, Peachtree City, GA 30269 (770) 487-1234 (770) 487-9910 (FAX)

Furukawa Electric Co. Ltd. 6-1, Marunouchi 2-chome, Chiyoda-ku, Tokyo 100, Japan (PH) 81-3-3286-3226 (FAX) 81-3-3286-3747

Rubudue Wire Company 5150 E. La Palma Av., Suite 108 Anaheim Hills, CA 92807 (714) 693-5512 (714) 693-5515 (FAX)

Belden Wire and Cable B.V., Edisonstraat 9, P.O. Box 9, NL 5900 AA Venlo, Netherlands (PH) 31 773 878 442 (FAX) 31 773 878 448

Transformer Varnishes

John C. Dolph, Co. Box 267, Monmouth Junction, NJ 08852 (908) 329-2333 (908) 329-1143 (FAX)

Schenectady Chemicals, Inc. Box 1046, Schenectady, NY 12301 (518) 370-4200 (518) 382-8129 (FAX)

P.D. George, 9 Ohio River Boulevard, Sewickley, PA 15143 (800) 999-5700 (412) 741-8892

Epoxylite Corp., 9400 Toledo Way, P.O. Box 19671, Irvine, CA 92713 (714) 951-3231 (714) 472-0980 (FAX)

Appendix B

Transformer Construction Examples

Two transformer design and construction examples using margin wound and triple insulated wire construction techniques are described below. These designs are based on the 12V, 15W universal input power supply shown in Figure 1. The design procedure for the two examples utilizes computer spreadsheet techniques described in application notes AN-16 and AN-17. The detailed step-by-step flyback power supply design procedure for using the spreadsheet is shown in AN-16. Two completed spreadsheet design examples are shown in this appendix (Table 1 and Table 6). Information derived from these spreadsheets is used in the construction examples.

Spreadsheet Input Parameters

Two power supply design spreadsheets are shown in Tables 1 and 6. Table 1 details a power supply design utilizing a margin wound transformer with an EF25 core. Table 6 shows a design for the same power supply utilizing a triple insulated wire

transformer with an EF20 core. The power supply design shown in Figure 1 was used as a starting point for both transformer design/construction examples. Target specifications for this power supply design are shown in Table 2. Specifications and selected component values from Table 2 are loaded into the application variables section of the spreadsheets. Table 3 shows *TOPSwitch* and output rectifier operating conditions used in the *TOPSwitch* variable section of the spreadsheets. Since both of the transformer designs are for the same power supply, the values loaded into the application variables section and *TOPSwitch* variable section for both spreadsheets are exactly the same, with the exception of the value used for reflected output voltage (V_{OR}, cell B16). For the triple insulated wire transformer design shown in Table 6, V_{OR} is adjusted to a value slightly lower than the default value recommended in AN-16 in order to reduce the number of primary turns. This is discussed in the paragraphs devoted to the triple insulated wire design example.

The transformer construction variables in the design spreadsheet are determined by the core, bobbin and transformer construction type, and are therefore different for the two design examples.
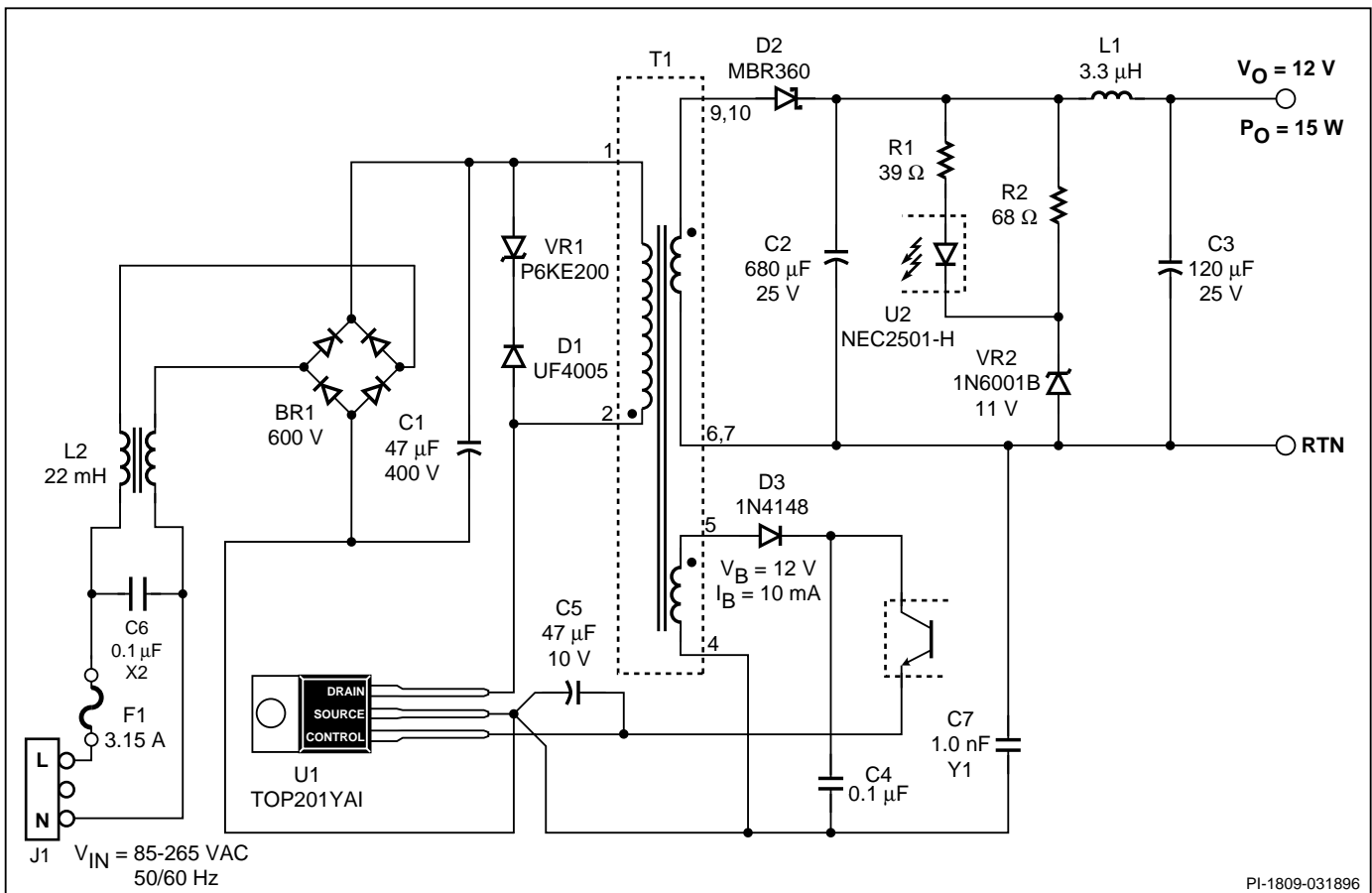

Figure 1. Typical TOPSwitch Power Supply for 12V, 15W Output.

