GENERAL POWER SYSTEM WIRING PRACTICES APPLIED TO TECNADYNE DC BRUSHLESS MOTORS

1. Introduction

The purpose of this application note is to describe some common connection and filtering issues that apply to many electrical systems but are of particular importance to DC power systems that incorporate DC brushless motors and instrumentation level signals. The principles discussed in this application note apply to all systems using Tecnadyne DC brushless thrusters, actuators and hydraulic pumps. It should be stressed that the principles discussed are good engineering principles that should be applied to all electrical power systems, where applicable, at both the design level and also at the system integration level. It is far easier to provide appropriate capacitive filtering and to avoid ground loops at the design and integration stages than it is to try and locate and identify these problems and then eliminate them in a complex system that has been fully assembled and wired.

2. Back EMF & capacitor banks

2.1. What is Back EMF

Brushless DC motors produce back EMF (electromotive force) – this is a reverse polarity voltage that briefly appears on an inductor or motor winding when the applied voltage is removed – though very short in duration, this back EMF pulse generally exceeds the applied voltage. In the case of a 3 phase brushless DC motor, each of the three phase windings is energized two times (once with forward polarity, once with reverse polarity) in each electrical revolution – this results in 6 back EMF spikes for each electrical revolution. Multiply this number times the number of pole pairs in the motor (3 & 4 pole pairs are common) and times the number of motor revolutions per second yields the frequency of the back EMF spikes (1-10kHz are typical frequencies). And since this back EMF is produced across a relatively low resistance motor winding (0.5 to 30 ohms are common), large back EMF current spikes also present, typically on the ground plane. Just as the back EMF voltage spikes are greater in amplitude than the bus voltage, the back EMF current spikes are also greater than the steady state current to the motor. In fact, during rapid speed change or motor reversal, the back EMF current spikes can easily exceed 10 times the steady state current, although for very short duration.

2.2. Filtering Back EMF with a capacitor bank

If back EMF simply appeared as high frequency, short duration voltage spikes, it would be relatively easy to filter using small, high frequency capacitors (such as polyester film capacitors). However, since the back EMF voltage is acting through the relatively low resistance motor winding (0.1 to 10 ohms are typical), the back EMF voltage spikes also produce a significant current spike with enough energy that a large capacitive filter is necessary.

As a rule of thumb, if the power source is a well filtered DC power supply, either located on the surface or on the vehicle, use a capacitor bank of 100-150mfd / Amp of motor electrical current. This is shown schematically in Figure 1.1.

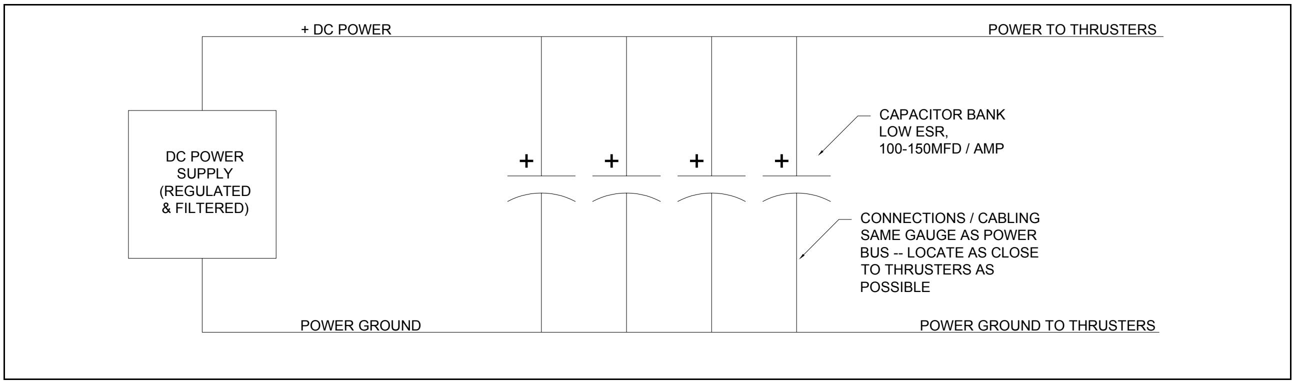

Figure 1.1

If the power source is a battery bank, then the capacitor bank should have at least 400-500mfd / Amp of motor electrical current. This is shown schematically in Figure 1.2.

