BONITRON

Solutions for AC Drives

Model M3464

PWM to Sine Wave Filter Module

Customer Reference Manual

Bonitron, Inc.
Nashville, TN

An industry leader in providing solutions for AC drives.

ABOUT BONITRON

Bonitron designs and manufactures quality industrial electronics that improve the reliability of processes and variable frequency drives worldwide. With products in numerous industries, and an educated and experienced team of engineers, Bonitron has seen thousands of products engineered since 1962 and welcomes custom applications.

With engineering, production, and testing all in the same facility, Bonitron is able to ensure its products are of the utmost quality and ready to be applied to your application.

The Bonitron engineering team has the background and expertise necessary to design, develop, and manufacture the quality industrial electronic systems demanded in today's market. A strong academic background supported by continuing education is complemented by many years of hands-on field experience. A clear advantage Bonitron has over many competitors is combined on-site engineering labs and manufacturing facilities, which allows the engineering team to have immediate access to testing and manufacturing. This not only saves time during prototype development, but also is essential to providing only the highest quality products.

The sales and marketing teams work closely with engineering to provide up-to-date information and provide remarkable customer support to make sure you receive the best solution for your application. Thanks to this combination of quality products and superior customer support, Bonitron has products installed in critical applications worldwide.

AC Drive Options

In 1975, Bonitron began working with AC inverter drive specialists at synthetic fiber plants to develop speed control systems that could be interfaced with their plant process computers. Ever since, Bonitron has developed AC drive options that solve application issues associated with modern AC variable frequency drives and aid in reducing drive faults. Below is a sampling of Bonitron's current product offering.

World Class Products

Undervoltage Solutions

Uninterruptible Power for Drives
(DC Bus Ride-Thru)
Voltage Regulators
Chargers and Dischargers
Energy Storage

Overvoltage Solutions

Braking Transistors
Braking Resistors
Transistor/Resistor Combo
Line Regeneration
Dynamic Braking for Servo Drives

Common Bus Solutions

Single Phase Power Supplies
3-Phase Power Supplies
Common Bus Diodes

Portable Maintenance Solutions

Capacitor Formers
Capacitor Testers

Power Quality Solutions

12 and 18 Pulse Kits

Green Solutions

Line Regeneration

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1. INTRODUCTION

1.1. WHO SHOULD USE

This manual is intended for use by anyone who is responsible for integrating, installing, maintaining, troubleshooting, or using this equipment with any AC drive system.

Please keep this manual for future reference.

1.2. PURPOSE AND SCOPE

This manual is a user's guide for the model M3464 PWM to sine wave filter. It will provide the user with the necessary information to successfully install, integrate, and use the M3464 with most any PWM inverter.

In the event of any conflict between this document and any publication and/or documentation related to the drive system, the latter shall have precedence.

1.3. MANUAL VERSION AND CHANGE RECORD

An Operation Note (Section 2) was added in Rev 07b.

A typo was corrected in Table 6-1 in Rev 07c.

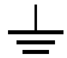
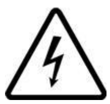
About Bonitron section was updated in Rev 07d.

The manual template was updated in Rev 07e.

The part number breakdown was updated in Rev 08a.

Figure 1-1: Model M3464-H24-3F9-B7

1.4. Symbol Conventions Used in this Manual and on Equipment

	Earth Ground or Protective Earth
	AC Voltage
	DC Voltage
 **DANGER!**	Electrical Hazard - Identifies a statement that indicates a shock or electrocution hazard that must be avoided.
 **DANGER!**	DANGER: Identifies information about practices or circumstances that can lead to personal injury or death, property damage, or economic loss.
 **CAUTION!**	CAUTION: Identifies information about practices or circumstances that can lead to property damage, or economic loss. Attentions help you identify a potential hazard, avoid a hazard, and recognize the consequences.
 **CAUTION!**	Heat or burn hazard - Identifies a statement regarding heat production or a burn hazard that should be avoided.

2. PRODUCT DESCRIPTION

There are many applications in industry that utilize low horsepower, IGBT type, PWM drives. Newer versions of these PWM drives typically have very fast transistor rise times and high carrier frequencies. When used with motors that have moderate to long cable lengths, high voltages caused by reflected waves might be present. Users of these drives may experience some problems with their systems due this condition. These problems may include any one or more of the following:

Premature motor winding failures

Premature motor bearing failures

Cable insulation failures

Drive ground fault problems

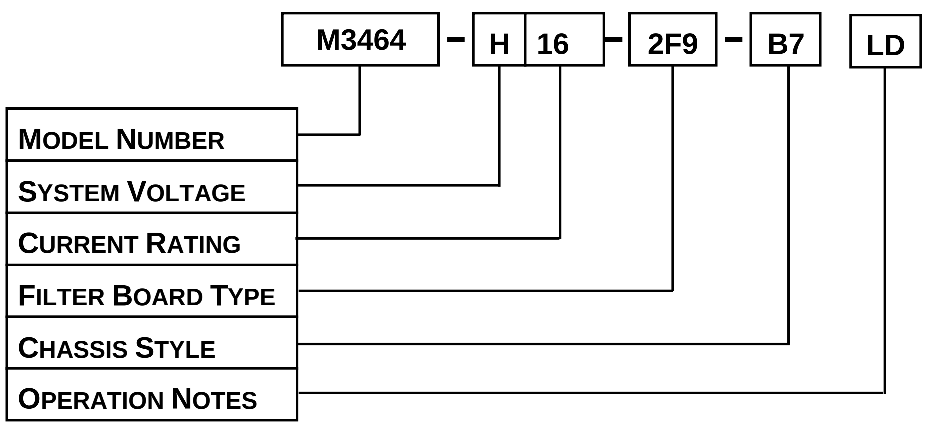
Noise interference in analog signal transducers

Noise interference in RF communication systems

One way to alleviate these problems is to use filtering. Bonitron, Inc. manufactures a line of PWM to sine wave filter modules for use with low horsepower, IGBT, PWM drives. The M3464 series of PWM to sine wave filter modules is available for use with PWM drives rated for up to 575VAC. These modules are designed around Bonitron's 3464F series of PWM filter boards which can handle motor currents of up to 8 amps each. Multiple boards can be combined in parallel configurations to achieve higher motor current ratings as needed.

2.1. PART NUMBER BREAKDOWN

Figure 2-1: Example of Part Number Breakdown



BASE MODEL NUMBER

The base model number for a PWM to sine wave filter is **M3464.**

SYSTEM VOLTAGE RATING

The system voltage rating indicates the nominal AC voltage levels the filter is intended to support. A code letter indicates the system voltage.

Table 2-1: System Voltage Rating Codes

SYSTEM VOLTAGE RATING CODE	NOMINAL AC VOLTAGE
L	230 VAC
H	460 VAC
C	575 VAC

CURRENT RATING

The current rating indicates the maximum current which may be safely handled by the M3464 PWM to sine wave filter unit. The rating is directly represented by a two-digit number. For example, the current rating for a 16A unit is **16**. The current rating is derived using 8 kHz carrier. De-rating must be done at lower carrier frequencies.

FILTER BOARD TYPE

The type of filter board used is denoted by a character code as shown below. If multiple boards are used the number of boards used will precede the board number.