	A	B	C	D	E	F
1		INPUT		OUTPUT		
2	ENTER APPLICATION VARIABLES					
3	VACMIN	85			Volts	Minimum AC Input Voltage
4	VACMAX	265			Volts	Maximum AC Input Voltage
5	fL	50			Hertz	AC Mains Frequency
6	fS	100000			Hertz	TOPSwitch Switching Frequency
7	VO	12			Volts	Output Voltage
8	PO	15			Watts	Output Power
9	n	0.8				Efficiency Estimate
10	Z	0.5				Loss Allocation Factor
11	VB	12			Volts	Bias Voltage
12	tC	3			mSeconds	Bridge Rectifier Conduction Time Estimate
13	CIN	47			uFarads	Input Filter Capacitor
14						
15	ENTER TOPSWITCH VARIABLES					
16	VOR	135			Volts	Reflected Output Voltage
17	VDS	10			Volts	TOPSwitch on-state Drain to Source Voltage
18	VD	0.4			Volts	Output Winding Diode Forward Voltage Drop
19	VDB	0.7			Volts	Bias Winding Diode Forward Voltage Drop
20	**KRP**	**0.60**				Ripple to Peak Current Ratio (0.4 < KRP < 1.0)
21						
22	ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
23		EF25				Core Type
24	AE	0.525			cm^2	Core Effective Cross Sectional Area
25	LE	5.75			cm	Core Effective Path Length
26	AL	1800			nH/T^2	Ungapped Core Effective Inductance
27	BW	15.1			mm	Bobbin Physical Winding Width
28	M	3			mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
29	**L**	**2**				Number of Primary Layers
30	**NS**	**6**				Number of Secondary Turns
31						
32	DC INPUT VOLTAGE PARAMETERS					
33	VMIN			94	Volts	Minimum DC Input Voltage
34	VMAX			375	Volts	Maximum DC Input Voltage
35						
36	CURRENT WAVEFORM SHAPE PARAMETERS					
37	DMAX			0.62		Duty Cycle at Minimum DC Input Voltage (VMIN)
38	IAVG			0.20	Amps	Average Primary Current
39	IP			0.46	Amps	Peak Primary Current
40	**R**			0.28	Amps	Primary Ripple Current
41	IRMS			0.26	Amps	Primary RMS Current
42						
43	TRANSFORMER PRIMARY DESIGN PARAMETERS					
44	LP			1884	uHenries	Primary Inductance
45	NP			65		Primary Winding Number of Turns
46	NB			6		Bias Winding Number of Turns
47	ALG		441		nH/T^2	Gapped Core Effective Inductance
48	**BM**			**2537**	Gauss	Maximum Flux Density (2000 < BM < 3000)
49	BAC		761		Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
50	ur		1569			Relative Permeability of Ungapped Core
51	**LG**			**0.11**	mm	Gap Length (Lg >> 0.051 mm)
52	BWE		18.2		mm	Effective Bobbin Width
53	OD			0.28	mm	Maximum Primary Wire Diameter including insulation
54	INS		0.05		mm	Estimated Total Insulation Thickness (= 2 * film thickness)
55	DIA			0.23	mm	Bare conductor diameter
56	AWG			32	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
57	CM		64		Cmils	Bare conductor effective area in circular mils
58	**CMA**			**245**	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 500)
59						
60	TRANSFORMER SECONDARY DESIGN PARAMETERS					
61	ISP			5.03	Amps	Peak Secondary Current
62	ISRMS			2.25	Amps	Secondary RMS Current
63	IO			1.25	Amps	Power Supply Output Current
64	IRIPPLE			1.87	Amps	Output Capacitor RMS Ripple Current
65						
66	CMS		550		Cmils	Secondary Bare Conductor minimum circular mils
67	AWGS			22	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
68	DIAS			0.65	mm	Secondary Minimum Bare Conductor Diameter
69	ODS			1.52	mm	Secondary Maximum Insulated Wire Outside Diameter
70	INSS		0.44		mm	Maximum Secondary Insulation Wall Thickness
71						
72	VOLTAGE STRESS PARAMETERS					
73	VDRAIN			678	Volts	Maximum Drain Voltage Estimate (Includes Effect of Leakage Inductance)
74	PIVS			46	Volts	Output Rectifier Maximum Peak Inverse Voltage
75	PIVB			47	Volts	Bias Rectifier Maximum Peak Inverse Voltage
76						
77	ADDITIONAL OUTPUTS					
78	VX	12			Volts	Auxiliary Output Voltage
79	VDX	0.7			Volts	Auxiliary Diode Forward Voltage Drop
80	NX			6.15		Auxiliary Number of Turns
81	PIVX			47	Volts	Auxiliary Rectifier Maximum Peak Inverse Voltage
82						

Table 1. Design Spreadsheet for 15W Margin Wound Transformer.

APPLICATION VARIABLES (INPUT TO TABLE 1 AND TABLE 6 SPREADSHEETS)				
DESCRIPTION	**SYMBOL**	**VALUE**	**SOURCE**	**CELL #**
Minimum AC Input Voltage	V_{ACMIN}	85 VAC	Supply Specification	B3
Maximum AC Input Voltage	V_{ACMAX}	265 VAC	Supply Specification	B4
AC Mains Frequency	f_L	50 Hz	Supply Specification	B5
TOPSwitch Switching Frequency	f_S	100,000 Hz	AN-16 Default Value	B6
Output Voltage	V_O	12 V	Supply Specification	B7
Output Power	P_O	15 W	Supply Specification	B8
Estimated Efficiency	η	0.8	AN-16 Default Value	B9
Loss Allocation Factor	Z	0.5	AN-16 Default Value	B10
Bias Voltage	V_B	12 V	Supply Specification	B11
Bridge Rectifier Conduction Time Estimate	t_C	3 msec	AN-16 Default Value	B12
Input Filter Capacitor (C1)	C_{IN}	47 μF	AN-16 Default Value	B13

Table 2. Application Variables for Design Spreadsheets for Figure 1 Power Supply .

The spreadsheets for the two designs diverge at this point. The following paragraphs will describe completed construction examples; first for the margin wound design, then the triple insulated wire design.

Margin Wound Construction Example

In order to carry the margin wound example to completion, the remainder of the design parameters needed to complete the Table 1 spreadsheet input section are described. The construction example is then completed with the information from the spreadsheet.

