www.powertoroid.com

# TOROIDAL POWER TRANSFORMERS

## TECHNICAL GUIDE & SPECIFICATIONS

***Standard & Custom Transformers***
***for OEM Applications***
***20VA to 10KVA***

ISO 9001
CERTIFIED

**BICRON** Electronics Company

## The BICRON Advantage . . .

- ISO 9001 Certified
- Designing and producing quality magnetics since 1964
- State-of-the-art engineering development tools offering:
  - Finite element analysis
  - Circuit simulation
- UL, TUV, IEC, etc. approved products for:
  - Medical
  - Audio
  - General purpose

BAUART GEPRÜFT
TÜV Rheinland

- Transformers ranging from 20VA to 10,000VA
- Long history servicing many of the Fortune 500 companies
- Capabilities to design/manufacture value added assemblies

***Our goal is to exceed our customers' expectations by constantly seeking better ways to deliver service and value.***

**BICRON** Electronics Company

*The Bicron design and production team is dedicated to solving your problems with quality products, technical innovation and on-time delivery.*

# *Guide for Optimum Specification of Toroidal Transformers*

**PAGE**

*Help? Call our design and sales engineers — 800-625-2766 or 860-824-5125*

## COST SAVING ADVANTAGES

### Lower Off-load Power Consumption

Lower off-load power consumption leads to long term cost savings due to increased electrical efficiency. The efficiency or losses at each point in the whole system determines the overall system operating cost. Each point of conversion has losses. Minimizing these losses lowers the cost of product and provides long term cost savings to your customer. (Fig. 1)

### Smaller and Lighter

High packing density and related advantages lead to reduced design costs. A physically smaller transformer is less expensive to manufacture, and will also reduce your overall system cost by allowing for smaller packaging (Fig. 2)

A smaller transformer also means lighter weight, which will save you costs by reducing the structural chassis design, and improving portability. (Fig. 3)

### Wider Choice of Configuration

Selecting a transformer core designed from a single strip of steel will save cost by providing you the option of an infinite variety of configurations. This advantage leads to custom transformer dimensions to meet almost any product or system parameter.

### Low Radiated EMI

Selecting a transformer exhibiting low radiated EMI will save costs by significantly reducing interference and shielding between the transformer and sensitive electronic components. (Fig. 4)

### Virtually No Audible Noise

Selecting a transformer inherently void of low frequency audible noise will save costs by simplifying installation and improving the quality of the product.

### Safety Recognition

Installation of a safety agency's listed or recognized transformer, or certification of compliance, can help save costs incurred in the regulatory approval process. Typical safety agency approvals and standards applied to Bicron transformer products include UL, CSA, VDE, TUV, and IEC.