Table 2-2: Filter Board Type Codes

FILTER BOARD CODE	FILTER BOARD TYPE
F7	3464F7 board – L/C-Wye, 230 VAC, 4 A, 10% duty for 2 minutes ON, 4kHz min, removable plugs
F9	3464F9 board – L/C-Wye, 460 VAC, 8 A at 8 kHz, removable plugs
FD	Component on chassis construction – L/C-Delta

CHASSIS STYLE

There are several types of chassis available for use with the M3464 PWM to sine wave filter:

Table 2-3: Chassis Style Codes

CHASSIS CODE	CHASSIS
L2	Open chassis L-bracket for 3464F7 boards
L3	Open chassis L-bracket for 3464F9 boards
B7	Tall NEMA-1 enclosure (17.75”H x 7”W x 9”D)
M3	Short NEMA-1 enclosure (12.75”H x 3”W x 9”D)
M4	Short NEMA-1 enclosure (12.75”H x 4”W x 9”D)
M7	Short NEMA-1 enclosure (12.75”H x 7”W x 9”D)

OPERATION NOTES

This section is used to denote any special instructions:

Table 2-4: Operation Note Codes

OPERATION NOTE CODE	OPERATION NOTES
LD	Indicates unit is designed for less than 100% Duty Cycle.
1P	Single phase only

2.2. GENERAL SPECIFICATIONS CHART

Table 2-5: General Specifications

PARAMETER	SPECIFICATION
Storage Temp	-20°C to +65°C
Humidity	Below 90% non-condensing
Atmosphere	Free of corrosive gas and conductive dust

Table 2-6: Standard Wye Filters rated up to 120Hz

MODEL NUMBER	MAX DRIVE VOLTAGE	DRIVE HP RATINGE	MOTOR CURRENT AT 8KHZ CARRIER	MOTOR CURRENT AT 4KHZ CARRIER
M3464-L01-F7-L2	230 VAC	0.5 HP	1 A	0.75 A
M3464-L01-F7-L2-1P	230 VAC	0.5 HP	1 A	0.75 A
M3464-L04-F7-L2-LD	230 VAC	2.0 HP	4 A	3 A
M3464-L01-F7-M3	230 VAC	0.5 HP	1 A	0.75 A
M3464-L04-F7-M3-LD	230 VAC	2 HP	4 A	3 A
M3464-H08-F9-L3	460 VAC	5 HP	8 A	6 A
M3464-H08-F9-M3	460 VAC	5 HP	8 A	6 A
M3464-H16-2F9-M7	460 VAC	10 HP	16 A	12 A
M3464-H24-3F9-B7	460 VAC	20 HP	24 A	18 A
M3464-H32-FD-B7	460 VAC	25 HP	32 A	24 A
M3464-C24-FD-B7	575 VAC	25 HP	24 A	18 A
M3464-C32-FD-B7	575 VAC	30 HP	32 A	24 A

2.3. GENERAL PRECAUTIONS AND SAFETY WARNINGS

DANGER!

- **HIGH VOLTAGES MAY BE PRESENT!**
- **NEVER ATTEMPT TO OPERATE THIS PRODUCT WITH THE ENCLOSURE COVER REMOVED!**
- **NEVER ATTEMPT TO SERVICE THIS PRODUCT WITHOUT FIRST DISCONNECTING POWER TO AND FROM THE UNIT!**
- **ALWAYS ALLOW ADEQUATE TIME FOR RESIDUAL VOLTAGES TO DRAIN BEFORE REMOVING THE ENCLOSURE COVER.**
- **FAILURE TO HEED THESE WARNINGS MAY RESULT IN SERIOUS BODILY INJURY OR DEATH!**

CAUTION!

- **THIS PRODUCT WILL GENERATE HIGH AMBIENT TEMPERATURES DURING OPERATION.**
- **THIS PRODUCT SHOULD BE INSTALLED ACCORDINGLY ON NON-FLAMMABLE SURFACES WITH CLEARANCES OF AT LEAST TWO INCHES IN ALL DIRECTIONS.**
- **ALWAYS ALLOW AMPLE TIME FOR THE UNIT TO COOL BEFORE ATTEMPTING SERVICE ON THIS PRODUCT.**
- **BEFORE ATTEMPTING INSTALLATION OR REMOVAL OF THIS PRODUCT, BE SURE TO REVIEW ALL DRIVE AND/OR RESISTIVE LOAD DOCUMENTATION FOR PERTINENT SAFETY PRECAUTIONS.**
- **INSTALLATION AND/OR REMOVAL OF THIS PRODUCT SHOULD ONLY BE ACCOMPLISHED BY A QUALIFIED ELECTRICIAN IN ACCORDANCE WITH NATIONAL ELECTRICAL CODE OR EQUIVALENT REGULATIONS.**

ANY QUESTIONS AS TO APPLICATION, INSTALLATION, OR SERVICE SAFETY SHOULD BE DIRECTED TO THE EQUIPMENT SUPPLIER.

3. INSTALLATION INSTRUCTIONS

3.1. ENVIRONMENT

Units should be installed in area with 50ºC or lower ambient.

3.2. UNPACKING

Upon receipt of this product, please verify that the product received matches the product that was ordered and that there is no obvious physical damage to the unit. If the wrong product was received or the product is damaged in any way, please contact the supplier from which the product was purchased.

3.3. MOUNTING

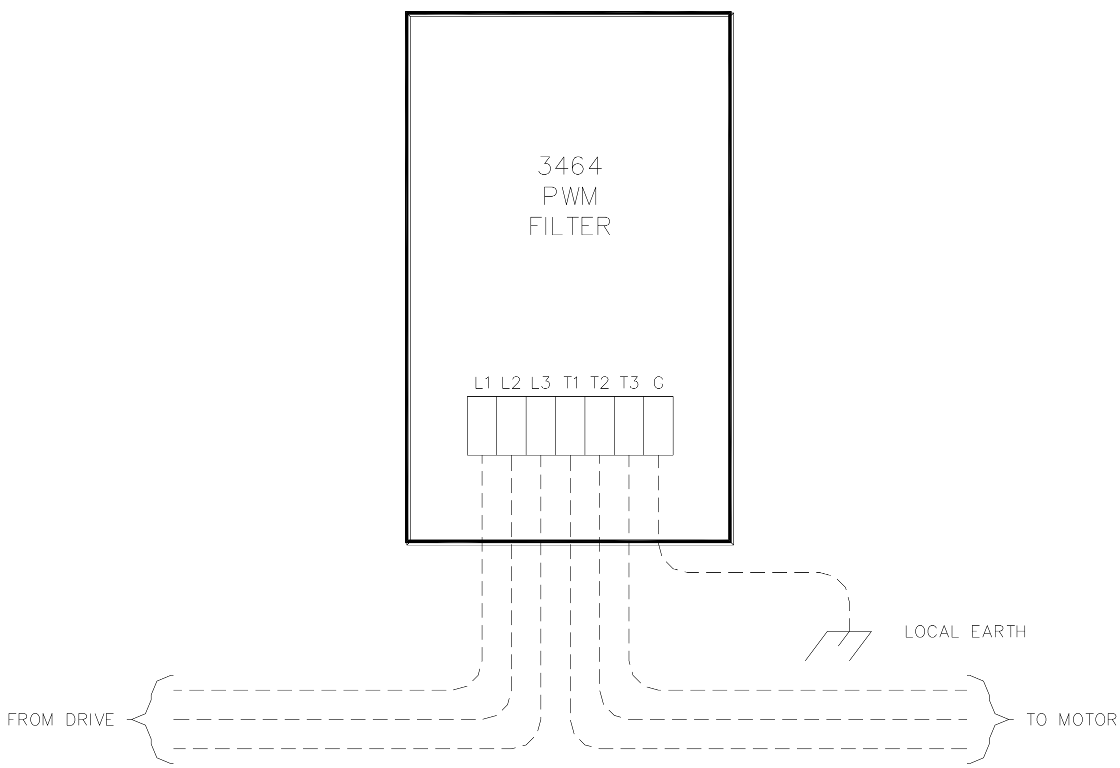
Units should be mounted with minimum of 2" clearance on sides and 4" clearance on top and bottom.

Refer to Section 6.3 for mounting dimensions.