Determining Transformer Construction Variables

In order to complete the input portion of the Table 1 spreadsheet, information is needed for the transformer/core construction variable section. Table 4 shows the transformer core/construction variables chosen for this margin wound transformer construction example. The EF25 core is chosen from the transformer core chart in Appendix A as representative for the power level and construction type. Dimensional and electrical characteristics for the core and a compatible bobbin are shown in Figures 2 and 3. The core electrical parameters necessary for

the spreadsheet design are A_e, L_e, and A_L, and are loaded into spreadsheet cells (B24), (B25), and (B26) respectively. A margin width (M) of 3 mm (0.118 in) is chosen for the margin wound design to meet international safety regulations for universal input voltage range, and loaded into cell (B28). The number of primary layers (B29) is set at 2 to optimize the core size and to reduce the transformer leakage inductance and stray capacitance.

The variable BW (Bobbin Physical Winding Width), required for the transformer design spreadsheet, represents the width of the bobbin available for winding. This value can be read directly from many bobbin specifications. However, in some cases it is not given directly, and must be calculated from the minimum total bobbin width and the maximum width of the bobbin end flanges. The EF25 bobbin drawing shown in Figure 3 does not show a value for BW. Instead, the total bobbin width (W_T) and flange width (W_F) are given, including tolerances. BW can be calculated from these values using the equation:

$$BW = W_{T(MIN)} - \left[2 \times W_{F(MAX)} \right]$$

TOPSwitch VARIABLES (INPUT TO TABLE 1 AND TABLE 6 SPREADSHEETS)				
DESCRIPTION	**SYMBOL**	**VALUE**	**SOURCE**	**CELL #**
Reflected Output Voltage	V_{OR}	135 V*/130V**	*AN-16 Default Value **(See Text)	B16
TOPSwitch Drain to Source Voltage with MOSFET on	V_{DS}	10 V	AN-16 Default Value	B17
Output Diode (D2) Forward Voltage Drop	V_D	0.4 V	Estimated	B18
Bias Diode (D3) Forward Voltage Drop	V_{DB}	0.7 V	Estimated	B19
Primary Current Ripple to Peak Ratio	K_{RP}	0.6	Optimized Through Iteration	B20

Table 3. TOPSwitch Variables for Design Spreadsheets.

$W_{T(MIN)}$ is the *minimum* total bobbin width, and $W_{F(MAX)}$ is the *maximum* flange width. For the bobbin in Figure 3, $W_{T(MIN)}$ is 16.7 mm and $W_{F(MAX)}$ is 0.8 mm. For these values, BW is:

$$BW = 16.7 - (2 \times 0.8) = 15.1 mm$$

This BW value is entered into cell B27 of the spreadsheet.

The optimum number of secondary turns, N_S (B30), for a transformer design is a function of the power supply input voltage range, the desired K_{RP}, and the effective core cross-sectional area A_e. Using the spreadsheet, it is a simple matter to iterate the value for N_S until a design is reached that fits on the desired transformer core and bobbin and results in satisfactory values for primary winding current capacity (CMA), Gap Length (L_G), and maximum flux density (B_M). Suggested starting values for N_S in terms of volts per turn are found in AN-16. For this design using the EF25 core, the optimum N_S after iteration is 6 turns. At this point the spreadsheet design is complete, and the transformer construction example can proceed using the output data from the completed and optimized spreadsheet.

Margin Wound Example Completion

The parameters needed to specify the margin wound transformer design are shown in Table 5. The spreadsheet parameters from Table 1 are used to determine the transformer wire size, tape sizes, and sleeving size.

Primary Wire Size
From cell (D56) of the Table 1 spreadsheet, the wire size is given as 32 AWG. The primary winding current capacity is given in cell (D58) as 245 circular mils/ampere, and meets the current capacity guideline of 200-500 circular mils/ampere. This wire size is also suitable for use at 100 KHz, as its diameter is smaller than twice the 100KHz skin depth, as shown by Figure 13.

Secondary Wire Size
Looking at cell (B66) of the spreadsheet, a secondary bare wire area of 550 circular mils is required to make the secondary CMA equal to the primary CMA. From cell (D67) of the Table 1 spreadsheet, the closest AWG wire size that can satisfy this requirement with a single wire is 22 AWG. This wire size is too large for use at 100KHz, and several parallel wires, size 26 AWG or smaller, should be used instead to allow full utilization of the wire cross-sectional area. From the wire table in Appendix A, it can be seen that two parallel strands of 26 AWG wire (CM of 252.8 circular mils per wire) have a total bare wire area of 505.6 circular mils, which is within 10% of the required CM of 550 circular mils. The current capacity of the parallel winding can be calculated from the formula:

$$CMA_S = \frac{N \times CM}{I_{SRMS}}$$

CMA_S is the current capacity of the secondary winding in circular mils per ampere, N is the number of strands in the

TRANSFORMER CONSTRUCTION VARIABLES (INPUT TO TABLE 1 SPREADSHEET)				
DESCRIPTION	**SYMBOL**	**VALUE**	**SOURCE**	**CELL #**
Core Type	-	EF25	Core Specifications	B23
Core Effective Cross Sectional Area	A_e	0.525 cm^2	Core Specifications	B24
Core Effective Path Length	L_e	5.75 cm	Core Specifications	B25
Core Ungapped Inductance Coefficient	A_L	1800 nH/T^2	Core Specifications	B26
Bobbin Physical Winding Width	BW	15.1 mm	Calculated from Bobbin Specifications	B27
Margin Width	M	3 mm	Default Value from AN-16	B28
Number of Primary Winding Layers	L	2	Default Value from AN-16	B29
Number of Secondary Turns	N_S	6 t	See Text	B30

Table 4. Transformer Construction Variables for EF25 Margin Wound Transformer Design.
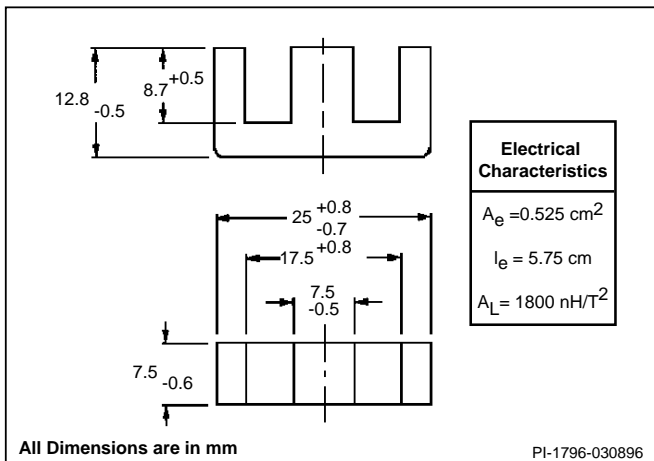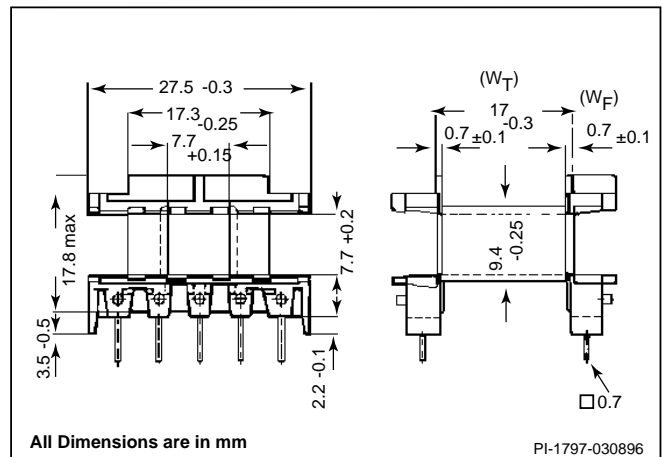

Figure 2. EF25 Core.

