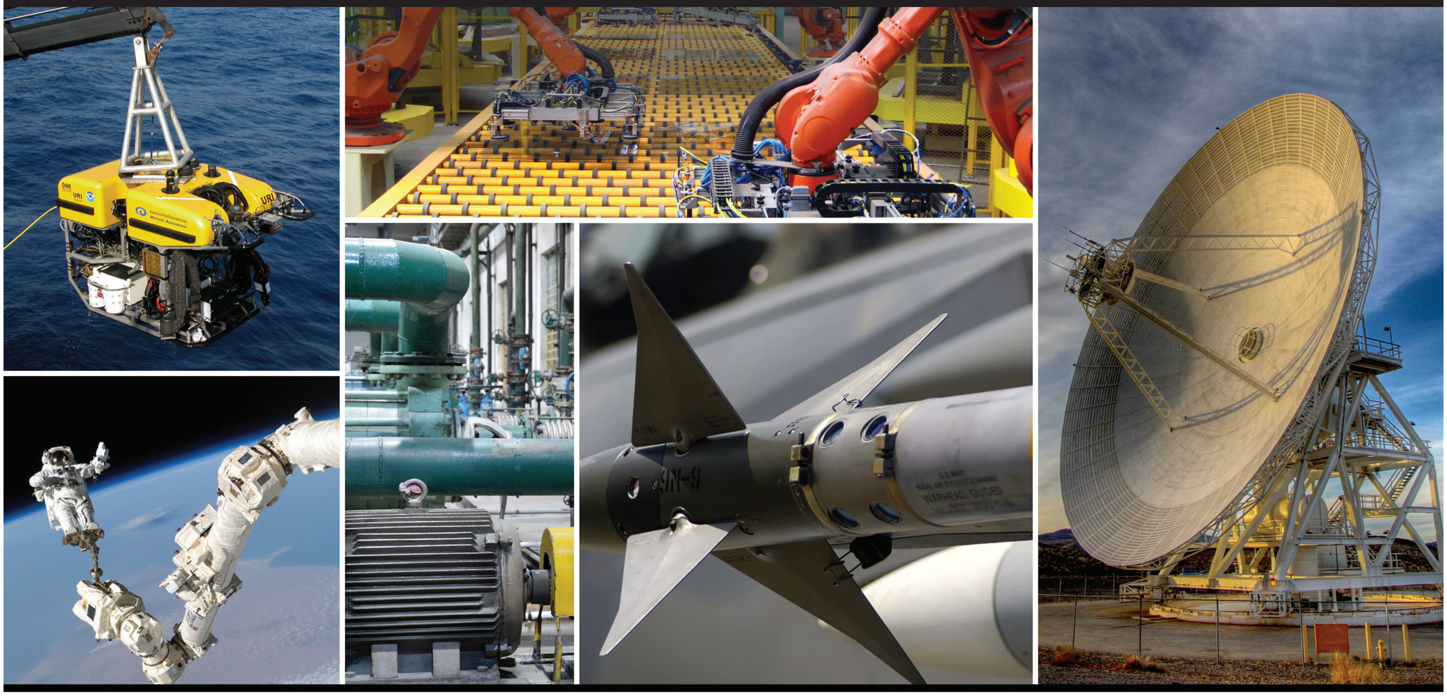
White Paper

MOTION CONTROL



BLDC Motor Controllers...
for Maximum Performance & Efficiency

October 2015

By Don Laskay
Sr. Applications Engineer, Motor Controllers & Drives
Data Device Corporation

© 2015 Data Device Corporation. All trademarks are the property of their respective owners.

BLDC Motor Controllers... for Maximum Performance & Efficiency

Introduction

Modern Brushless DC (BLDC) motor controllers that are housed in compact assemblies are ideal for integration into systems that require precision control and efficiency. This enabling technology fulfills the requirements of both simple and complex motor systems, while offering significant advantages and improving time to market.