3.4. Wiring and Customer Connections

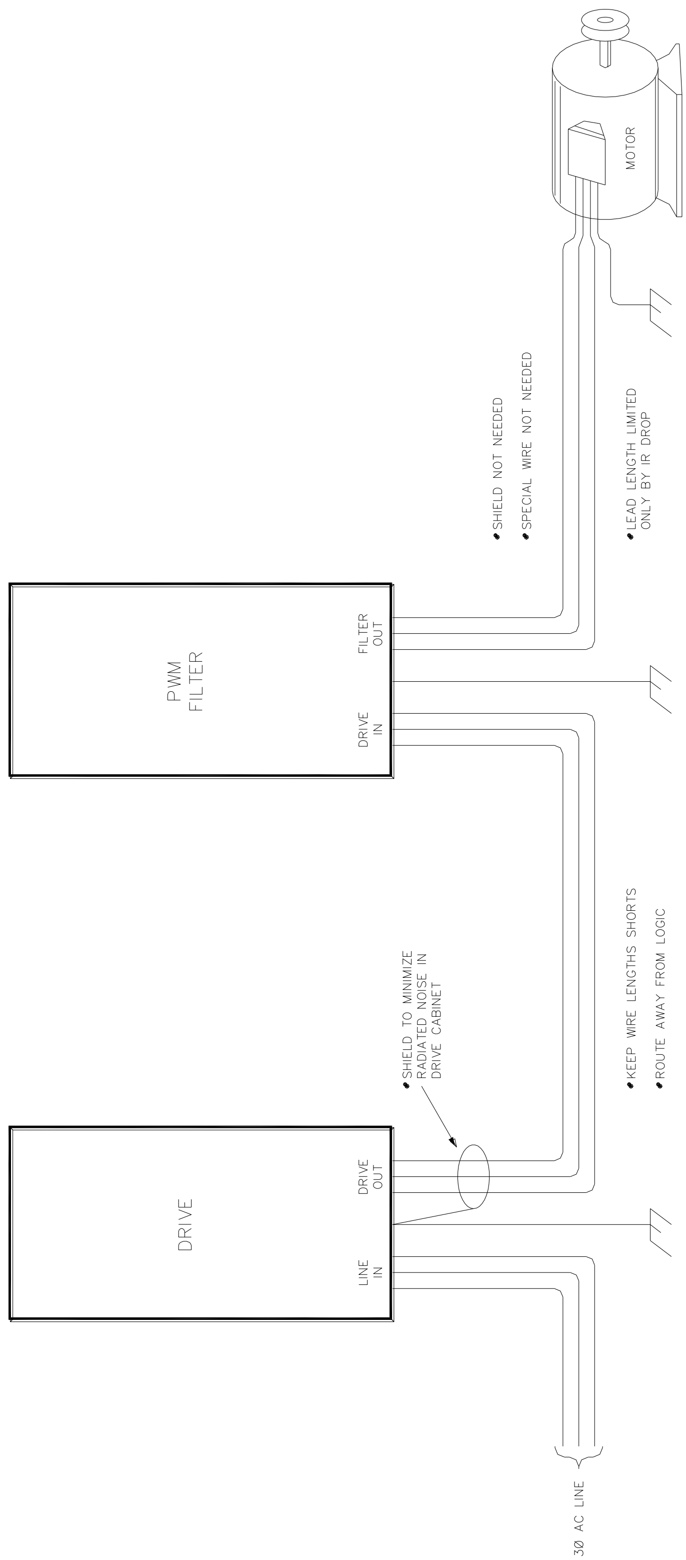
3.4.1. TERMINAL LAYOUT

Figure 3-1: Typical Field Connections



3.4.2. SYSTEM WIRING

Figure 3-2: Typical System Interconnections



3.4.2.1. GROUNDING REQUIREMENTS

Earth ground is provided and is absolutely needed for common mode filtering.

3.5. TYPICAL CONFIGURATIONS

3.5.1. FILTER BASICS

The **M3464** series of PWM sine wave filters provide filtering for either single-phase applications or three-phase applications with either delta or wye output configurations. The filters provide a low pass filter with a cut-off frequency of 120 Hz. These filters use low loss line reactors to minimize noise and losses. In addition to limiting the dV/dt rise times, the M3464 filter also filters out the carrier frequency.
Figure 3-3 shows both the PWM drive and M3464 filter output waveforms at 8kHz carrier frequency (60Hz fundamental).