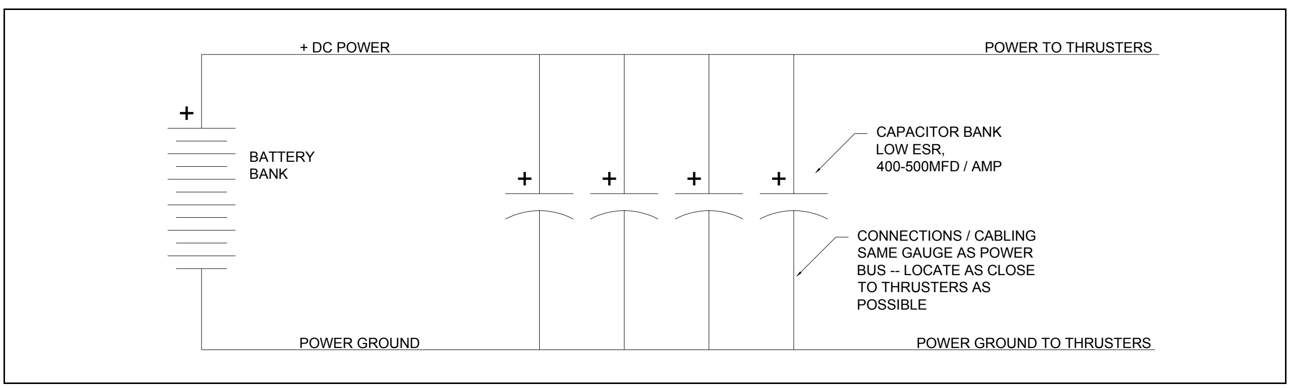

Figure 1.2

And if the power source is rectified AC, then the capacitor bank should have at least 600-700mfd / Amp of motor electrical current. This is shown schematically in Figure 1.3.

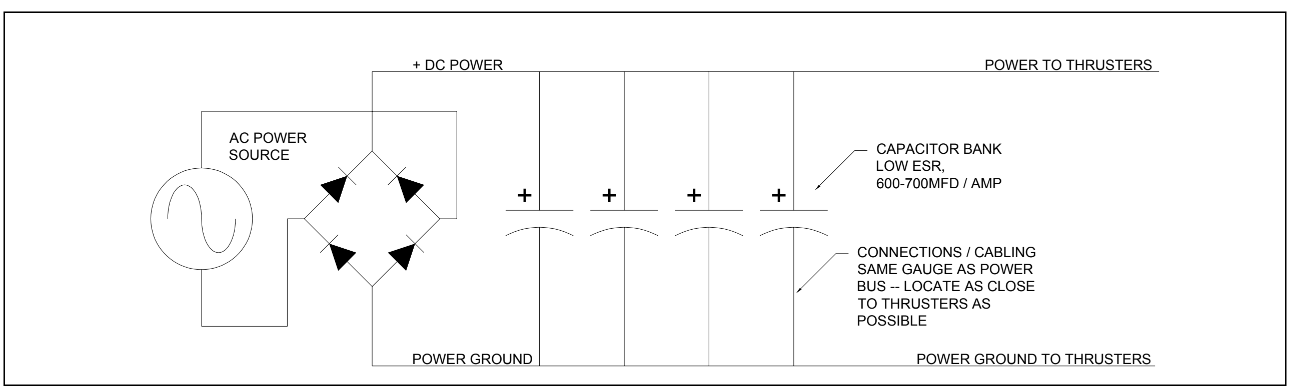

Figure 1.3

It is necessary to use aluminum electrolytic capacitors (as other types are not able to give the capacitance values at the voltages necessary). The capacitors should be low ESR (equivalent series resistance) type (Cornell Dublier 380LX are good) and the voltage rating must be 50% greater than the bus voltage. In accordance with good electrical engineering practice, locate the capacitor bank as close to the source of the noise as possible – in this case the motor. And connect the capacitor bank to the power rail with copper conductors at least as large as the power rail itself.