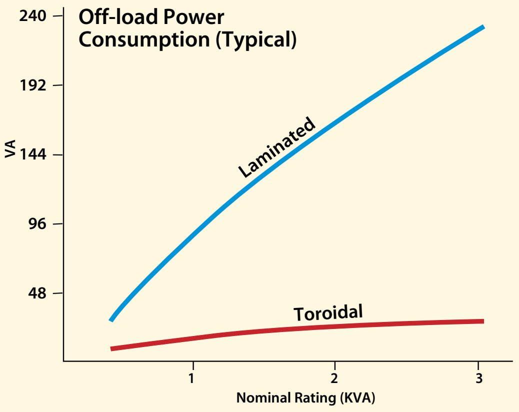


Fig. 1

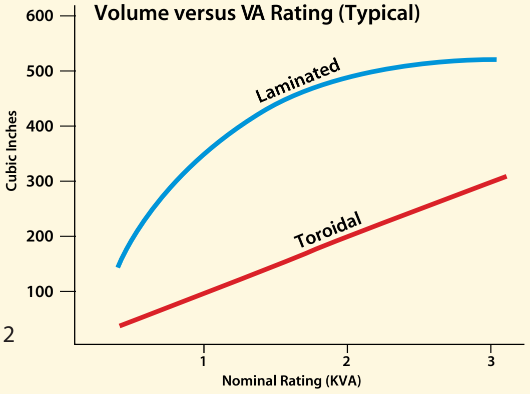


Fig. 2

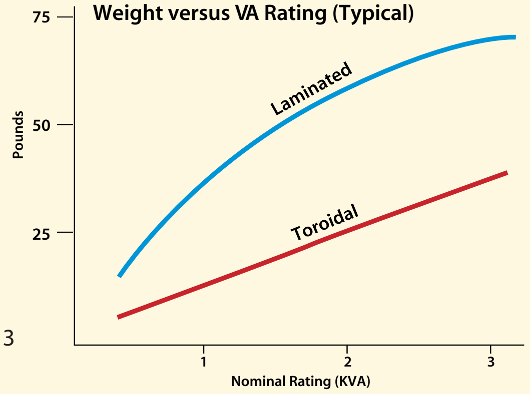


Fig. 3

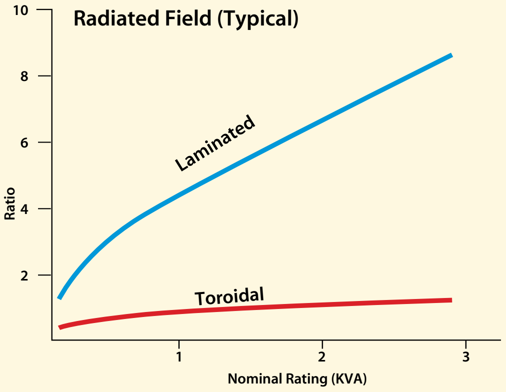


Fig. 4

## TRANSFORMER FUNDAMENTALS

### TRANSFORMER EFFICIENCY

All transformer windings and transformer cores produce copper and magnetic losses that appear as heat:

$VA_{in} = VA_{out} + W_{loss}$
where VA = volts × amperes
$W_{loss} = W_{cu} + W_{fe}$
$W_{cu}$ = watts dissipated through copper losses in the windings
$W_{fe}$ = watts dissipated through magnetic losses in the core

The toroidal transformer typically requires only 10% of the magnetizing current required by laminated transformers. Higher flux densities are permitted because the direction of the magnetic flux is the same as the steel core grain. High flux densities allow fewer turns of copper wire, reducing the DCR of the winding. Figure 5 shows the efficiency that can be expected in terms of VA power ratio.

### HIGH PACKING DENSITY

Toroidal transformer cores are the ideal shape, which minimizes the amount of core material and allows symmetrical distribution of the winding around the entire core. This, along with higher operating flux densities, permit fewer copper wire turns than required on an equivalent laminated core. These inherent characteristics result in considerable weight and volume savings, as well as other advantages.

Referring to Faraday's equation for induced voltage in a transformer winding:

$ERMS = 4.44 \times N \times AC \times F \times B \times 10^{-8}$
where:
F = frequency
N = number of turns
B = flux density (gauss)
AC = core cross section area ($cm^2$)

Toroidal transformers can operate at flux densities up to 16.5 kilogauss, approximately 40% higher than the conventional laminated power transformer. Operation of any core beyond its maximum rated flux density will result in increased $W_{fe}$ losses in addition to waveform distortion.

The weight of a transformer is comprised of the following items:

(1) Copper (windings)
(2) Steel (core)
(3) Insulation materials
(4) Mounting hardware or potting material

The obvious trade-off for weight reduction is between the amount of copper wire and the size of the core. A well-designed transformer will be a balance of copper and steel needed to obtain reasonable AC regulation, temperature rise, and minimum physical size. See Fig. 3 for a comparison of Toroidal vs. Laminated weights.