Figure 3-3: Drive and Filter Output Signal Comparison

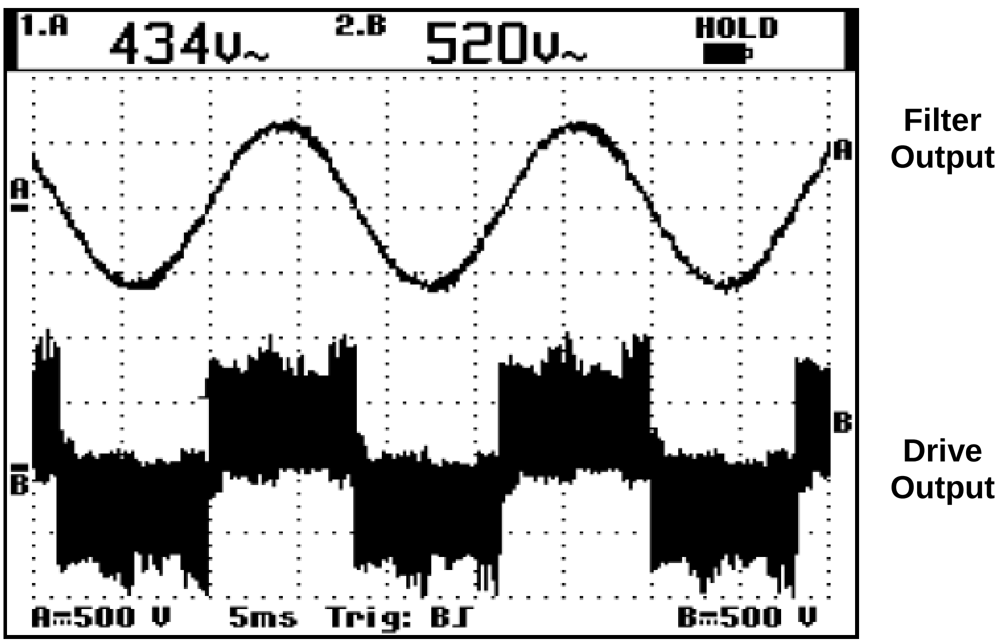


Figure 3-4: Motor Current and Voltage at 8kHz carrier frequency

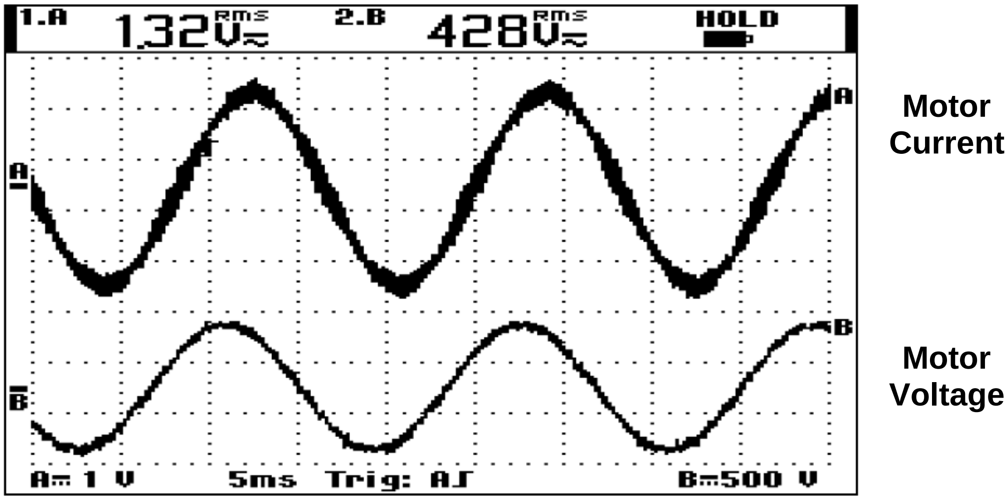


Figure 3-5: Motor Current and Voltage at 4kHz carrier frequency

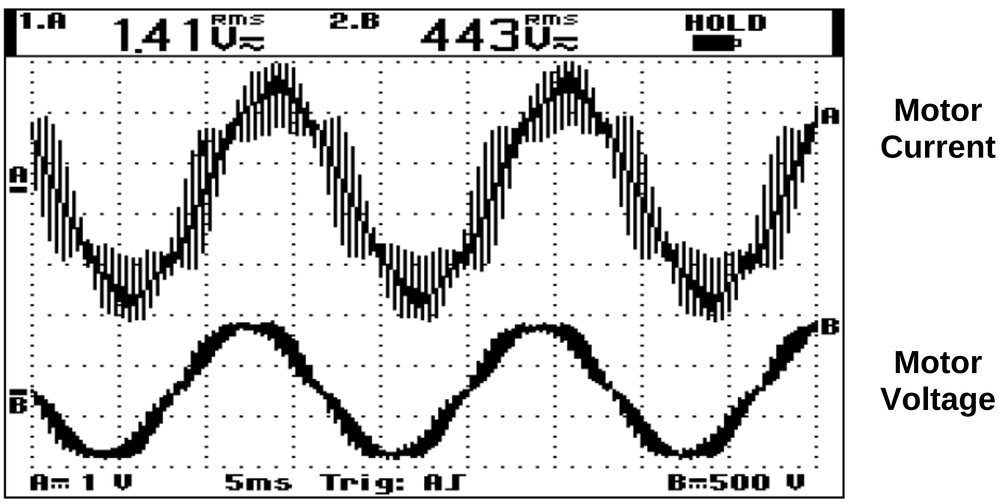
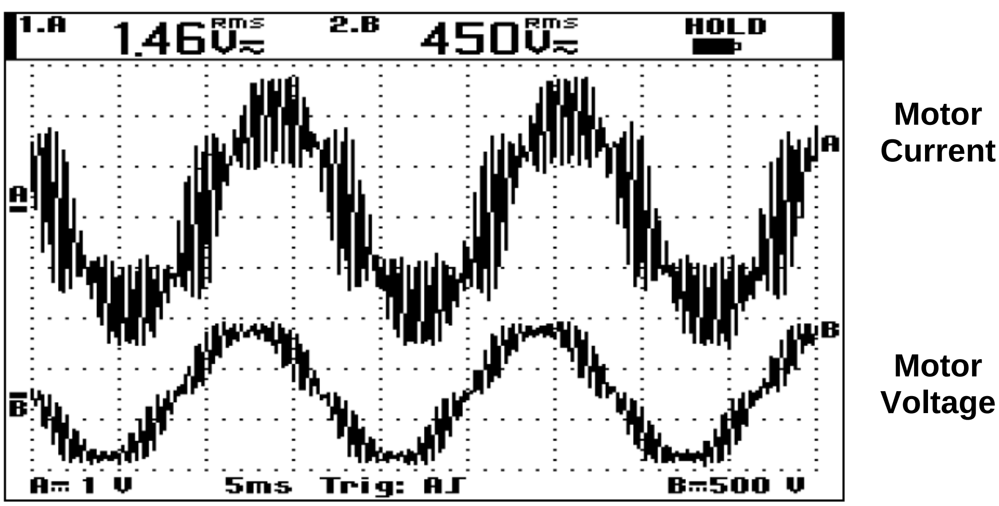


Figure 3-6: Motor Current and Voltage at 2kHz carrier frequency



3.5.2. FILTER CONFIGURATIONS

The model M3464 PWM filter module is designed around five basic L/C filter configuration types. These include a single-phase configuration with 2-wire output (type-1), a standard 3-phase configuration with delta output with GND (type-2), a high-impedance 3-phase configuration with delta output with GND (type-3), a 3-phase configuration with 4-wire wye output (type-4), and a 3-phase configuration with common mode noise filter and delta output with GND (type-5). These five basic configurations are shown on the following pages.

Note that on each of the delta configurations (type-2 & type-3) a secondary wye filter has been included on the output. By connecting the neutral (N) terminal of the secondary wye filter to the chassis ground (G) terminal, the filter can be used for limited common mode filtering. See Section 7.1.2 for more information on common mode filtering.

The type-5 delta configuration was designed specifically for use as a sine-wave filter with common mode noise filter to reduce common mode voltages induced in motor bearings. It is used to reduce electrostatic etching and fluting on bearings. The common mode filter may be connected to ground or the motor frame.