The demand for electric motors is increasing at a rate of 5-6 percent annually, and is projected to rise through 2017 to a TAM (Total Available Market) of $14.4 billion in the US alone. The growth rate is even higher in China and Asia, as these countries modernize and improve infrastructure. Within these markets, the expansion of mid-range horsepower motors outpaces that of smaller fractional horsepower types. Driving this demand are heating and cooling equipment markets, along with electric vehicles, which will provide the best growth opportunities. All systems, from industrial, avionic, military and space are seeing demand to improve efficiency and reduce weight. Along these lines, European markets have issued a directive to improve motor efficiency. Reductions in size and improvements in operating and ownership cost are also being driven in military and avionic markets worldwide. To achieve these goals, more reliable and efficient motors and control techniques must be considered. As this market continues to grow, the brushless DC motor is the most sensible choice based upon its reliability, efficiency and size.

The BLDC motor provides clear advantages over other motor types in terms of optimizing efficiency and size in demanding motor applications. BLDC motors do not have brushes and require less maintenance and system down time. Yet these motors require electronic controllers that range from simple to complex. The motors typically have efficiency of over 80%, and the controllers in the 95% range. Thus the enabling technology is the ever improving evolution of the BLDC motor controller. The most efficient controllers use Pulse Width Modulation (PWM) sampling to drive a motor from DC power. There are also other power conditioning requirements that range from rectification of an AC signal, to Electromagnetic Interference (EMI) filtering that is required in most applications.

Motor Applications

Defining and understanding the motor application is essential to selecting the optimum controller choice. The most common motor control techniques and applications can be broken down as shown in Table 1.

Table 1. Motor Control Techniques and Applications		
Control	**Technique**	**Applications**
Speed	Rotate at constant or multiple RPMs	Pumps, Fans and Compressors
Torque	Maintain force while changing direction	Doors, Wing Slats/Flaps, Fins
Position	Move to precise location	Robotics, Radar, Satellite Communications, Turrets

Each of these systems utilizes specific motor control techniques that require tuning of one or more control loops – torque, speed and/or position. Precision and efficiency is determined by the method which is used in controlling voltage, which sets the speed, and current, that controls the torque. A designer must consider the approaches of analog and digital motor control solutions.

Analog Motor Controllers

Analog motor controllers utilize resistors and capacitors for loop tuning. This typically requires knowledge of control loops and can be supported by data sheets, technical staff and formulas that aid in optimum component selection. Each loop's design characteristics must be chosen carefully.

In the case of a speed and torque controller, the loops must be tuned correctly. These designs are application-specific and can require additional optimization as the system is tested to the full range of performance. Changes are often required as motors and loads are changed or added. The upside to the analog approach is that these motor controllers come in a compact form. The tuning is accomplished by changing resistors and capacitors to set the Proportional and Integral loop gains of each loop.

Avionic Applications

The compact size of analog controllers is ideal for use in avionic applications due to the size and the cost of certifying programmable devices. Avionic specifications implemented by the Federal Aviation Administration (FAA) in 2005, to ensure the safety of civilian aircraft electronic systems, require rigorous design approach and certification.

Avionic Specifications

The specifications that are used for design control are as follows:

- **DO254** sets development and compliance standards for complex electronic hardware such as Processors, Field Programmable Gate Arrays (FPGAs), Digital Signal Processors (DSP), Programmable Logic Devices (PLD), and Application Specific Integrated Circuits (ASICs). The levels for this certification range from (A) Flight critical, to (E) Non Flight critical.

- **DO178B** sets development and compliance standards for software used in avionic applications.

Space Applications

Analog controllers are also commonly used in space applications to minimize the cost of utilizing radiation proof components such as processors, ASICs or FPGAs. Yet radiation test and characterization is still required. Total Dose Testing predicts the life of the electronics and Single Event Testing predicts reaction to events such as solar flares. Manufacturers of these devices, such as Data Device Corporation (DDC), design hybrid microcircuits to meet common radiation requirements and perform testing to verify radiation tolerance performance. Additionally, hybrid microcircuits save space and weight.