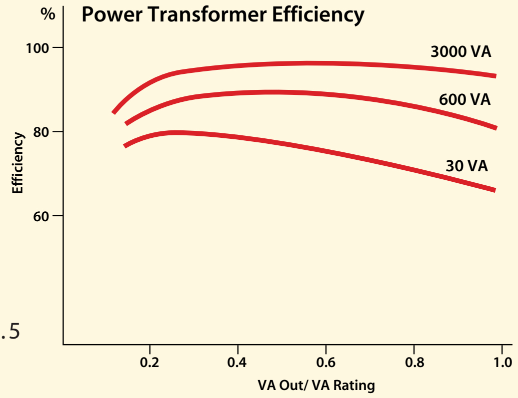


Fig. 5

The physical dimensions (volume) of a transformer can be varied for any given design. The core of the toroid transformer is made of a strip of grain oriented silicon steel. The strip width determines the height of the core while the inside and outside diameters determine the physical dimensions and the cores' cross-section area. The cost to produce a custom vs. standard toroid core is relatively low. Most toroidal transformers have a diameter to height ratio of 3:1, but ratios of 2:1 (high profile) and 7:1 (low profile) are possible. See Figure 2 for a comparison of the standard Toroid vs. Laminated volumes.

### OTHER ADVANTAGES OF HIGH PACKING DENSITY

EMI fields are very low because of the unique construction of the Toroid transformer. These transformers are wound on a ring shaped core, a configuration that provides maximum containment of magnetic fields. Unlike laminated transformers, toroid transformers do not have air gaps within the core. Air gaps cause a discontinuity in the magnetic path giving rise to increased radiated fields. Additionally, the even distribution of the primary winding over the secondary winding, uniformly around the entire core, ensures that the magnetic fields generated in the windings can be cancelled. Reductions of up to eight times, relative to the laminated transformer, can be expected. Further reduction is possible with a metal bellyband around the outside of the transformer, or full containment of the transformer within a steel enclosure. See figure 9.

Audible noise generated by a Toroid transformer is inherently low. The single strip of steel wound into a ring and welded at both ends is very solid and stable. The copper windings and insulation system completely envelope the core, further stabilizing the transformer and dampening the acoustical noise caused by magnetostriction phenomena.

Transformer noise can also be minimized by increasing DC ripple requirements in linear power supply applications. Low DC ripple require the transformer to deliver very large pulses of current in short periods of time. The high energy pulses further increase the magnetostriction action.

### LINE FREQUENCY

The majority of toroidal power transformers are designed to operate in 50/60Hz, 60Hz or 400Hz applications. As the frequency increases the thickness of the strip steel is decreased to improve efficiency. The core size and/or the winding also decreases, making for a smaller transformer. This reduction in the physical size of the transformer, as a function of frequency, should be considered when packaging a transformer in the product. A 60Hz transformer will be 20% smaller than a 50/60Hz transformer.

### PRIMARY VOLTAGE

A transformer operates using magnetic induction. The basic transformer consists of two coils of wire wound on a steel core. When a voltage is applied to one of the coils, it magnetizes the core and a voltage is induced in the second coil. The ratio of the primary voltage to the secondary voltage depends on the turns ratio of the two coils:

$$V_P / V_S = T_P / T_S$$

where $V$ = voltage and $T$ = turns

Taps may be provided on the transformer to compensate for different country requirements. Figure 6 shows typical primary voltage configurations.

Note: Multiple primary windings must be connected in parallel or series to maintain rated power.

### SECONDARY VOLTAGE

The secondary voltage(s) of the transformer is specified with rated primary voltage and full load secondary current.

### SECONDARY VOLTAGE REGULATION

The voltage regulation of the transformer is the relationship of the open circuit (no load condition) to the rated voltage (full load condition). This condition can be expressed as:

$$\text{Reg} = (V_{NL} - V_{FL}) / V_{FL}$$

where $V_{NL}$ = no load AC voltage and $V_{FL}$ = full load AC voltage

Regulation can be improved by decreasing the $W_{cu}$ losses or by specifying a transformer with a larger VA ratiing.