Figure 3. EF25 Bobbin.

MARGIN WOUND DESIGN TRANSFORMER CONSTRUCTION PARAMETERS FROM TABLE 1 SPREADSHEET			
DESCRIPTION	**SYMBOL**	**VALUE**	**CELL #**
Core Type, Material	-	EF25, Siemens N67 Part# B66317-G-X130	-
Bobbin Type	-	EF25, 10 PIN, Siemens PIN B66208-A 1110-T1	-
Number of Primary Turns	N_P	65 T	D45
Number of Secondary Turns	N_S	6 T	B30
Number of Bias Winding Turns	N_B	6 T	D46
Primary Wire Size	AWG	32 AWG	D56
Secondary Wire Size	AWG_S	26 AWG	D67 (See Text)
Bias Winding Wire Size	AWG_B	24 AWG	See Text
Core Gapped Inductance Coefficient	A_{LG}	441 nH/T^2 ±5%	C47
Primary Inductance	L_P	1884 µH +/-10%	D44
Reinforced Insulation Tape Width	BW	15.1 mm	B27
Basic Insulation Tape Width	W_{TB}	9.1 mm	See Text
Margin Tape Width	M	3 mm	B28
Sleeving Size	-	24 AWG	See Text

Table 5. Construction Parameters for Margin Wound Design Example.

secondary winding, CM is the bare area of a single secondary conductor in circular mils (from the wire table in Appendix A), and I_{SRMS} is the secondary RMS current from cell (D62) of the spreadsheet. 26 AWG wire has a bare area of 252.8 circular mils. Two parallel strands of 26 AWG wire have a current capacity of:

$$CMA_S = \frac{2 \times 252.8}{2.25} = 224.7 \text{ circular mils/ampere}$$

This value is close to the primary current capacity (within 10%), and satisfies the CMA design limits.

Bias Wire Size

The bias winding wire size is chosen to fill as much of the bobbin width as possible. Since there are usually relatively few primary bias winding turns, this is best accomplished by using a bifilar winding rather than a large diameter wire, effectively doubling the number of physical turns. The required TC can be calculated as follows:

$$TC = \frac{2 \times N_B \times 10}{BW - (2 \times M)} = \frac{2 \times 6 \times 10}{15.1 - (2 \times 3)}$$
$$= 13.2 \, turns/cm$$

From the wire table in Appendix A, the closest wire size with TC greater than or equal to 13.2 turns/cm is 22 AWG, with a TC of 14.25 turns/cm. This is too large a wire size to use with an EF25 core and bobbin. As a compromise, 24 AWG wire is used instead. This wire size will not completely cover the available bobbin width, but is an acceptable compromise for the sake of manufacturability. Since the output current of this winding is 10 mA or less, there is no need to consider the current capacity of the wire or high frequency skin effect. The wire size in this case is determined by space-filling requirements rather than current capacity.

Transformer Construction Style

Since this transformer is a margin wound design for a secondary regulated application, appropriate construction styles are Figures 7A and 10A. Because this design is for a 15W application, the split primary winding shown in Figure 10A is not necessary, and more cost effective single section primary design of Figure 7A should be used.

Tape Sizes

For a margin wound design, three sizes of tape are required for reinforced insulation, basic insulation, and margins. The tape width required for the reinforced insulation layers on this transformer is equal to BW. From cell (B27) of the Table 1 spreadsheet, this is 15.1 mm. The width W_{TB} of the basic insulation tape is calculated as:

$$W_{TB} = BW - (2 \times M) = 15.1 - (2 \times 3) = 9.1 mm$$

The margin tape width (M) is read from cell (B28) of the spreadsheet, and is set at 3 mm to meet international safety regulations for creepage distance for universal input.
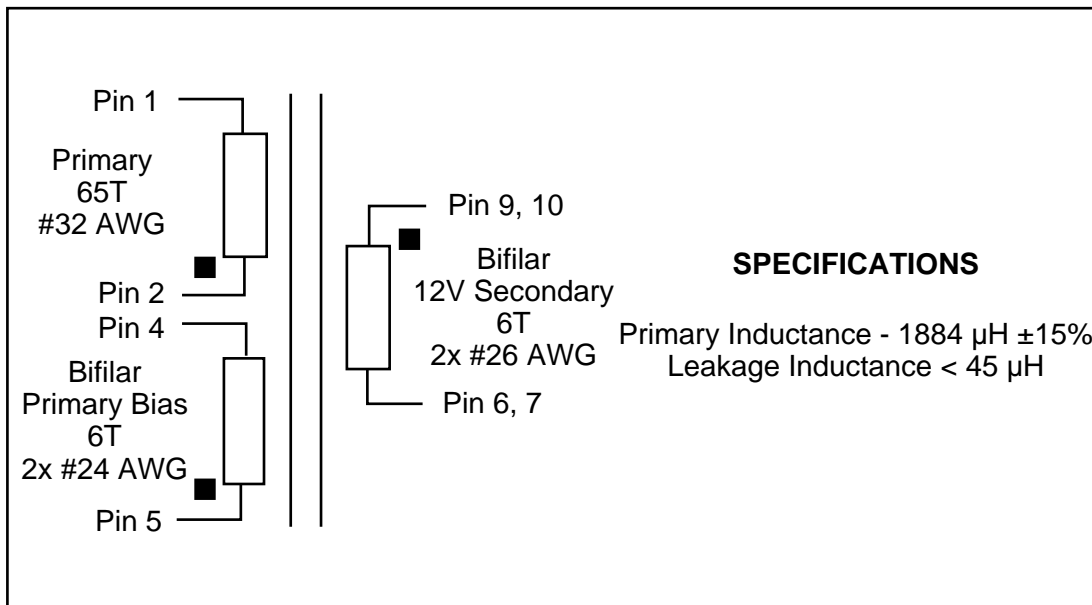
Insulating Sleeving Size

The insulating sleeving size required for this transformer deign is equivalent to the largest wire size in the transformer, or 24 AWG. The sleeving should have a wall thickness of at least 0.4 mm to meet international safety regulations.