3. Ground loops & single point ground

3.1. What is a ground loop

In a DC power system, a ground loop is any part of the DC return path (ground) that has more than one possible path between any two points. If, using a schematic diagram of the actual system wiring (a diagram that shows all of the physical connections and their approximate spatial relationships), it is possible to trace a loop on the ground plane (trace between any two points by two or more different routes), then ground loops exist.

3.2. What is a single point ground

As its name implies, a single point ground requires that the power system have a single physical point to which all subsystem grounds are attached. It is only through the rigorous application of a true single point ground that the system designer can be assured that ground loops will not exist. Earth ground (or frame ground in a subsea system) must also be attached to the system at the single ground point. In some systems, a single ground point may not be practical and in these cases it is acceptable to use a large bus bar (copper bar many times larger than the system wiring gauge) instead of the single point ground. However, this copper bus bar must not have any loops in it, either. Similarly, it is consistent with good engineering practice to employ a single point of attachment for the system power (positive DC) voltage.

3.3. Identifying and eliminating ground loops

The most common noise problems encountered in large scale electronic systems result from poor and incorrect grounding practices. Problems are exacerbated when high power motor systems are combined with instrumentation level signals and when these systems are operated in sea water. When more than one ground path exists, the electrical return will share these paths, often altering the electrical potential of the return paths and causing noise and sometimes erratic behavior of sensitive equipment. Noise problems become worse when a DC brushless motor, which generates high levels of back EMF noise, is installed in a system with multiple ground paths, or ground loops. And a ground loop noise problem that exists with a single DC brushless motor will be even greater with two or more motors.

As an example, consider a typical ROV installation using a Tecnadyne thruster operating at 150vdc (from a well filtered power supply). The smaller Tecnadyne thrusters (Models 250, 280, 300, 520, 540, 560, 1020, 1040 and 1060) require an isolated +12vdc supply to power the electronics (at some bus voltages, the Model 1020, 1040 and 1060 have an internal DC-DC converter to supply this voltage) – the ground of the isolated +12vdc supply must be isolated from the power ground. The control signal must also be referenced to this isolated +12vdc instrumentation supply. Since the power ground and the instrumentation power ground are connected within the thruster (due to design constraints), it is necessary that they remain isolated everywhere else in the vehicle system in order to prevent ground loops. Figure 2.1 shows an installation with a ground loop that will severely limit the thruster performance and probably introduce noise into other portions of the ROV system (camera, data link, sonar, etc.). In Figure 2.1, it can be seen that the output of the DC-DC converter is connected to power ground – this is either because the DC-DC converter used is non-isolated DC-DC converter or because its output ground was tied to the input ground improperly. Replace the non-isolated DC-DC converter with an isolated one or remove the connection between the output ground and power ground and full thruster performance will be restored and system noise will be reduced or eliminated.