### SECONDARY DUTY CYCLE

The secondary VA requirements can be reduced if the load is intermittent and the "on" time is shorter than the transformer thermal time constant. Thermal time constants for transformers are typically a few minutes to fifteen minutes, depending on physical mass of the transformer.

$$\text{Duty Cycle} = (T_{ON} / (T_{ON} + T_{OFF})^{1/2}$$

where $T_{ON}$ = time transformer is powering load and

$T_{OFF}$ = time transformer is not powering load

### SECONDARY VA REQUIREMENTS

The secondary winding capacity is defined in terms of voltage, current and duty cycle:

$$VA = V_{FL} \times I_{FL} \times (\text{Duty Cycle})$$

where:

$V_{FL}$ = AC secondary voltage at specified current requirements and

$I_{FL}$ = AC secondary current at specified maximum requirement

***Many different primary voltage configurations are available to meet virtually any possible requirement.***

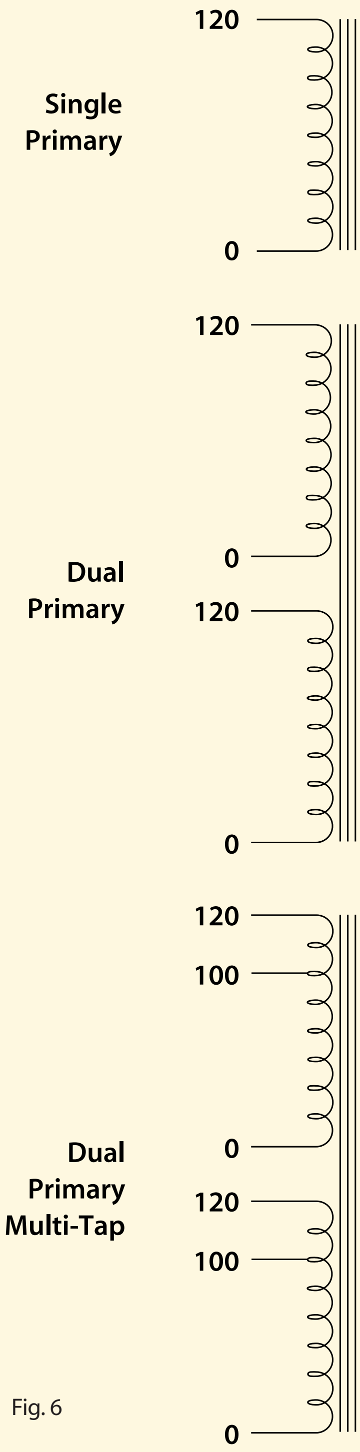
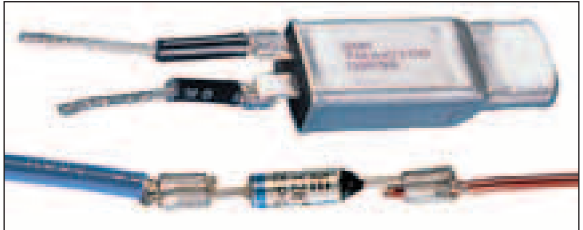


Fig. 6

## ELECTROSTATIC SHIELDS

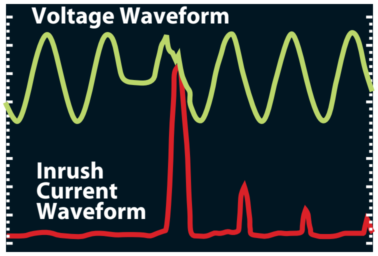
There are two distinct types of transients present on the power grid; Common Mode and Transverse. Transverse noise are transients present, but not referenced to ground. Typical examples are switching power supplies, universal motors, etc. This noise is usually extinguished at its source with line filters. Common mode noise are transients present on the power grid but referenced to ground. Typical examples are lighting strikes, switching, electromagnetic pulses, etc. To decrease common mode noise, transformers can be modified by incorporating an electrostatic shield between the primary and secondary windings. The capacitance between the primary and the shield channels most of the common mode noise to ground.