Figure 3-7: (Type-1) Single Phase 2-Wire Output

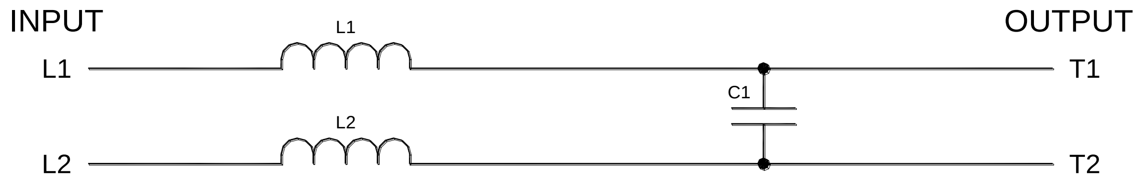


Figure 3-8: (Type-2) 3-Phase Delta Output

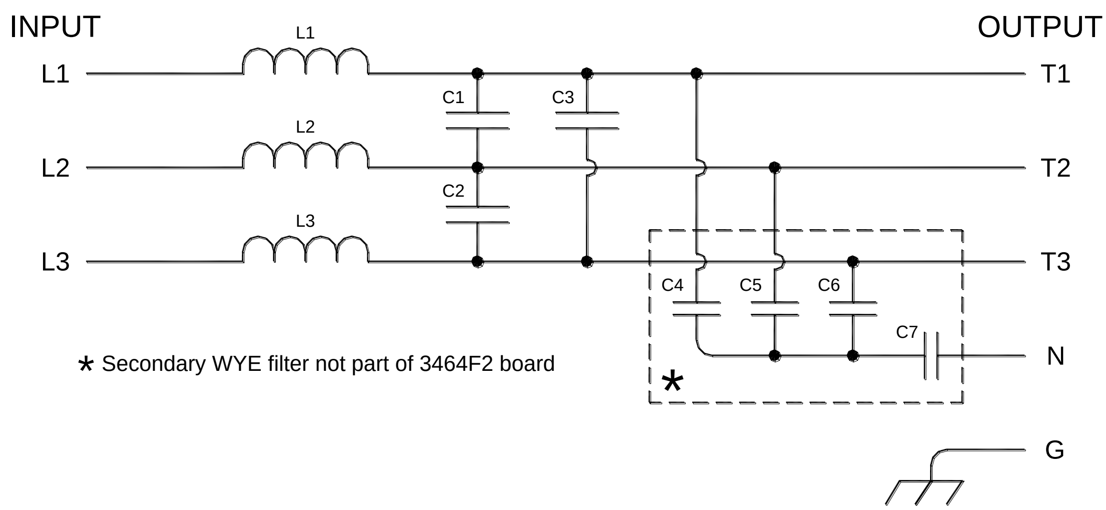


Figure 3-9: (Type-3) High Impedance, 3-Phase Delta Output

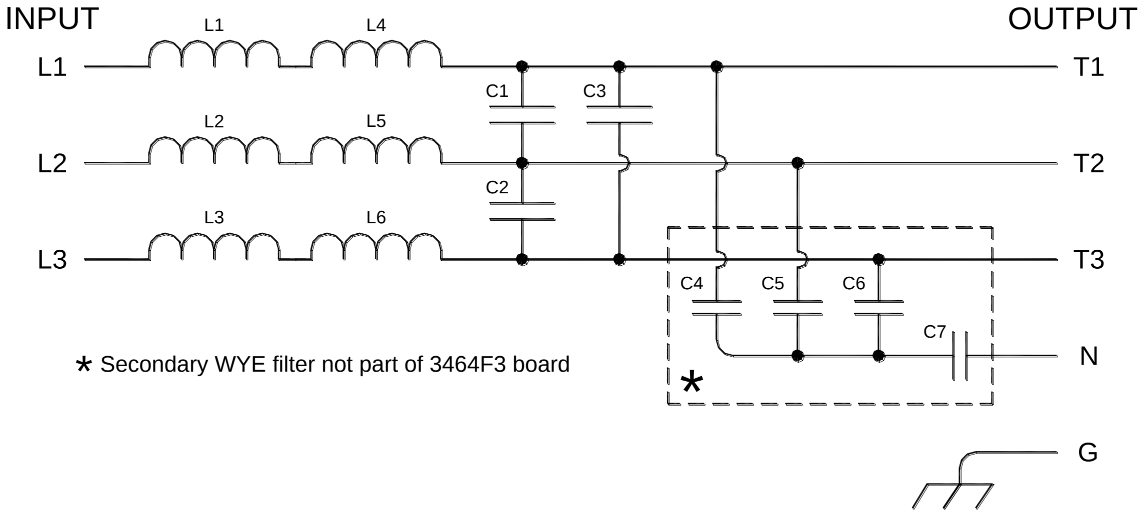


Figure 3-10: (Type-4) 3-Phase Wye Output

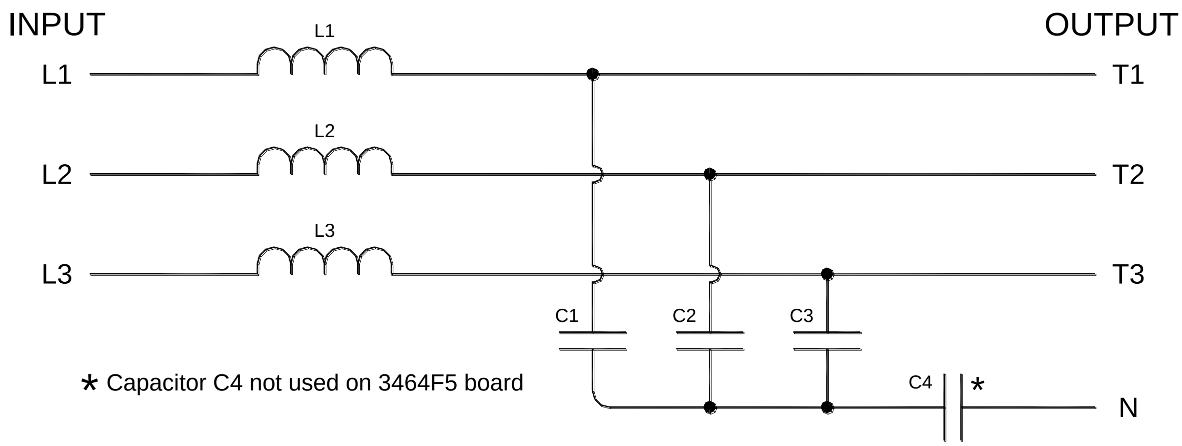
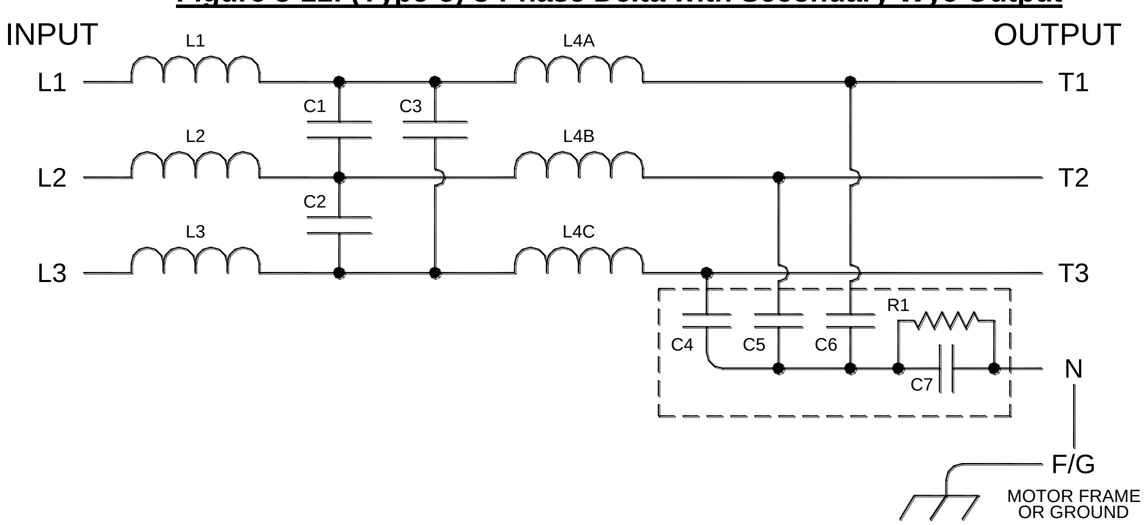


Figure 3-11: (Type-5) 3-Phase Delta with Secondary Wye Output



4. Operation

4.1. Functional Description

Bonitron's 3464 filter series is designed to smooth the voltage and current to the connected motor load of a variable frequency drive. Each time the drive inverter switches, the output voltage swings quickly to the DC positive and negative rails, creating a very fast changing square wave.

L/C PWM filters operate using inductance to slow the rate of current change, and capacitance to smooth out the voltage waveform. The fast switching, PWM square wave will be smoothed into a sinusoidal waveform suitable for the motor and connecting wires.

4.2. Features

All units use L/C type filtering.

Units are available for single phase and 3-phase delta or wye configurations.

Units are designed to handle fundamental frequencies up to 120 Hz. Modules designed for higher fundamental frequencies are possible.

Can be used at any V/Hz ratio.

Units are available for use with drives utilizing carrier frequencies as low as 2 kHz although 4 kHz or higher is preferred.

Individual units using circuit board construction are available at ratings of up to 8 A each at up to 460 VAC input. These units can be added together in parallel configurations to achieve higher current ratings as needed. Units using component-on-chassis construction are not limited to the 8 A individual unit rating. These units can be designed for specific applications and requirements as needed.

Available in open-chassis or NEMA-1 packages.

4.2.1. All M3464 PWM Sine Wave Filter Modules share the following characteristics:

- L/C type filtering.
- Designed to handle fundamental frequencies up to 120 Hz.
- Can be used at any V/Hz ratio.
- Units are available for use with drives utilizing carrier frequencies as low as 2 kHz.
- Units can be added in parallel configurations to achieve higher current ratings as needed.
- Filter modules are rated for continuous usage (100% duty at 8 kHz carrier frequency) unless otherwise specified.

4.3. Startup

1. Ensure phasing to motor is correct to prevent backwards operation.
2. Set drive carrier for 8 kHz.
3. Start drive.
4. With o-scope, monitor link between drive and filter for excessive currents.
5. With o-scope, monitor filter output voltage.
6. Check the noise problem that instigated the filter purchase.

4.4. OPERATIONAL ADJUSTMENTS

There are no adjustments or calibrations for this unit.

5. MAINTENANCE AND TROUBLESHOOTING

Repairs or modifications to this equipment are to be performed by Bonitron approved personnel only. Any repair or modification to this equipment by personnel not approved by Bonitron will void any warranty remaining on this unit.

5.1. MAINTENANCE ITEMS

There is no periodic maintenance to perform on standard filters.

Note: special filters may include a fan for cooling and unit should be cleaned as needed.

5.2. TROUBLESHOOTING

Table 5-1: Troubleshooting Guide

SYMPTOM	ACTION
Overheating	Raise carrier frequency Check motor current Check fan, if equipped
Excessive noise	Raise carrier frequency
Excessive drive currents	Raise carrier frequency
M3464 Filter does not solve noise problems	Common mode filtering may be required.

CAUTION!

REPAIRS OR MODIFICATIONS TO THIS EQUIPMENT ARE TO BE PERFORMED BY BONITRON APPROVED PERSONNEL ONLY. ANY REPAIR OR MODIFICATION TO THIS EQUIPMENT BY PERSONNEL NOT APPROVED BY BONITRON WILL VOID ANY WARRANTY REMAINING.

5.3. TECHNICAL HELP – BEFORE YOU CALL

If possible, please have the following information when calling for technical help:

- Exact model number of affected units
- Serial number of unit
- Name and model number of attached drives
- Name of original equipment supplier
- Brief description of the application
- The AC line to line voltage on all 3 phases
- The DC bus voltage
- KVA rating of power source
- Source configuration Wye/Delta and grounding

This information will help us support you much more quickly. Please contact us at (615) 244-2825 or through www.bonitron.com

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6. ENGINEERING DATA

6.1. WATT LOSS

Typically, 95% efficient at full load.