Digital Motor Controllers

Advantages: Performance & Efficiency

Digital motor controllers offer several performance and efficiency advantages that make them the controller selection of choice for many applications. Additionally, the versatility of digital controllers has advanced as the evolution of DSP (Digital Signal Processing) and ASIC (Application-Specific Integrated Circuit) based processors now enable designers to create flexible products and improve time-to-market.

Digital Signal Processing (DSP)

The most versatile of these digital motor controller designs are based on DSP architectures, which allow integration into a wide range of systems, from simpler sensorless systems to complex multi-axis position control systems. The processing power of the DSP, along with associated Graphical User Interfaces (GUIs), takes the complicated math out of the user's designs, requiring only basic knowledge and support to meet the expected motor system performance goals. The torque, speed and position loops are often calculated for the designer based upon motor and system parameter entry via the GUI. Furthermore, many controllers offer multiple control options.

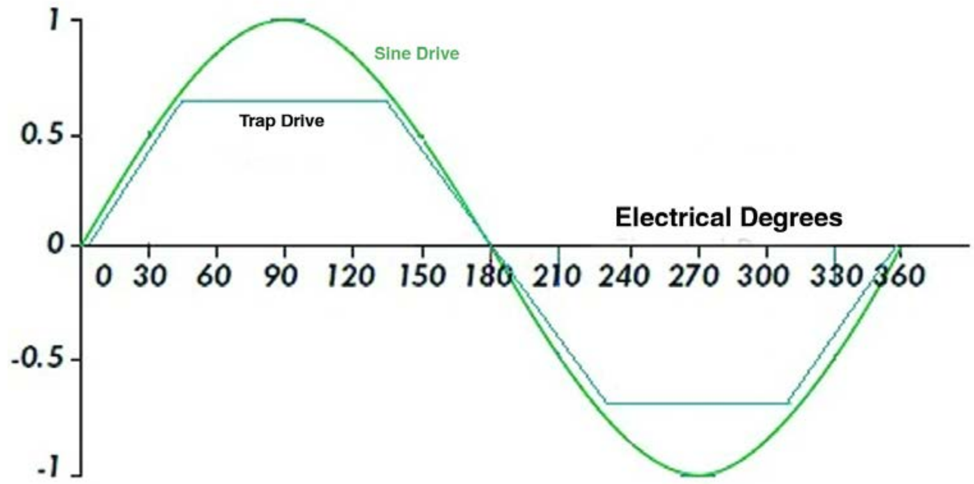


Figure 1. Commutation Signals

The embedded control and control logic in the DSP can contain complex mathematical calculations and algorithms that are required to gain the efficiencies of the field oriented (FOC) sinusoidal motor commutation technique. This technique delivers power to the motor by means of a sinusoidal (sine) waveform (see Figure 1). The sinusoidal signal provides maximum voltage/speed in relation to the DC bus voltage and reduces noise by over 30% relative to a trapezoidal (trap) drive. The trap drive commutates the motor with a trapezoidal AC signal. The system losses in a sine drive are in the motor, while the trapezoidal drive's losses are in the controller. Additionally, a sine wound motor will improve motor efficiencies as well. The torque ripple on a sinusoidal motor can be as low as 1%, while the ripple for a trapezoidal motor is over 13-14%. The sinusoidal system also reduces noise, which is essential to meeting EMI requirements. The trap drive system EMI signature and current ripple are higher due to the sharp edges and flatness of a trapezoidal signal. These signals are modulated by the PWM frequency in the motor controller.

The processing power of DSPs also enables flexible motor control that can be utilized in a wide range of applications, from a sensorless motor system, such as a fan or pump, to a complex multi-axis design, such as those that are used in turrets and robotics.

Speed Controllers

The speed controller uses internal sensing and algorithms that are required for speed regulation, and sets the control loop parameters for torque. Torque is proportional to current, and speed is proportional to voltage. The bandwidth for the current/torque loop is greater than that of the speed loop.