Gapped Core Inductance Coefficient

The A_{LG} for this transformer design is given in cell (C47) of the design spreadsheet, and should be used as the center value for specifying the core A_{LG} on the transformer specification.

Finished Margin Wound Transformer Design

The information required to assemble a transformer specification for the margin wound transformer example is summarized in Table 5. A completed transformer schematic diagram and parts list are shown in Figure 4. A construction drawing is shown in Figure 5.
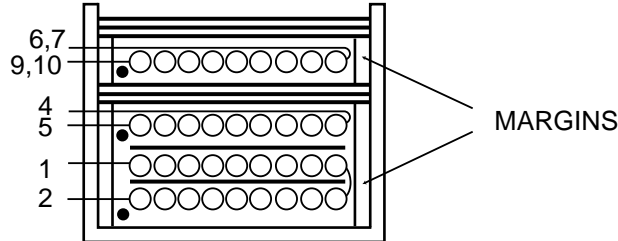
Pin 1

Primary
65T
#32 AWG

Pin 2

Pin 4

Bifilar
Primary Bias
6T
2x #24 AWG

Pin 5

Pin 9, 10

Bifilar
12V Secondary
6T
2x #26 AWG

Pin 6, 7

SPECIFICATIONS

Primary Inductance - 1884 µH ±15%
Leakage Inductance < 45 µH

PARTS LIST FOR EF25 TRANSFORMER DESIGN EXAMPLE				
Item	**Amt.**	**Description**	**Part #**	**Manufacturer**
1	1pr.	Core, EF25 N67 Mat'l	B66317-G-X167*	Siemens
2	1ea.	Bobbin, EF25, 10 pin	B66208-A1110-T1	Siemens
3	A/R	Wire, 32 AWG Heavy Nyleze		
4	A/R	Wire, 24 AWG Heavy Nyleze		
5	A/R	Wire, 26 AWG Heavy Nyleze		
6	A/R	Tape, Polyester 3.0 mm wide	#44	3M
7	A/R	Tape, Polyester 9.1 mm wide	#1296	3M
8	A/R	Tape, Polyester 15.1 mm wide	#1296	3M
9	A/R	Tubing, Teflon, 24 AWG, 0.4 mm minimum wall thickness		

*Gap for A_{LG} of 441 nH/T^2 ± 5%

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Figure 4. Parts List for EF25 Transformer Design Example.

MARGIN WOUND TRANSFORMER CONSTRUCTION

WINDING INSTRUCTIONS	
Margins	Apply 3mm tape margins as shown.
Two-layer "C" Wound Primary	Start at pin 2. Wind 33 turns of 32 AWG heavy nyleze magnet wire from left to right. Apply 1 layer of polyester tape, 9.1 mm wide, for basic insulation. Continue winding 32 turns from right to left. Finish at pin 1. Sleeve start and finish leads.
Basic Insulation	Apply 1 layer of 9.1 mm wide tape for basic insulation.
Primary Bias (Bifilar)	Start at pin 5. Wind 6 bifilar turns of 24 AWG heavy nyleze magnet wire in a single layer, from left to right. Finish at pin 4. Sleeve start and finish leads.
Reinforced Insulation	Apply 3 layers of 15.1 mm wide polyester film tape, for reinforced insulation.
Margins	Apply 3 mm tape margins as shown.
Parallel Bifilar Secondary	Start at pins 9 & 10. Wind 6 bifilar turns of 26 AWG heavy nyleze magnet wire in 1 layer from left to right. Finish at pins 6 & 7. Sleeve start and finish leads.
Outer Insulation	Apply 3 layers of 15.1 mm wide tape for outer insulation.
Final Assembly	Assemble and secure core halves. Impregnate uniformly with varnish.

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Figure 5. EF25 Margin Wound Construction Example.

Triple Insulated Wire Construction Example

In the following paragraphs, the design parameters needed to complete the Table 6 spreadsheet input section will be described. A triple insulated wire transformer construction example will then be completed with the information from the spreadsheet.

Determining Transformer Construction Variables

In order to complete the input portion of the Table 6 spreadsheet, information is needed for the transformer/core construction variable section. Table 7 shows the transformer core/construction variables chosen for the triple insulated transformer construction example. The EF20 core was chosen from the transformer core chart in Appendix A. Dimensional and electrical characteristics for the core and a compatible bobbin are shown in Figures 6 and 7. The core electrical parameters necessary for the spreadsheet design are A_e, L_e, and A_L, and are loaded into spreadsheet cells (B24), (B25), and (B26), respectively. Margin width (M) was set to zero for the triple insulated wire design and loaded into cell (B28). The number of primary layers (B29) is set at 2 to optimize the core size and to reduce the transformer leakage inductance and stray capacitance. BW (Bobbin Physical Winding Width) is calculated as in the margin wound example, since it is not directly available from the Figure 7 bobbin drawing. $W_{T(MIN)}$ is 13.4 mm and $W_{F(MAX)}$ is 0.7 mm, so BW for the EF20 bobbin is:

$$BW = W_{T(MIN)} - \left[2 \times W_{F(MAX)}\right]$$
$$= 13.45 - (2 \times 0.7) \cong 12.0 mm$$

This BW value is entered into cell (B27) of the Table 6 spreadsheet. The optimum number of secondary turns, N_S (B30), is determined as 9 turns after iteration. The number of primary layers (B29) is set at 2 to optimize the core size and to reduce the transformer leakage inductance and stray capacitance.

Completion of Triple Insulated Wire Transformer Example

Information necessary to specify the triple insulated wire transformer example is shown in Table 8. The entries in Table 8 were taken directly from the Table 6 spreadsheet or calculated from the spreadsheet values. Unlike the Table 1 spreadsheet design for the EF25 transformer, the Table 6 spreadsheet requires one additional iteration cycle to optimize the primary wire size. This iteration cycle and the remaining steps in the transformer design are described below.

Adjusting Primary Wire Size and CMA

The design spreadsheet adjusts the primary wire size to the closest AWG value that will fit within the available bobbin width. In some cases the AWG wire size given by the spreadsheet may result in a CMA value outside of the desired range of 200-500 circular mils/ampere. The CMA and resulting AWG values in the spreadsheet are dependent variables and cannot be adjusted directly. The number of primary turns in the spreadsheet cannot be manipulated directly, as it is a function of the number of secondary turns. Gross adjustments can be made indirectly to the primary CMA value by changing the number of secondary turns (N_S) or the core size (see AN-16). Adjusting the number of secondary turns changes the number of primary turns proportionally to maintain the reflected output voltage, V_{OR}, at its specified value. Changing the core size changes the available bobbin width (BW). The spreadsheet will change the primary wire size to fill the available bobbin width using the specified number of primary winding layers.