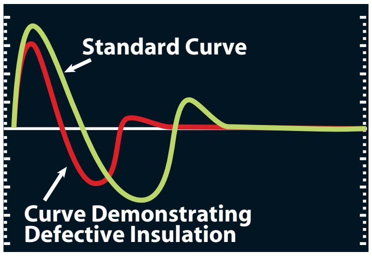
*Auto reset (top) or non-reset thermal fuses may be wired in series with the transformer winding.*

## THERMAL PROTECTION

There are two types of thermal protection available for transformers; Non-reset and Auto-reset. The purpose of these devices is to shut down the transformer in the event of overheating. The non-reset is used primarily for protection from internal transformer faults, tripping at a preset temperature. The auto reset provides intermittent protection from internal transformer faults and external overloads. This device will open at a preset high temperature and close at a preset lower temperature. These devices are mounted internal to the transformer and wired in series with the winding.

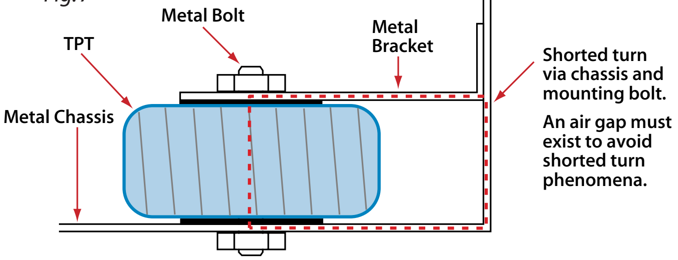


*(Fig. 8a) Primary Inrush Current Waveform, which can cause nuisance tripping of breakers, occurs when power is removed and then reapplied in the same polarity half cycle.*



*(Fig. 8b) Surge test waveform indicating a turn-to-turn voltage breakdown within a transformer winding.*

*Fig. 7*



## MOUNTING PRECAUTIONS

The inadvertent design of a shorted turn by providing a conductive loop (turn) through the center of a toroidal transformer must be avoided. This typically occurs when designing special mounting hardware for the transformer. A shorted turn results in high circulating currents, excessive heat, and poor performance. (Fig. 7)

## INRUSH PRECAUTIONS

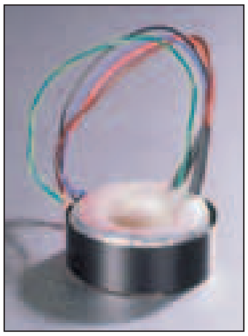
Because the core does not have air gaps, toroidal transformers have the advantage over traditional E-I transformers of low standby power consumption (magnetization current). However, this results in a higher residual flux (remanence) when power is removed. When power is reapplied the core may go into saturation, causing a current inrush which may be 15 times higher than the steady state current. The condition rarely lasts for more than two cycles as can be seen in figure 8a.

There are several approaches for addressing inrush:

1. *Adding a resistor in series with the primary winding of the transformer, which is removed from the circuit after power is applied.*
2. *Utilizing delayed action fuses for the protection devices.*
3. *Reduce the residual flux (Remanence) which will increase the magnetization current in the core. Methods used to reduce residual flux include: introducing a gap, or utilizing alternate materials and/or annealing methods.*

Bicron has had much success in designing transformers with low inrush, and can assist you in determining the best approach for your application.

*Fig. 9*
*Further reduction of any radiated fields is possible with a metal bellyband around the outside of the transformer or full containment of the transformer within a steel enclosure.*



## TOROIDAL POWER TRANSFORMER PRODUCT GUIDE

### Choose from a broad range of standard starting points for the custom Toroidal Power Transformer design you require — 20VA to 10,000VA!

Bicron Toroidal Power Transformers are available in a wide range of sizes and configurations up to 10KVA. The table at right shows typical specifications.