Torque Controllers

Torque controllers are used in applications that require holding torque and changes in direction, since these controllers maintain smooth transitions in torque through zero speed. This is known as a four quadrant controller. Controlling current/torque to the motor will allow for precision speed control. Torque controllers utilize a position sensor on the motor to determine the position of the shaft, in order to energize the appropriate winding for precision control. This is most commonly a Hall Effect Device, but can alternatively be resolvers, encoders etc.

Position Controllers

A position controller utilizes an interface with position sensors on the motor and at the load. The position loop is the outer control loop in this system. The speed and torque loops must be tuned as well. All three control loops must be tuned based on the motor and system parameters. Many applications will utilize a torque or speed controller with customer based algorithms that can close the position loop. These torque and speed controllers can be found on the DDC website, and are the heart of any motor control system.

Programmable Motor Control Devices

Graphical User Interface (GUI)

Figure 2. Graphical User Interface (GUI)

Programmable motor control devices include a GUI that will aid, and perform these calculations, based upon the motor used and system requirements. As a system is implemented in the lab or in the field, system parameters often change and may require retuning to attain the desired performance. The GUI is the perfect tool to minimize the time impact of additional tuning. Another benefit of tunable controllers is that a motor can be swapped out and its replacement made operational in a short time, with the simple change of parameters. Also, multiple motors can be used with the same controller. This will reduce the cost of ownership, which is a key consideration for motor control systems.

Interfacing

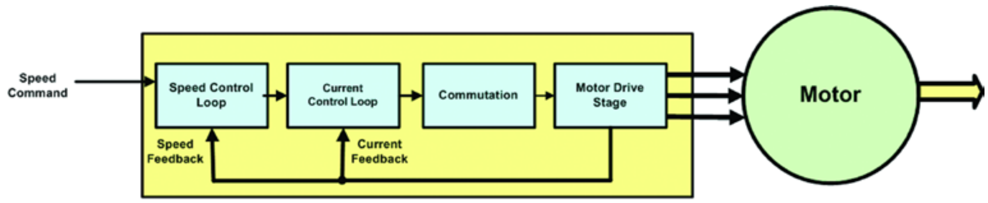


Figure 3. Sensorless Motor Control System

DSP-based solutions also allow for interfacing with host processor controlled systems that communicate on serial networks such as CAN, RS-485, RS-422, etc. Alternatively, speed and/or torque can be set by means of an analog voltage input, when advanced features are not required. Also, on-board or system processors can coordinate 2 axis movement as required in satellite base stations, radars, turrets or robotic systems. Motor control suppliers, such as Data Device Corporation, offer products that incorporate all control algorithms and sensor interfaces, as well as provide advanced protection, such as over temperature, over current, etc. This is true for both analog/trapezoidal drives and digital/sine drives. These devices have protection built in the hardware. The DSP based solution also can have soft limits set that interface with the motor control system, with parameters set by the GUI. The control and power stages for these motor controllers are available in compact form, such as a hybrid or module, which can be integrated into larger systems. DDC provides a “systematic re-use” topology that allows portions of any control system to be adapted to meet custom motor requirements.