6.2. RATINGS CHARTS

Table 6-1: Ratings and Specifications

MODEL NUMBER	$V_{(MAX)}$	$I_{(CONT.)}$	HP	$I_{(SURGE)}$	MINIMUM CARRIER FREQ.*	RECOMMENDED CARRIER FREQ.	SPECIAL RATINGS
M3464-L01-F7-L2	230 VAC	1 A	0.5 HP	200%	4 kHz	8 kHz	Capable of 1A Continuous duty
M3464-L01-F7-L2-1P	230 VAC	1 A	0.5 HP	200%	4 kHz	8 kHz	Capable of 1A Continuous duty
M3464-L04-F7-L2-LD	230 VAC	4 A	2 HP	200%	4 kHz	8 kHz	10% Duty for 2 minutes ON
M3464-L01-F7-M3	230 VAC	1 A	0.5 HP	200%	4 kHz	8 kHz	Capable of 1A Continuous Duty
M3464-L04-F7-M3-LD	230 VAC	4 A	2 HP	200%	4 kHz	8 kHz	10% Duty for 2 minutes ON
M3464-L08-F9-L3	230 VAC	8 A	5 HP	200%	4 kHz	8 kHz	5 A at 4kHz
M3464-H08-F9-M3	460 VAC	8 A	5 HP	200%	4 kHz	8 kHz	5 A at 4kHz
M3464-H16-2F9-M7	460 VAC	16 A	10 HP	200%	4 kHz	8 kHz	10 A at 4kHz
M3464-H24-3F9-B7	460 VAC	24 A	20 HP	200%	4 kHz	8 kHz	18 A at 4kHz
M3464-H32-FD-B7	460 VAC	32 A	25 HP	200%	4 kHz	8 kHz	24 A at 4kHz
M3464-C24-FD-B7	575 VAC	24 A	25 HP	200%	4 kHz	8 kHz	18 A at 4kHz
M3464-C32-FD-B7	575 VAC	32 A	30 HP	150%	4 kHz	8 kHz	24 A at 4kHz

* For optimal performance use the highest available carrier frequency. Testing done at 60 Hz fundamental.