Bicron's safety agency recognitions include: **Medical** – UL544, IEC601-1; **Consumer Electronics** – UL1411, UL6500, IEC60065; **General Purpose** – UL478. Recognized insulation systems include: **Class B** –130°C, **Class F** –155°C, **Class H** –180°C. Custom transformers can be designed and manufactured to comply with various other standards such as UL2601, UL5606, UL1778, UL1950, and UL60950.

The Bicron standard part numbering code is shown as an aid to quickly specifying the unit which you require. See Fig. 6 on page 5 and Fig. 11 on page 8 for a sampling of winding and connection alternatives.

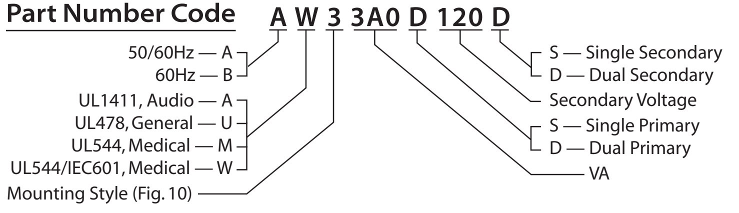
The Bicron Technical Sales and Engineering Team is ready to help you design and specifiy the precise unit that will best meet the needs of your application. Size, power rating, mounting, height/diameter ratio, lead configuration, agency approval type, insulation and shielding are just some of the common factors we consider in every design.

Need Help? Call us at 1-800-6-BICRON (1-800-624-2766).

| 50/60Hz AM/AW/AU/AA Power (VA) | 60Hz BU Power (VA) | Regulation Full Load (%) | Size * O.D. x Ht. (inches) | Wgt. (lbs) | Part Number |
|---|---|---|---|---|---|
| **AA/AU/BU SERIES — AUDIO, GENERAL PURPOSE** | | | | | |
| 20 | 24 | 25 | 2.7 x 1.5 | 0.8 | __202AD __ D |
| 30 | 36 | 25 | 2.7 x 1.9 | 1.2 | __203AD __ D |
| 40 | 48 | 20 | 3.5 x 1.5 | 1.5 | __204AD __ D |
| 60 | 72 | 15 | 3.5 x 1.8 | 1.9 | __206AD __ D |
| 80 | 96 | 13 | 4.2 x 1.7 | 2.1 | __208AD __ D |
| 100 | 120 | 11 | 4.2 x 1.9 | 2.3 | __210AD __ D |
| 160 | 200 | 10 | 4.7 x 2.0 | 3.1 | __216AD __ D |
| 230 | 275 | 8 | 4.7 x 2.5 | 5.5 | __223AD __ D |
| 330 | 400 | 7 | 4.8 x 3.1 | 6.8 | __233AD __ D |
| 400 | 480 | 7 | 5.7 x 2.6 | 7.5 | __240AD __ D |
| 530 | 640 | 6 | 5.7 x 3.2 | 9.8 | __253AD __ D |
| 600 | 720 | 5 | 5.7 x 3.5 | 11.0 | __260AD __ D |
| 750 | 900 | 5 | 6.3 x 3.5 | 13.0 | __275AD __ D |
| 1,000 | 1200 | 5 | 6.3 x 3.8 | 16.0 | __31A0D __ D |
| 1,200 | 1440 | 5 | 6.3 x 4.5 | 18.0 | __31A2D __ D |
| 1,500 | 1800 | 5 | 7.9 x 3.5 | 21.0 | __31A5D __ D |
| 2,000 | 2400 | 5 | 7.9 x 4.1 | 28.0 | __32A0D __ D |
| 2,500 | 3000 | 4 | 8.1 x 5.1 | 34.5 | __32A5D __ D |
| 3,000 | | 4 | 8.3 x 5.3 | 36.5 | __33A0D __ D |
| **AM/AW SERIES — MEDICAL** | | | | | |
| 100 | | 11 | 4.3 x 2.0 | 3.0 | A_210AD120S |
| 230 | | 8 | 4.8 x 2.6 | 6.0 | A_223AD120S |
| 400 | | 7 | 5.8 x 2.5 | 7.0 | A_240AD120S |
| 600 | | 5 | 5.8 x 3.6 | 11.0 | A_260AD120S |
| 750 | | 5 | 6.5 x 3.6 | 13 .0 | A_375AD120S |
| 1,000 | | 5 | 6.5 x 4.2 | 18.0 | A_31A0D120D |
| 1,500 | | 5 | 8.1 x 4.5 | 30 .0 | A_31A5D120D |
| 2,000 | | 4 | 8.6 x 5.1 | 41.0 | A_32A0D120D |
| 2,500 | | 4 | 9.2 x 5.2 | 46 .0 | A_32A5D120D |
| 3,000 | | 3 | 9.3 x 5.3 | 48.0 | A_33A0D120D |
| **HIGH POWER RATED TRANSFORMERS** | | | | | |
| 5,000<br>6,000<br>7,000<br>8,000<br>9,000<br>10,000 | **Bicron Toroidal Transformers with power ranges from 5,000VA TO 10,000VA are readily available in a wide range of configurations designed to meet specific requirements for size, input/output values, lead configuration, shielding, mounting . . . and much more. Call for details.** | | | | |