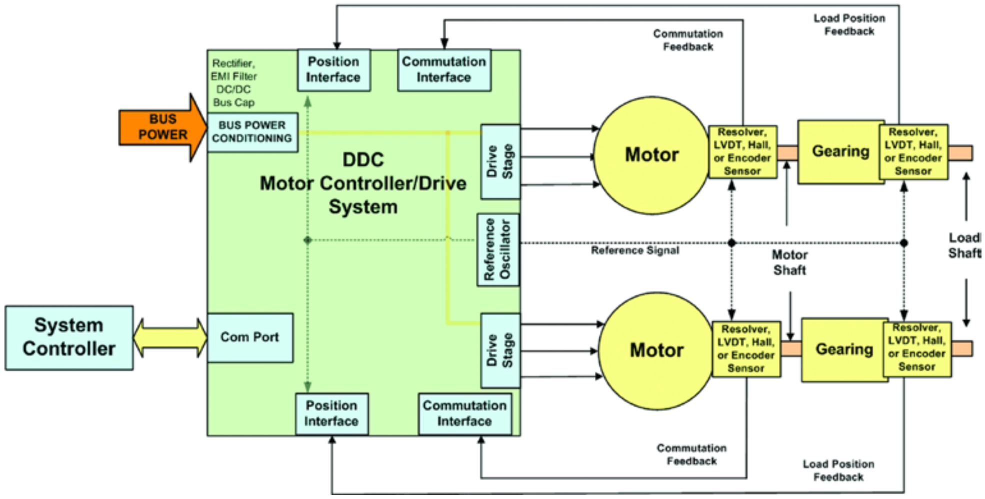


Figure 4. Dual Axis Motor Control

The controllers and supporting electronics typically are mounted on or near the motor. The motor system will also include a DC bus capacitor to reduce ripple, and possibly EMI filters to reduce noise on the system bus. Consideration must also be given to dissipate motor energy Back Electro Motive Force (BEMF) that is generated when the motor shuts down. A large amount of mechanical energy is converted back into electrical energy, and this must be considered in the overall system design, with implementation of a braking resistor or other method to store or dissipate this energy, such as capacitor networks or batteries. For higher voltage systems, the bus capacitor should be of good quality and low equivalent series resistance (ESR) to reduce bus ripple. This capacitor should be located close to the controller to reduce resistance.

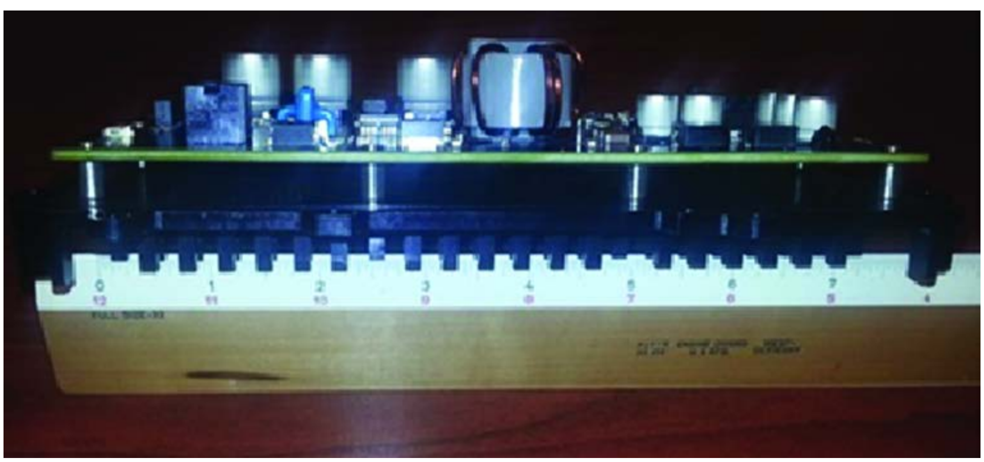


Figure 5. Compact Avionic Grade Design Utilizing Existing Design Blocks

Electro Magnetic Interference (EMI)

Most electronic systems must meet Electro Magnetic Interference (EMI) standards for system compatibility. This ensures that the electronics will not interfere with, or be interfered by, other devices. Standards govern the device's radiated radio frequency (RF) emissions as well as susceptibility. There are commercial and military standards such as MIL-STD-461 that is typically used for US military and avionic systems, and less rigorous FCC standards in the US. Europe issued an EMC Directive (89/336/EC) in the 1980s and other countries have similar standards. A quality motor and controller system must be designed to these standards, and have an EMI filter integrated into the system. This filter can be found either at the motor, or located in a box level motor control solution, at or near the motor. In a larger system, an overall solution is used. The object is to reduce the cost of qualifying the system as well as meeting control system size and weight constraints. To achieve these goals, several applications utilize the systematic re-use of DDC's PW-82560 design for control functionality, along with an integrated customer interface, and EMI filter.