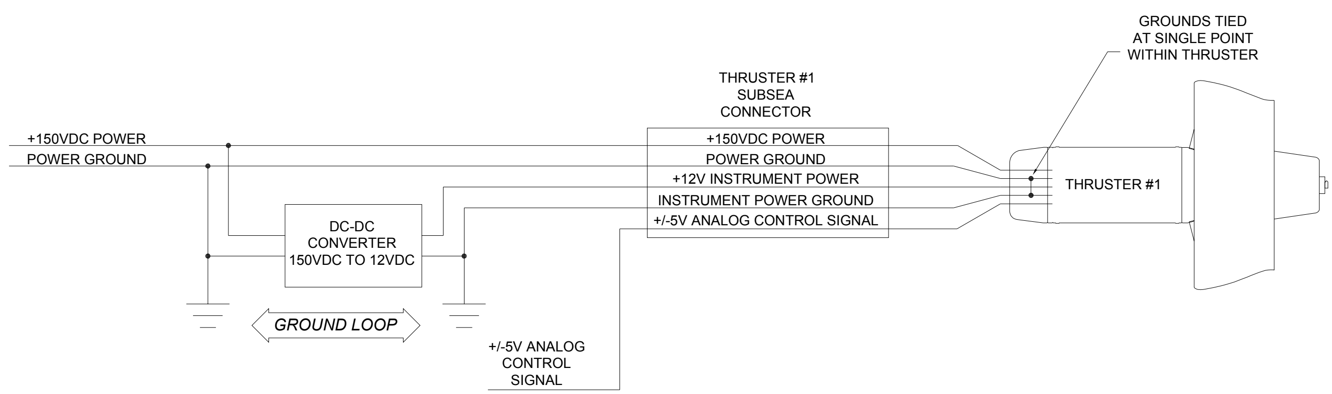

Figure 2.1

As a second example, consider a more complex system – in this case a 48vdc battery powered AUV with thruster control from an onboard CPU with a D/A converter card. A schematic diagram of this system is shown in Figure 2.2. Remember, of course, that the battery supply must be filtered by a low ESR capacitor bank as described in Section 1, above. As in the previous example, the system shown in Figure 2.2 will have a ground loop between the two grounding points – and since the computer chassis is connected to ground it is more difficult to provide isolation in this case. There are multiple additional ground loops since the instrumentation power and control signal of all thrusters are in common. We have even experienced cases in which the ground loop noise was so severe that it damaged the computer D/A converter board, since most commercial D/A converter boards have little or no isolation and very little protection.