6.3. Dimensions and Mechanical Drawings

Figure 6-1: L2 Chassis Dimensional Outline

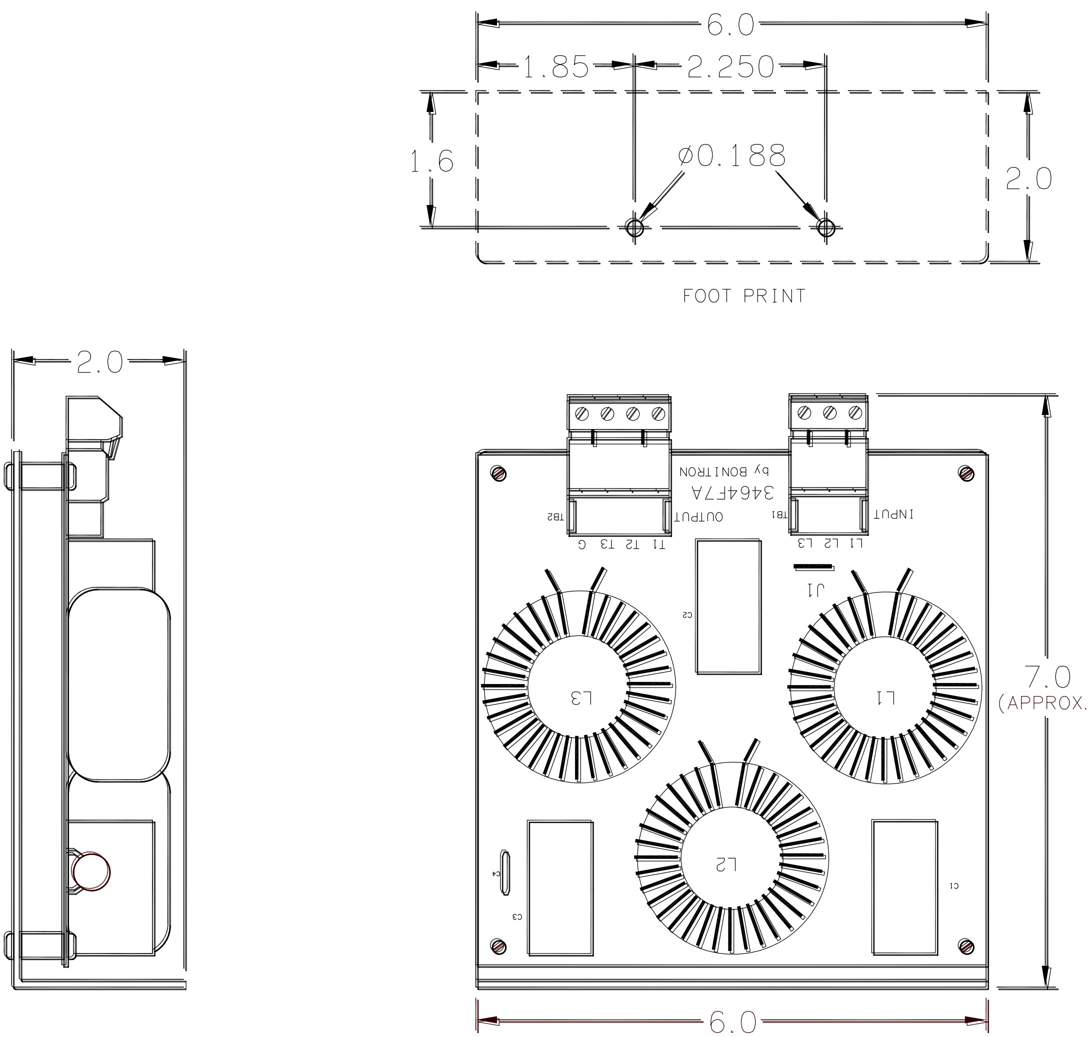

Figure 6-2: L3 Chassis Dimensional Outline

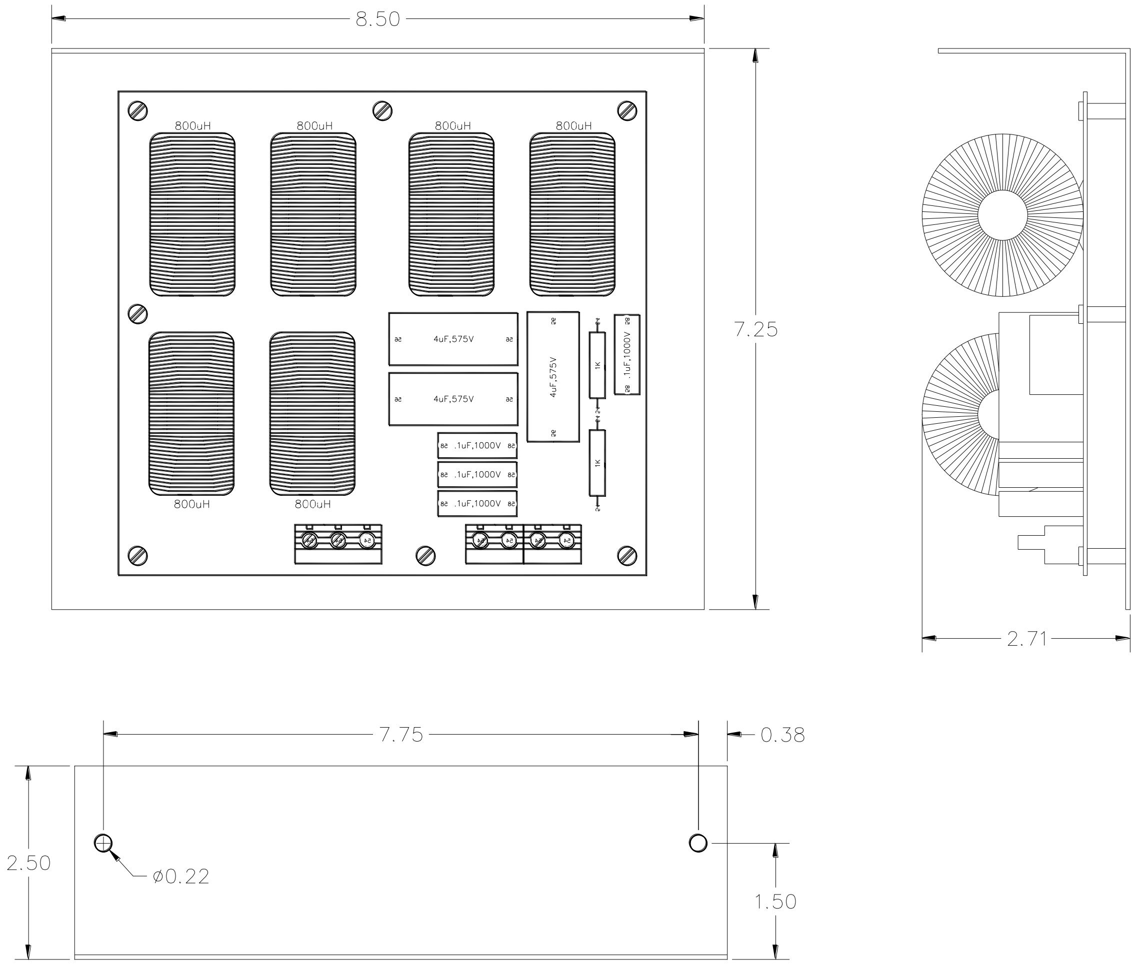

Figure 6-3: Enclosure Dimensional Outline

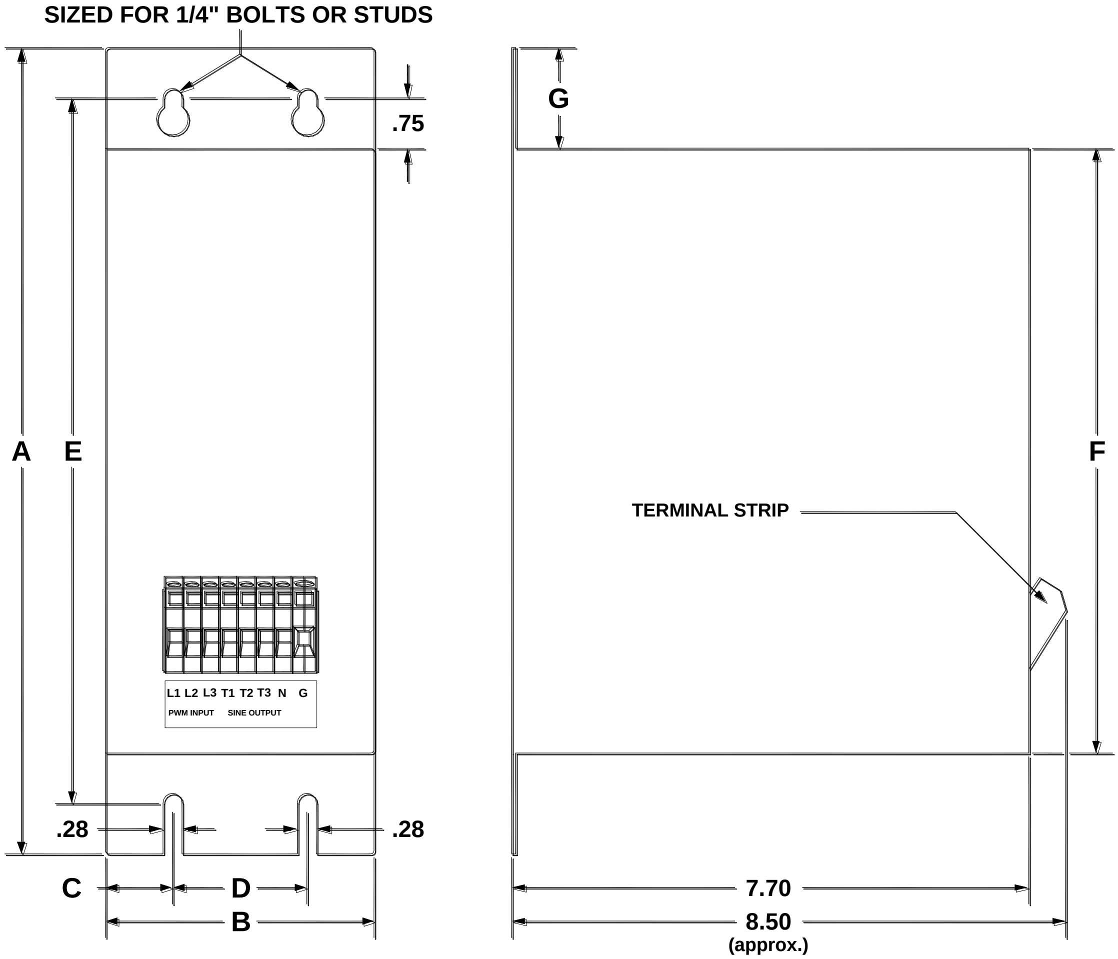

Table 6-2: Enclosure Dimensions

<table>
<tr><th>CHASSIS</th><th>DIM.A</th><th>DIM.B</th><th>DIM.C</th><th>DIM.D</th><th>DIM.E</th><th>DIM.F</th><th>DIM.G</th></tr>
<tr><td>M3</td><td rowspan="3">12.75”</td><td>3.00”</td><td>1.50”</td><td>N/A</td><td rowspan="3">12.00”</td><td rowspan="3">10.50”</td><td rowspan="3">1.13”</td></tr>
<tr><td>M4</td><td>4.00”</td><td>1.25”</td><td>1.75”</td></tr>
<tr><td>M7</td><td>7.00”</td><td>1.00”</td><td>5.00”</td></tr>
<tr><td>B7</td><td>17.75”</td><td>7.00”</td><td>1.00”</td><td>5.00”</td><td>16.75”</td><td>15.00”</td><td>1.38”</td></tr>
</table>

7. APPENDICES

7.1. APPLICATION NOTES

7.1.1. CARRIER FREQUENCY

One trick to good drive system performance is using the proper carrier switching frequency. Tradeoffs are made in power losses, voltage drops, audible noise, and heating. Knowing what these trade-offs are can help determine where to set the carrier frequency for your application.

THE DRIVE

Most of today's inverters have the ability to change the PWM switching frequency. This frequency can be set to maximize performance for any application. Typically drives are factory set for a low carrier of 4 kHz, and are HP rated at this carrier frequency. Increasing this frequency will de-rate the drive HP capability so it is typically not recommended by the drive manufacturer.

Basic rule: Lower carrier is better due to less heating in drive from switching losses. Increasing carrier frequency de-rates inverter. If using a PWM filter, lowering carrier too much will cause excessive drive currents and oscillations between filter and drive.

THE MOTOR

There are many different types of motors. Many new motors are "inverter duty" rated which means they have special insulation and bearings to allow long term use with fast switching PWM inverters. These motors should not need a filter to increase their life, but may still need a filter because noise can still be generated between the inverter and motor. This noise acts somewhat like an AM radio transmitter and can be seen by electronic equipment in the near vicinity, which causes all kinds of ghost problems.

Older motors are not rated for the high voltage spikes and they can burn up windings, or pit the bearings quickly. A PWM filter can be used to keep the motor from burning up prematurely as well as stopping radiated noise.

Basic rule: If motor is "inverter duty rated" a higher carrier is better due to less heating in motor and less audible noise. If not "inverter duty" rated, more switching can cause more voltage spikes and may actually decrease motor life.

THE FILTER

Bonitron designs and builds filters that strip most of the high frequency out of the motor leads, eliminating premature motor failures associated with using new PWM inverters on old motors, and non "inverter duty" rated motors.