In some cases, changing the number of secondary turns results either in too large a change in primary wire size or has a deleterious effect on other parameters, such as maximum flux density or transformer gap length. Also, it may not be desirable to change the core size for reasons of cost, availability, or size constraints. The following techniques are useful for fine adjustment of the AWG and CMA of the primary winding without changing the core/bobbin size or the number of secondary turns:

- To reduce the primary wire size to a slightly smaller value, adjust the number of primary layers to a value less than the default value of 2 layers in increments of 0.1 layer (for example, try 1.9 layers, 1.8 layers, etc.).

- To increase the primary wire size to a slightly larger value, adjust the reflected voltage V_{OR} *downward* in increments of 1-2 volts. This will slightly reduce the number of primary turns. Maximum duty cycle (D_{MAX}) will be reduced slightly, L_G will become smaller and B_M will rise slightly. Do not adjust the reflected primary voltage more than 10% below the maximum recommended value suggested in AN-16. If more adjustment is needed, reduce the number of secondary turns instead or use a larger core size.

Initially, the Table 6 spreadsheet used the default value of 135V for V_{OR} in cell (B16). For N_S = 9 turns, this resulted in N_P = 96 turns, and a primary wire size of 33 AWG, which for this design, is slightly too small (CMA of 196 circular mils/ampere) to satisfy the CMA requirement of 200-500 circular mils/ampere. Adjusting the number of primary turns by reducing the secondary turns resulted in a transformer design with a maximum flux density larger than the design limit of 3000 Gauss. To avoid this condition, the number of primary turns was instead reduced from 98 turns to 94 turns by reducing V_{OR} from 135V to 130V in small steps. This allowed the primary wire size, AWG (D56), to change from 33 AWG to 32 AWG and brought the primary winding CMA (D58) up to 243 circular mils/ampere. Maximum duty cycle and maximum flux density were only slightly affected by this change.

	A	B	C	D	E	F
1		INPUT		OUTPUT		
2	**ENTER APPLICATION VARIABLES**					
3	VACMIN	85			Volts	Minimum AC Input Voltage
4	VACMAX	265			Volts	Maximum AC Input Voltage
5	fL	50			Hertz	AC Mains Frequency
6	fS	100000			Hertz	TOPSwitch Switching Frequency
7	VO	12			Volts	Output Voltage
8	PO	15			Watts	Output Power
9	n	0.8				Efficiency Estimate
10	Z	0.5				Loss Allocation Factor
11	VB	12			Volts	Bias Voltage
12	tC	3			mSeconds	Bridge Rectifier Conduction Time Estimate
13	CIN	47			uFarads	Input Filter Capacitor
14						
15	**ENTER TOPSWITCH VARIABLES**					
16	VOR	130			Volts	Reflected Output Voltage
17	VDS	10			Volts	TOPSwitch on-state Drain to Source Voltage
18	VD	0.4			Volts	Output Winding Diode Forward Voltage Drop
19	VDB	0.7			Volts	Bias Winding Diode Forward Voltage Drop
20	**KRP**	**0.60**				Ripple to Peak Current Ratio (0.4 < KRP < 1.0)
21						
22	**ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES**					
23		**EF20**				Core Type
24	AE	0.335			cm^2	Core Effective Cross Sectional Area
25	LE	4.49			cm	Core Effective Path Length
26	AL	1470			nH/T^2	Ungapped Core Effective Inductance
27	BW	12			mm	Bobbin Physical Winding Width
28	M	0			mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
29	**L**	**2**				Number of Primary Layers
30	**NS**	**9**				Number of Secondary Turns
31						
32	**DC INPUT VOLTAGE PARAMETERS**					
33	VMIN			94	Volts	Minimum DC Input Voltage
34	VMAX			375	Volts	Maximum DC Input Voltage
35						
36	**CURRENT WAVEFORM SHAPE PARAMETERS**					
37	DMAX			0.61		Duty Cycle at Minimum DC Input Voltage (VMIN)
38	IAVG			0.20	Amps	Average Primary Current
39	IP			0.47	Amps	Peak Primary Current
40	IR			0.28	Amps	Primary Ripple Current
41	IRMS			0.26	Amps	Primary RMS Current
42						
43	**TRANSFORMER PRIMARY DESIGN PARAMETERS**					
44	LP			1829	uHenries	Primary Inductance
45	NP			94		Primary Winding Number of Turns
46	NB			9		Bias Winding Number of Turns
47	ALG		205		nH/T^2	Gapped Core Effective Inductance
48	**BM**			**2712**	Gauss	Maximum Flux Density (2000 < BM < 3000)
49	BAC		814		Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
50	ur		1568			Relative Permeability of Ungapped Core
51	**LG**			**0.18**	mm	Gap Length (Lg >> 0.051 mm)
52	BWE		24		mm	Effective Bobbin Width
53	OD			0.25	mm	Maximum Primary Wire Diameter including insulation
54	INS		0.05		mm	Estimated Total Insulation Thickness (= 2 * film thickness)
55	DIA			0.21	mm	Bare conductor diameter
56	AWG			32	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
57	CM		64		Cmils	Bare conductor effective area in circular mils
58	**CMA**			**243**	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 500)
59						
60	**TRANSFORMER SECONDARY DESIGN PARAMETERS**					
61	ISP			4.91	Amps	Peak Secondary Current
62	ISRMS			2.22	Amps	Secondary RMS Current
63	IO			1.25	Amps	Power Supply Output Current
64	IRIPPLE			1.84	Amps	Output Capacitor RMS Ripple Current
65						
66	CMS		540		Cmils	Secondary Bare Conductor minimum circular mils
67	AWGS			22	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
68	DIAS			0.65	mm	Secondary Minimum Bare Conductor Diameter
69	ODS			1.33	mm	Secondary Maximum Insulated Wire Outside Diameter
70	INSS		0.34		mm	Maximum Secondary Insulation Wall Thickness
71						
72	**VOLTAGE STRESS PARAMETERS**					
73	VDRAIN			668	Volts	Maximum Drain Voltage Estimate (Includes Effect of Leakage Inductance)
74	PIVS			48	Volts	Output Rectifier Maximum Peak Inverse Voltage
75	PIVB			49	Volts	Bias Rectifier Maximum Peak Inverse Voltage
76						
77	**ADDITIONAL OUTPUTS**					
78	VX	12			Volts	Auxiliary Output Voltage
79	VDX	0.7			Volts	Auxiliary Diode Forward Voltage Drop
80	NX			9.22		Auxiliary Number of Turns
81	PIVX			49	Volts	Auxiliary Rectifier Maximum Peak Inverse Voltage
82						

Table 6. Design Spreadsheet for 15 W Triple Insulated Wire Transformer.