*Data Subject to Change.*

* *Sizes include hardware for mounting style type 2 or 3. Sizes are approximate and may vary based on voltage configurations and shield options.*



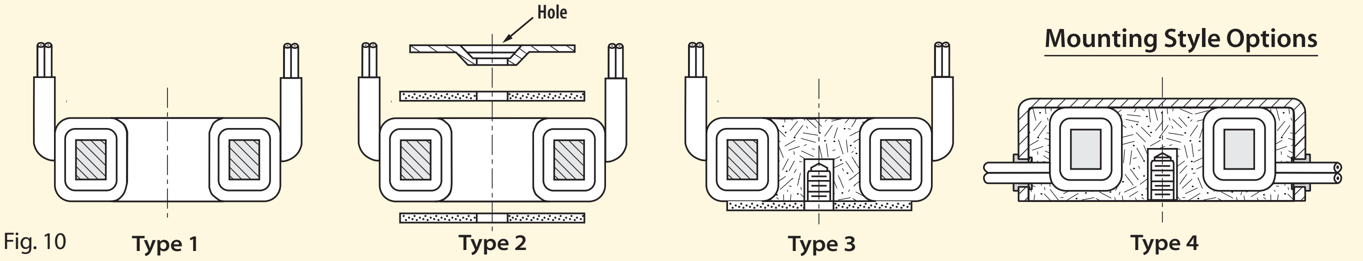


Fig. 10

## TECHNICAL NOTES

### LINEAR POWER SUPPLY DESIGN

Typically there are three system configurations used in conjunction with linear power supplies. The half wave (HW), the full wave (FW), and the full wave center tap (FWCT). Each configuration will have impact on the VA requirements of the transformer and the circuit components comprising the rectification and filtering. Please contact Bicron engineering for specific transformer parameters.

### THREE PHASE SYSTEM BASICS

Three single phase transformers may be connected to form a 3-phase bank in the configurations shown. Also shown are the voltages and currents based on ideal conditions. The VA rating of each transformer is one third the total system regardless of the selected configuration. The voltage and current ratings of each transformer is, however, configuration dependent.

### AUTOTRANSFORMER BASICS

The same transformation of voltage and current can be obtained with a single winding autotransformer as with the normal two winding transformer. There are two major differences: (1) In the autotransformer, the secondary winding is common to both the primary and secondary winding, and (2) There is a direct copper connection between the primary and secondary circuits. Autotransformers have lower leakage reactance, lower losses, smaller excitation currents, and they can be smaller and less expensive than dual winding transformers when the voltage ratio is less than 2:1. And, of course, they provide no isolation.