Optimized Performance

The DSP-based devices feature Graphical User Interfaces (GUIs) that can operate the motor, and be used to optimize performance. Complex calculations are carried out for the control loops. The processor memory also enables users to save motor data, such as voltage and current. Users can analyze start up issues by reviewing motor current and voltage, as well as optimize the bandwidth to reduce torque ripple, for further motor performance optimization. These types of tools have become the industry standard, and are included with the purchase of the motor controller.

(a) **(b)** **(c)**

Figure 6. Hybrid, Board & System Level Motor Controller Solutions: (a) Hybrid Motor Controller; (b) DSP Based Motor Controller and (c) Complete Enclosed Solution

Growing Demand

Modern motor control products will continue to meet the growing demand for automation and motor control, as complex systems can now be supported with compact solutions. DDC provides base level motor controller functions, along with essential building blocks to meet system needs, while our system and box level designs provide all the processing power required for precise and efficient motor control.

Don Laskay
Sr. Applications Engineer
Data Device Corporation

For more information, contact Don Laskay at 631-567-5600 ext.7797 or laskay@ddc-web.com. Visit DDC on the web: www.ddc-web.com.

Data Device Corporation (DDC) is a world leader in the design and manufacture of high-reliability Connectivity, Power and Control solutions (Data Networking; Power Distribution, Control and Conversion; Motor Control and Motion Feedback) for aerospace, defense, and industrial applications. With awards for quality, delivery, and support, DDC has served industry as a trusted resource for more than 50 years… providing proven solutions that are optimized for efficiency, reliability and performance. Data Device Corporation brands include DDC, Beta Transformer Technology Corporation, National Hybrid Inc., Pascall Electronics Ltd., and XCEL Power Systems Ltd. DDC is headquartered in Bohemia, NY and has manufacturing operations in New York, Mexico, and the United Kingdom. For more information, visit: www.ddc-web.com .

Connectivity Power Control

Data Device Corporation

Leadership Built on Over 50 Years of Innovation

Military | Commercial Aerospace | Space | Industrial

Data Device Corporation (DDC) is the world leader in the design and manufacture of high-reliability data bus products, motion control, and solid-state power controllers for aerospace, defense, and industrial automation applications. For more than 50 years, DDC has continuously advanced the state of high-reliability data communications and control technology for MIL-STD-1553, ARINC 429, Synchro/Resolver interface, and Solid-State Power Controllers with innovations that have minimized component size and weight while increasing performance. DDC offers a broad product line consisting of advanced data bus technology for Fibre Channel networks; MIL-STD-1553 and ARINC 429 Data Networking cards, components, and software; Synchro/Resolver interface components; and Solid-State Power Controllers and Motor Drives.

Product Families

Data Bus | Synchro/Resolver | Power Controllers | Motor Drives

DDC is a leader in the development, design, and manufacture of highly reliable and innovative military data bus solutions. DDC's Data Networking Solutions include MIL-STD-1553, ARINC 429, and Fibre Channel. Each Interface is supported by a complete line of quality MIL-STD-1553 and ARINC 429 commercial, military, and COTS grade cards and components, as well as software that maintain compatibility between product generations. The Data Bus product line has been field proven for the military, commercial and aerospace markets.

DDC is also a global leader in Synchro/Resolver Solutions. We offer a broad line of Synchro/Resolver instrument-grade cards, including angle position indicators and simulators. Our Synchro/Resolver-to-Digital and Digital-to-Synchro/Resolver microelectronic components are the smallest, most accurate converters, and also serve as the building block for our card-level products. All of our Synchro/Resolver line is supported by software, designed to meet today's COTS/MOTS needs. The Synchro/Resolver line has been field proven for military and industrial applications, including radar, IR, and navigation systems, fire control, flight instrumentation/simulators, motor/motion feedback controls and drivers, and robotic systems.