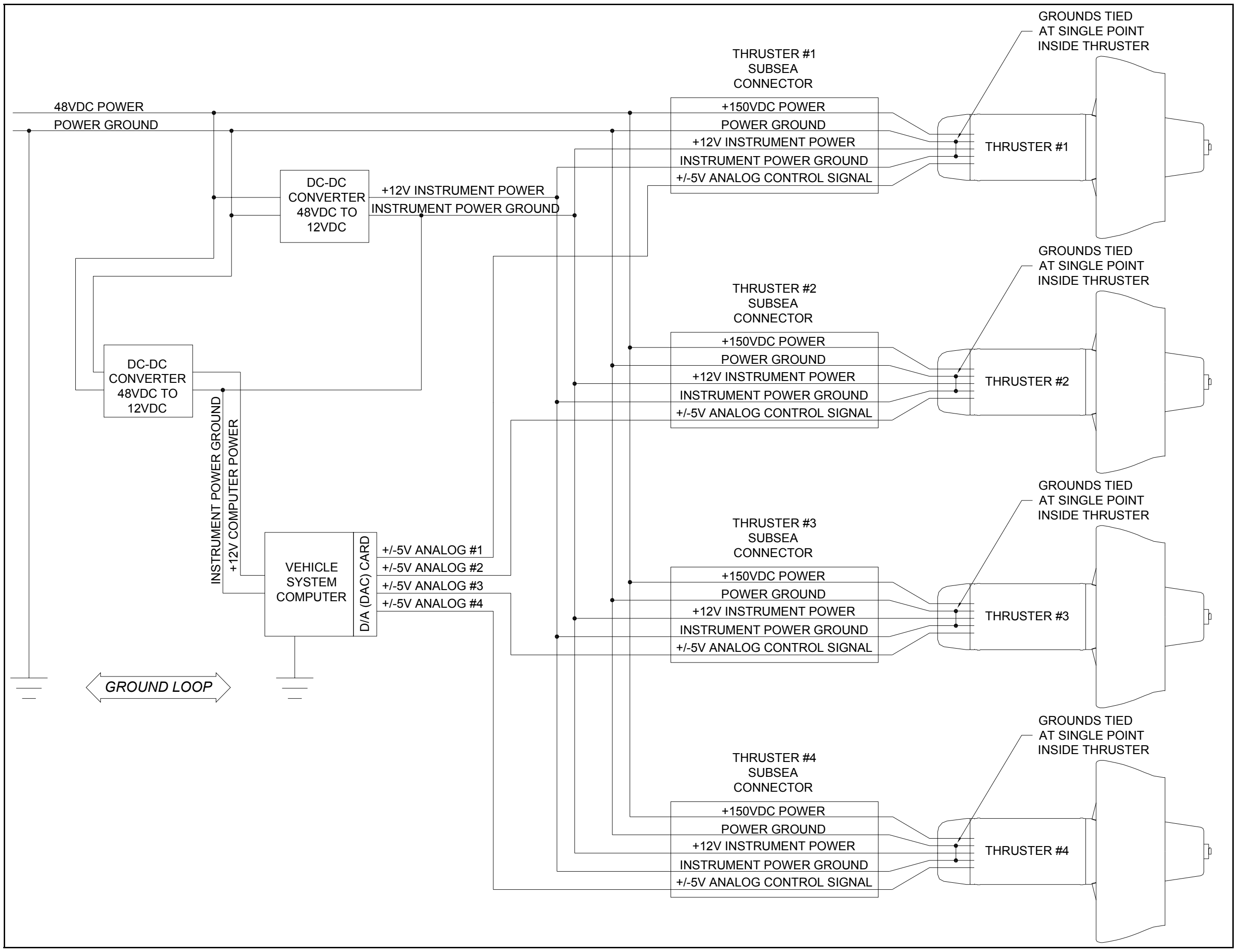

Figure 2.2

In this case, however, the solution to the problem is quite simple and not very costly. Tecnadyne manufactures a 4-channel isolation amplifier card that also incorporates isolated +12vdc instrumentation power – the card is referred to as an Iso-4. Installing this card would be in accordance with the schematic shown in Figure 2.3. The Iso-4 card provides 2,000v of isolation to each of four analog control channels and also provides separate isolated +12vdc supplies to each of these four channels. This card is suitable for operating all Tecnadyne motors using an analog speed input. It should be noted, that, even though the Iso-4 card provides isolated analog signals and +12vdc supplies to four separate channels, it is still necessary that the system designer take design steps to assure that no ground loops exist in other portions of the system.