The filter also slows down the rise time of the voltage changes from the PWM inverter, which in turn decreases the radiated or conducted noise through the motor cables.

Basic rule: higher carrier is better due to lower current ripple which reduces heating in filter, as well as provides a smoother waveform to the motor.

SUMMARY

Carrier frequency has a direct effect on heating of all three components. Compromise between drive, motor, and filter needs should ultimately determine carrier frequency.
NOTE: the output waveform does not have to be perfectly smooth to solve noise problems.

7.1.2. COMMON MODE FILTERING

COMMON MODE NOISE

New high efficiency drive systems exhibit fast rise times between earth ground and system potential. This "common mode noise" can be seen with an oscilloscope, and is seen by any connected equipment, sometimes having a negative effect. Anything connected will see this fast changing voltage, and the internal capacitance to earth may cause induced currents where they are not expected or wanted. Looking between earth and any motor phase will show this high fast switching voltage.

EFFECTS ON MOTOR

For motors these fast voltage rise times can cause capacitive coupling between the windings and the rotor. If the motor shaft is at a different potential, this built up voltage on the rotor will arc to ground through the metal bearings as they rotate and bounce. This arcing will cause pitting, which in turn increases the arcing, which in turn causes premature bearing failure. Testing shows that faster rise times and higher carrier frequencies tend to cause more build up and arcing. Testing also shows that typical 3- phase PWM filtering is not enough to stop this noise.

FILTERING

Typical PWM filtering will strip out the carrier frequency from the fundamental motor voltage to the windings, but they will not diminish common mode noise. If bearing pitting is occurring, then common mode filtering must be done. To remove 100% of this noise an isolation transformer must be used. However, by adding some capacitance between the PWM filters wye connection and earth, enough common mode filtering can be accomplished to increase motor life.

SIDE AFFECTS

Side effects of common mode filtering are increased inverter output currents, and decreased fundamental current rating of PWM filter. Capacitance and resistance can be used to tailor the amount of filtering, and is to be done at the field level.

FINE TUNING

Typical capacitance values are 0.01uF-0.1uF and resistor values from 100Ω-1kΩ. Capacitor value affects frequency response, and resistor value affects amount of filtering. The higher the cap value the more power will have to be burned off in the resistor. Using too low of resistor ohmic value can burn up the series capacitor due to excessive currents.

7.1.3. VARIOUS TYPES OF NOISE WITH PWM INVERTERS AND MOTORS

Today's PWM drives are very energy efficient, and the common topology has become fairly simple to produce low cost drives. Variable frequency drives are becoming economical for use with many types of systems. One of the negative issues associated with using PWM drives is the noise emitted from them. This noise comes in a few different ways:

1. Common mode noise
2. Conducted switching noise
3. Electromagnetic interference (EMI)
4. Audible noise

7.1.3.1. COMMON MODE NOISE

Common mode noise from PWM drives is typically out of the audible range, and affects connected equipment in various ways, including causing erroneous signals which can cause false trips, lock ups, or incorrect information in digital systems. Common mode noise is essentially the result of ultra-fast rise times from fast voltage changes, which are capacitively coupled to earth ground through paths of unknown stray capacitance. This can be seen looking between earth ground and any point connected to the drive, including non-isolated peripheral equipment. Common mode noise is usually not associated with the carrier fundamental switching frequency, but rather the dV/dt of the rise and fall times of the switching frequency.

7.1.3.2. CONDUCTED NOISE

Conducted switching noise is caused by fast current changes, and is usually seen at the carrier frequency. Voltage drops can be caused by the inductive effect from these fast changing currents. With a rise time of 8 ms (as seen in 60 Hz power systems), a small inductance of a wire or circuit lane does not matter much, but with a rise time of 1us, (as seen in 8 kHz carrier frequencies) the small inductor now shows an appreciable voltage drop. This voltage drop at the fast rise time can cause trouble if it is not known or compensated for. Special considerations must be given to grounding paths and special types of low inductance power connections. Long wire runs to the motor can cause larger drops and standing waves resulting in high peak voltages at the motor, which in turn causes insulation breakdown.

7.1.3.3. EMI NOISE

These fast changes in current also cause magnetic fields to occur, which causes EMI. Long wire runs act as antennas emitting signals in a range based on the rise times of the current. These emissions can be picked up by a common AM radio, or worse, a common circuit. The closer in proximity to this emission, the worse the effect. Replacing an old drive with a new drive can cause trouble where it never was seen before due to a different rise time in this current. A new switching component (IGBT) can have a faster turn on rate and change the Special shielded wire must be to decrease this effect on other equipment.

7.1.3.4. AUDIBLE NOISE

The magnetic field caused by the changing current can also cause physical movement when in close proximity to magnetic metals. This movement can often be heard, and is usually the carrier switching frequency of the drive.

In a typical PWM drive system the motor windings are used as the PWM filter. The inductance of the motor windings slows down the rate of current change, but the electromagnetic field that results not only moves the motor rotor, it also moves the windings and laminations. This movement causes audible noise.

This is somewhat backwards of a speaker in an audio system, where the windings are kept stationary and the diaphragm is free to move with changes in the magnetic field. The diaphragm is connected to a cone that moves air. The windings may physically move some, but it is negligible compared to the effects of cone movement so we do not think about it.

In a motor, the winding load is the rotor. The rotor moves in rotation with the rotating magnetic field at the fundamental frequency, but rotor laminations and motor windings also move due to the magnetic field created by current changes at the switching frequency. If you were to remove the speaker cone, and dump 5 HP (3750 W) into the speaker coil, you would hear the coil move!

Older motors were wire wound and bundled together, which allows much movement when hit with fast current changes. Today's PWM duty motors have heavier insulation ratings and are vacuum impregnated to decrease the amount of winding movement.

The audible sound can be heard in the drives capacitors or inductors, it can be heard in the wiring between the drive and the motor, but can usually best be heard in the motor windings. Since the most sensitive hearing range for most people is in the 1 kHz-4 kHz range, typically the lower the carrier frequency, the louder the noise. For a fixed voltage and inductance, the lower carrier frequencies allow greater ripple currents, create greater magnetic changes, have greater physical effect on components, which causes more audible noise. As carrier frequencies increase, there is a drop off in peak current changes, and audible noise. As carrier frequencies approach 16 kHz, the noise is greatly reduced due to small changes in current, decreased ability of components to physically respond to current change, and the frequency is getting out of human hearing range. The amount of noise heard is proportional to the frequency, the amount of current, the rate of current change, and the construction of the filter device (physical rigidity of windings).

When the drive DC bus drops, it begins to compensate by increasing the pulse width of the carrier. This increase in pulse width allows more current to build up in the motor windings, which causes more audible noise. When a drive changes torque, the audible sound changes as a result of the current intensity. More current causes more magnetism, which in turn causes more audible noise. If the drive DC bus drops due to a sag in line voltage, there is also an audible effect on the incoming feed magnetics, in that the current changes shape and increases to maintain the same power output. The hum heard at the 50 or 60 cycle rate will increase.

When ramping up a motor with a fixed carrier PWM drive, the audible frequency does not change, but the intensity and tone does. The sound heard is mostly the windings at the switching frequency, not the motor running at the fundamental frequency.

Some drives do change their carrier frequencies based on motor speed. These changes can be heard. Changes in load or changes in drive bus voltage will cause a change in intensity or tone, or even frequency. While the sound may make it seem like the motor changes speed, the sound is actually the drive trying to keep the motor speed constant. When a change in parameters occurs and a change in audible noise does not, one could assume the drive is not compensating.

In all these cases, a PWM filter can be used to "trap" these switching currents, or hold down the voltage changes, producing a smooth waveform to the motor to decrease or even eliminate the noise problems, but the noise will now be seen in the filter.

For complete common mode noise reduction, it is necessary to use an isolation transformer with an output wye configuration and electrostatic shielding. For all other types of noise, an LC filter can be used. It should be designed to handle the fast rise times from the VFD outputs. One problem remains. Now the audible noise will be heard in the filter.

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