As the world's largest supplier of Solid-State Power Controllers (SSPCs) and Remote Power Controllers (RPCs), DDC was the first to offer commercial and fully-qualified MIL-PRF-38534 and Class K Space-level screening for these products. DDC's complete line of SSPC and RPC boards and components support real-time digital status reporting and computer control, and are equipped with instant trip, and true I^2T wire protection. The SSPC and RPC product line has been field proven for military markets, and are used in the Bradley fighting vehicles and M1A2 tank.

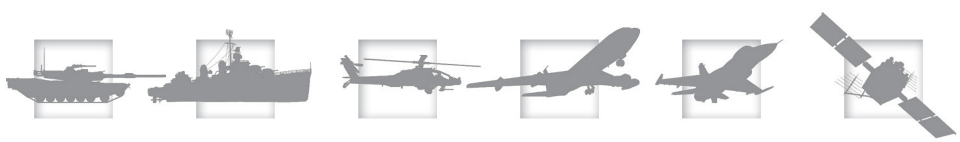
DDC is the premier manufacturer of hybrid motor drives and controllers for brush, 3-phase brushless, and induction motors operating from 28 Vdc to 270 Vdc requiring up to 18 kilowatts of power. Applications range from aircraft actuators for primary and secondary flight controls, jet or rocket engine thrust vector control, missile flight controls, to pumps, fans, solar arrays and momentum wheel control for space and satellite systems.

Certifications

Data Device Corporation is ISO 9001: 2008 and AS 9100, Rev. C certified.

DDC has also been granted certification by the Defense Supply Center Columbus (DSCC) for manufacturing Class D, G, H, and K hybrid products in accordance with MIL-PRF-38534, as well as ESA and NASA approved.

Industry documents used to support DDC's certifications and Quality system are: AS9001 OEM Certification, MIL-STD-883, ANSI/NCSL Z540-1, IPC-A-610, MIL-STD-202, JESD-22, and J-STD-020.



DATA DEVICE CORPORATION
REGISTERED TO:
ISO 9001:2008, AS9100C:2009-01
EN9100:2009, JIS Q9100:2009
FILE NO. 10001296 ASH09

The first choice for more than 45 years—DDC
DDC is the world leader in the design and manufacture of high reliability data interface products, motion control, and solid-state power controllers for aerospace, defense, and industrial automation.

Inside the U.S. - Call Toll-Free 1-800-DDC-5757

Headquarters and Main Plant
105 Wilbur Place, Bohemia, NY 11716-2426
Tel: (631) 567-5600 Fax: (631) 567-7358
Toll-Free, Customer Service: 1-800-DDC-5757

Web site: www.ddc-web.com
Data Device Corporation

Outside the U.S. - Call 1-631-567-5600

United Kingdom: DDC U.K., LTD
Mill Reef House, 9-14 Cheap Street, Newbury,
Berkshire RG14 5DD, England
Tel: +44 1635 811140 Fax: +44 1635 32264

France: DDC Electronique
10 Rue Carle-Hebert
92400 Courbevoie France
Tel: +33-1-41-16-3424 Fax: +33-1-41-16-3425

Germany: DDC Elektronik GmbH
Triebstrasse 3, D-80993 München, Germany
Tel: +49 (0) 89-15 00 12-11
Fax: +49 (0) 89-15 00 12-22

Japan: DDC Electronics K.K.
Dai-ichi Magami Bldg, 8F, 1-5, Koraku 1-chome,
Bunkyo-ku, Tokyo 112-0004, Japan
Tel: 81-3-3814-7688 Fax: 81-3-3814-7689
Web site: www.ddcjapan.co.jp

Asia: Data Device Corporation - RO Registered in Singapore
Blk-327 Hougang Ave 5 #05-164
Singapore 530327
Tel: +65 6489 4801

The information in this document is believed to be accurate; however, no responsibility is assumed by Data Device Corporation for its use, and no license or rights are granted by implication or otherwise in connection therewith. Specifications are subject to change without notice.