TRANSFORMER CONSTRUCTION VARIABLES (INPUT TO TABLE 6 SPREADSHEET)				
DESCRIPTION	**SYMBOL**	**VALUE**	**SOURCE**	**CELL #**
Core Type	-	EF20	Core Specification	B23
Core Effective Cross Sectional Area	A_e	0.335 cm^2	Core Specification	B24
Core Effective Path Length	L_e	4.49 cm	Core Specification	B25
Core Ungapped Inductance Coefficient	A_L	1470 nH/T^2	Core Specification	B26
Bobbin Physical Winding Width	BW	12.0 mm	Calculated from Bobbin Specification	B27
Margin Width	M	0	Default Value from AN-16	B28
Number of Primary Winding Layers	L	2	Default Value from AN-16	B29
Number of Secondary Turns	N_S	9 t	See Text	B30

Table 7. Transformer Construction Variables for EF20 Triple Insulated Wire Design.
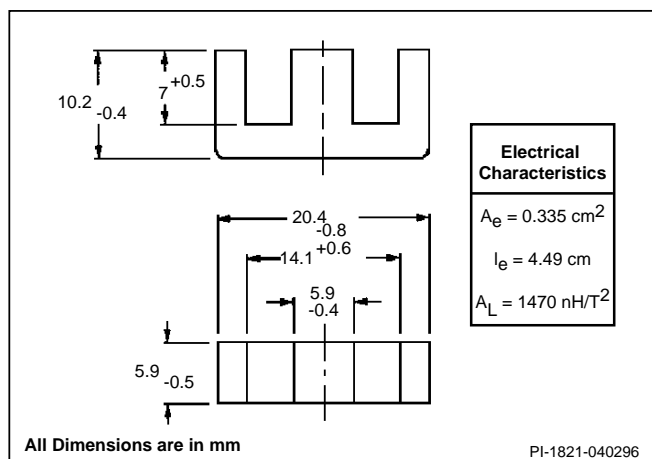
Figure 6. EF20 Core.
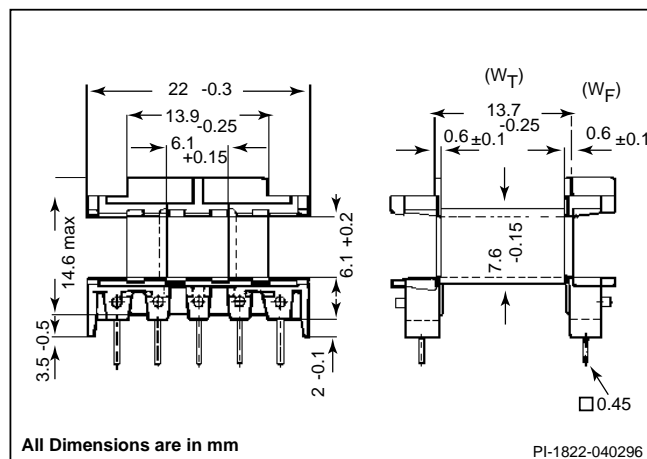
Figure 7. EF20 Bobbin.

TRIPLE INSULATED WIRE TRANSFORMER CONSTRUCTION PARAMETERS FROM TABLE 6 SPREADSHEET			
DESCRIPTION	**SYMBOL**	**VALUE**	**CELL #**
Core Type, Material, Part #	-	EF20, Siemens N67 Part# B66311-G-X130	-
Bobbin Type, Part #	-	EF20, 10 PIN, Siemens PIN B66206-A 1110-T1	-
Number of Primary Turns	N_P	94 turns	D45
Number of Secondary Turns	N_S	9 turns	B30
Number of Bias Winding Turns	N_B	9 turns	D46
Primary Wire Size	AWG	32 AWG	D56
Secondary Wire Size	AWG_S	26 AWG Triple Insulated	D67 (See Text)
Bias Winding Wire Size	AWG_B	24 AWG	See Text
Core Gapped Inductance Coefficient	A_{LG}	205 nH/T^2 ±5%	C47
Primary Inductance	L_P	1829 µH +/-10%	D44
Reinforced Insulation Tape Width	BW	N/A	B27
Basic Insulation Tape Width		12.0 cm	See Text
Margin Tape Width	M	N/A	B28
Sleeving Size	-	N/A	N/A

Table 8. Construction Parameters for Triple Insulated Wire Design Example.

Secondary Wire Size

From cell (B66) of the Table 6 spreadsheet, a secondary bare wire area of 540 circular mils is required to make the secondary CMA equal the primary CMA. From cell (D67), the closest AWG wire size that can satisfy this requirement with a single wire is calculated as 22 AWG. This wire size is too large for use at 100KHz, and several smaller parallel wires should be used instead to allow full utilization of the wire cross-sectional area. From the wire table in Appendix A, it can be seen that two parallel strands of 26 AWG triple insulated wire (CM of 252.8 circular mils per wire) have a total bare wire area of 505.6 circular mils, which is within 10% of the required CM of 540

circular mils. The current capacity of the parallel winding can be calculated from the formula:

$$CMA_S = \frac{N \times CM}{I_{SRMS}}$$

CMA_S is the current capacity of the secondary winding in circular mils per ampere, N is the number of strands in the secondary winding, CM is the bare area of a single secondary conductor in circular mils (from the wire table in Appendix A), and I_{SRMS} is the secondary RMS current from cell (D62) of the

spreadsheet. 26 AWG wire has a bare area of 252.8 circular mils. Two parallel strands of 26 AWG triple insulated wire have a current capacity of:

$$CMA_S = \frac{2 \times 252.8}{2.25} = 224.7 \text{ circular mils/ampere}$$

This value is within 10% of the primary CMA of 243 circular mils/ampere, and satisfies the CMA limit of 200-500 circular mils per ampere.

Bias Wire Size
The bias winding wire size is chosen to fill as much of the bobbin width as possible. Since there are usually relatively few turns on the primary bias winding, this is best accomplished by using a bifilar winding rather than a large diameter wire, effectively doubling the number of physical turns. The required TC to fill a single layer can be calculated as follows:

$$TC = \frac{2 \times N_B \times 10}{BW - (2 \times M)} = \frac{2 \times 9 \times 10}{12 - (2 \times 0)}$$
$$= 15 \text{ turns}/cm$$

From the wire table, the closest wire size with a TC greater than or equal to this value is 23 AWG, with a TC of 15.82 turns/cm. This wire is too large to use with a small bobbin. A compromise is to use the next smallest size, 24 AWG, which will not fill the bobbin width completely, but is easier to terminate to the bobbin pins. Since the output current of this winding is 10 mA

or less, there is no need to consider the current capacity of the wire. The wire size in this case is determined by fill factor requirements rather than current capacity.

Transformer Construction Style
Since this transformer is a triple insulated wire design for a secondary regulated application, appropriate construction styles are Figure 7B and 10B. Because this design is for a 15W application, a split primary winding as shown in Figure 10B is not necessary, and the more cost effective single section primary design of Figure 7B should be used.