### THERMAL CLASS

Thermal class is designated by a letter and defines the lowest temperature rating of the materials which make-up the transformer: Class A materials (105°C), Class B (130°C), Class F (155°C), Class H (180°C).

### TEMPERATURE RISE

The temperature rise of a transformer can be determined by the resistance method:

$t = ((R_2 2R_1)/ R_1)3(234.52t_2)\ 2\ (t_2 2t_1)$

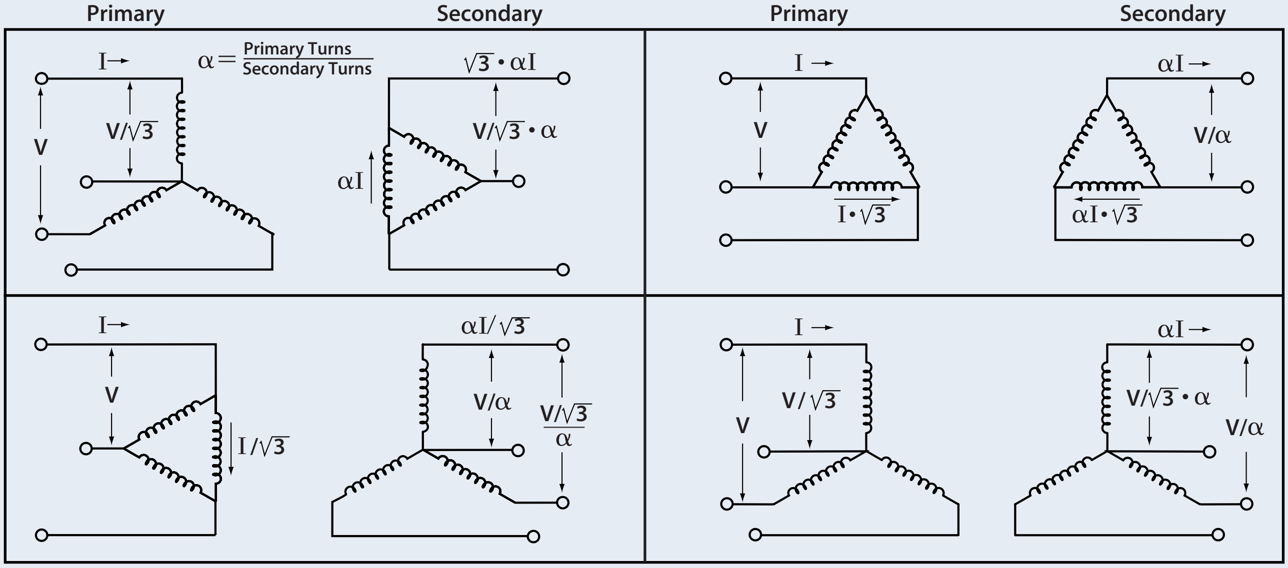
$t$ = temperature rise over ambient, $t_2$ (°C)

$R_2$ = resistance of winding at end of test

$R_1$ = resistance of winding at beginning of test

$t_2$ = ambient temperature at end of test (°C)

$t_1$ = ambient temperature at beginning of test (°C)



*Toroidal transformers connected to form three phase banks are shown above in four different input/output configurations in various combinations of delta and wye. Voltages and currents are based on ideal conditions.*

*Step-up and step-down autotransformers are shown at right. Autotransformers are the most economical solution when the voltage ratio is less than 2:1 and isolation is not required.*

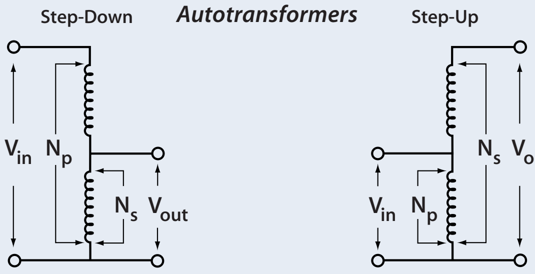


*Fig. 11*