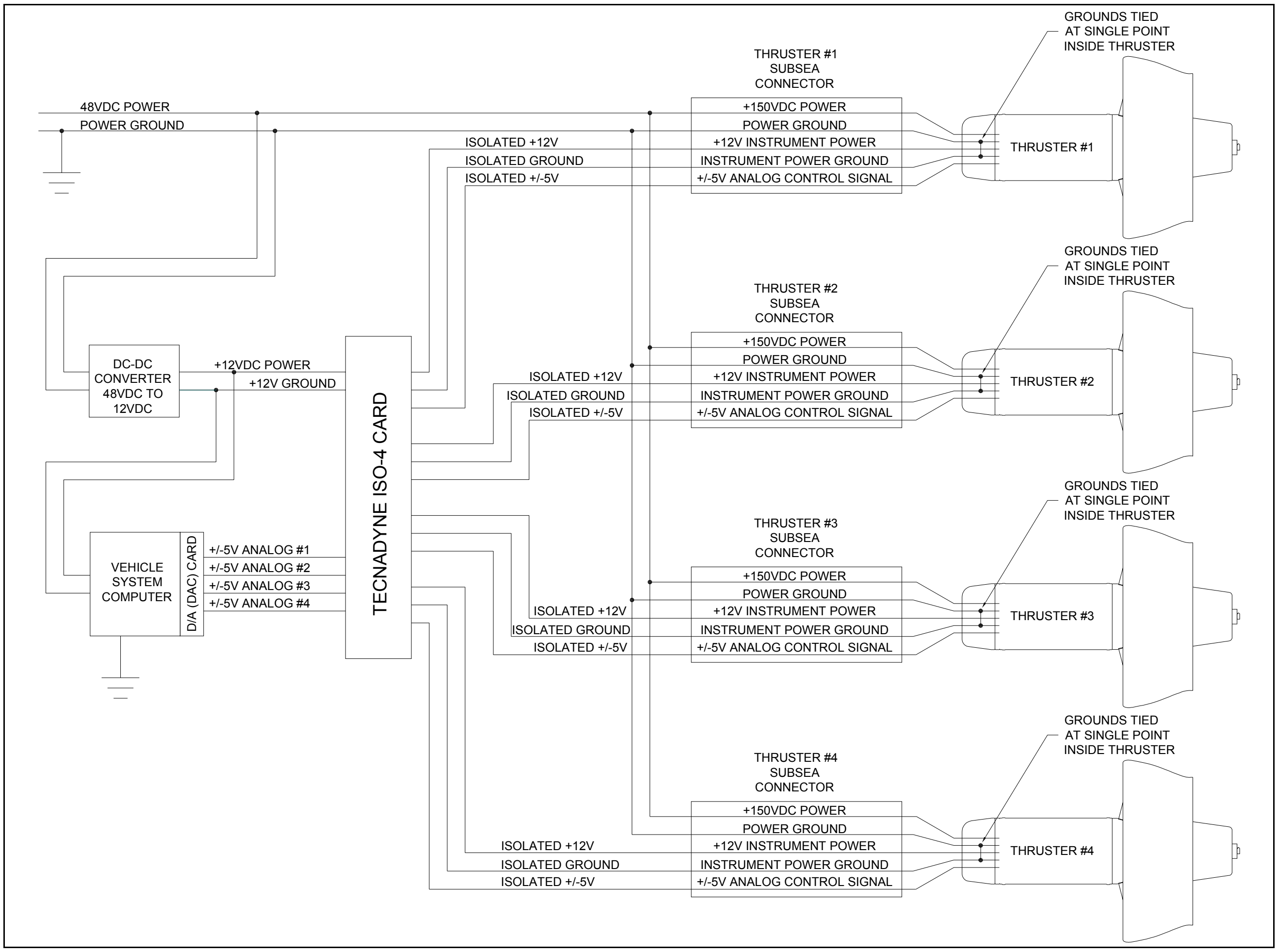
48VDC POWER
POWER GROUND
DC-DC CONVERTER 48VDC TO 12VDC
+12VDC POWER
+12V GROUND
VEHICLE SYSTEM COMPUTER
D/A (DAC) CARD
+/-5V ANALOG #1
+/-5V ANALOG #2
+/-5V ANALOG #3
+/-5V ANALOG #4
TECNADYNE ISO-4 CARD
ISOLATED +12V
ISOLATED GROUND
ISOLATED +/-5V
THRUSTER #1 SUBSEA CONNECTOR
THRUSTER #2 SUBSEA CONNECTOR
THRUSTER #3 SUBSEA CONNECTOR
THRUSTER #4 SUBSEA CONNECTOR
+150VDC POWER
POWER GROUND
+12V INSTRUMENT POWER
INSTRUMENT POWER GROUND
+/-5V ANALOG CONTROL SIGNAL
GROUNDS TIED AT SINGLE POINT INSIDE THRUSTER
THRUSTER #1
THRUSTER #2
THRUSTER #3
THRUSTER #4

Figure 2.3