Tape Sizes
Since this is a triple insulated design, one size of tape is required for basic insulation, with a width equal to BW. From cell (B27) of the Table 6 spreadsheet, this is 12.0 mm.

Insulating Sleeving Size
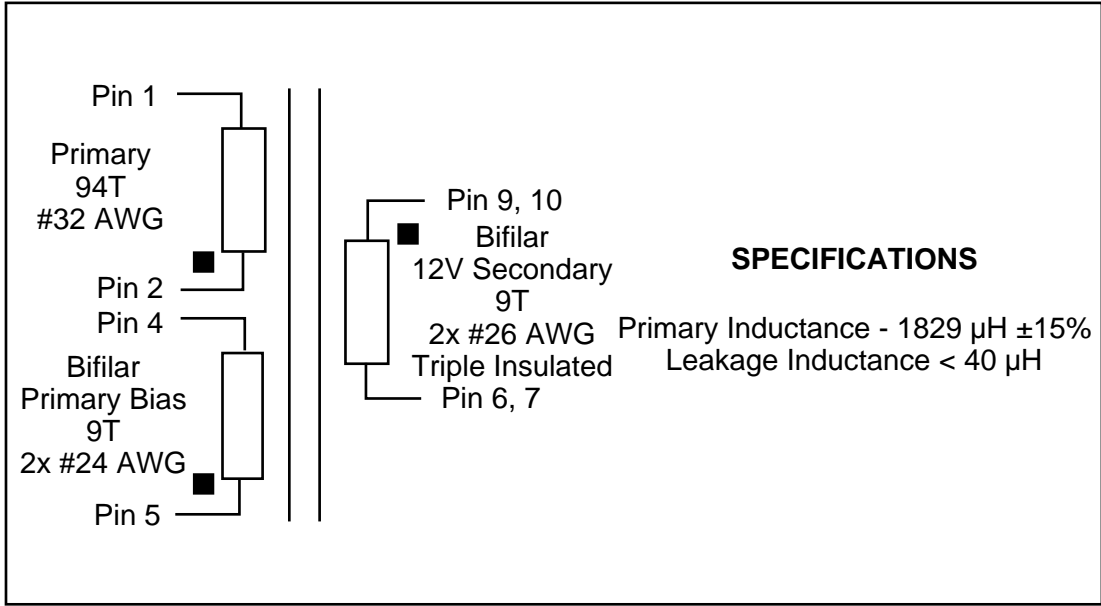Since this is a triple insulated wire design, no sleeving is required

Gapped Core Inductance Coefficient
The A_{LG} for this transformer design is given in cell (C47) of the design spreadsheet, and should be used as the center value for specifying the core A_{LG} on the transformer specification.

Finished Triple Insulated Wire Transformer Design
The information required to assemble a transformer specification for the triple insulated wire transformer example is summarized in Table 8. A completed transformer schematic diagram and parts list are shown in Figure 8. A construction drawing is shown in Figure 9.

Pin 1

Primary
94T
#32 AWG

Pin 2

Pin 4

Bifilar
Primary Bias
9T
2x #24 AWG

Pin 5

Pin 9, 10
Bifilar
12V Secondary
9T
2x #26 AWG
Triple Insulated
Pin 6, 7

SPECIFICATIONS

Primary Inductance - 1829 µH ±15%
Leakage Inductance < 40 µH

PARTS LIST FOR EF20 TRANSFORMER DESIGN EXAMPLE				
Item	**Amt.**	**Description**	**Part #**	**Manufacturer**
1	1pr.	Core, EF20 N67 Mat'l	B66311-G-X167	Siemens*
2	1ea.	Bobbin, EF20, 10 pin	B66206-A1110-T1	Siemens
3	A/R	Wire, 32 AWG Heavy Nyleze		
4	A/R	Wire, 24 AWG Heavy Nyleze		
5	A/R	Wire, 26 AWG Triple Insulated		
6	A/R	Tape, Polyester 12.0 mm wide	#1296	3M

*Gap for A_{LG} of 205 nH/T^2 ±5%

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Figure 8. Parts List for EF20 Transformer Design Example.

TRIPLE INSULATED TRANSFORMER CONSTRUCTION
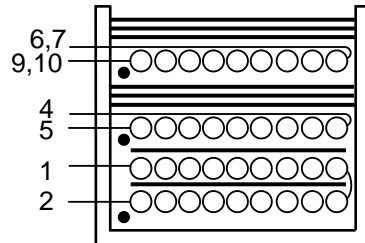
WINDING INSTRUCTIONS	
Two-layer "C" Wound Primary	Start at pin 2. Wind 47 turns of 32 AWG heavy nyleze wire from left to right. Apply 1 layer of polyester film tape, 12.0 mm wide, for basic insulation. Continue winding 47 turns from right to left. Finish at pin 1.
Basic Insulation	Apply 1 layer of 12.0 mm wide tape for basic insulation.
Primary Bias (Bifilar)	Start at pin 5. Wind 9 bifilar turns of 24 AWG heavy nyleze wire in a single layer, from left to right. Finish at pin 4.
Basic Insulation	Apply 1 layer of 12.0 mm wide tape for basic insulation.
Parallel Bifilar Triple Insulated Secondary	Start at pin 9 & 10. Wind 9 bifilar turns of 26 AWG triple insulated wire in approximately 1 layer from left to right. Finish at pin 6 & 7.
Outer Insulation	Apply 3 layers of 12.0 mm wide tape for outer insulation.
Final Assembly	Assemble and secure core halves. Impregnate uniformly with varnish.

PI-1816-032896

Figure 9. EF20 Triple Insulated Design Example.

References

1) Power Integrations, Inc., AN-15, "Power Supply Design Techniques for EMI and Safety"

2) Power Integrations, Inc., AN-16, "*TOPSwitch* Flyback Fundamentals"

3) Power Integrations, Inc., AN-17, "Flyback Transformer Design for *TOPSwitch* Power Supplies"

4) Power Integrations, Inc. DN-8, "Simple Bias Supplies Using the TOP200"

5) Col. William McLyman, Transformer and Inductor Design Handbook, New York, Marcel Dekker, Inc., 1978

6) Col. William McLyman, Magnetic Core Selection for Transformers and Inductors, New York, Marcel Dekker, Inc., 1982

7) Abraham I. Pressman, Switching Power Supply Design (2nd ed.), New York, McGraw-Hill, Inc., 1991

8) Ferdinand C. Geerlings, "SMPS Power Inductor and Transformer Design, Part 1", Powerconversion International, November/December 1979, pp. 45-52

9) Ferdinand C. Geerlings, "SMPS Power Inductor Design and Transformer Design, Part 2", Powerconversion International, January/February 1980, pp. 33-40

10) Coilcraft, Inc., Technical Note Number 8110, "V.D.E. Transformer Safety Requirements"