Application Note #5492

IB-98000 Inductor Board

For high efficiency, switching amplifiers such as the AMP-43040, AMP-20540, and AMP-19540, motor phase to phase inductance is an important characteristic when considering the heat dissipation and performance of the servo.

Galil switching amplifiers require an inductance of 0.2 - 0.5 mH or higher in order to ensure minimal heating power loses due to current switching through the motor.

For motors that fall below the required inductance specification, Galil offers an add-on inductor board called the IB-98000. This board is placed inline between the amplifier and the motor and adds an additional 0.33 mH inductance per phase. The IB-98000 increases the phase to phase inductance by 0.66 mH.

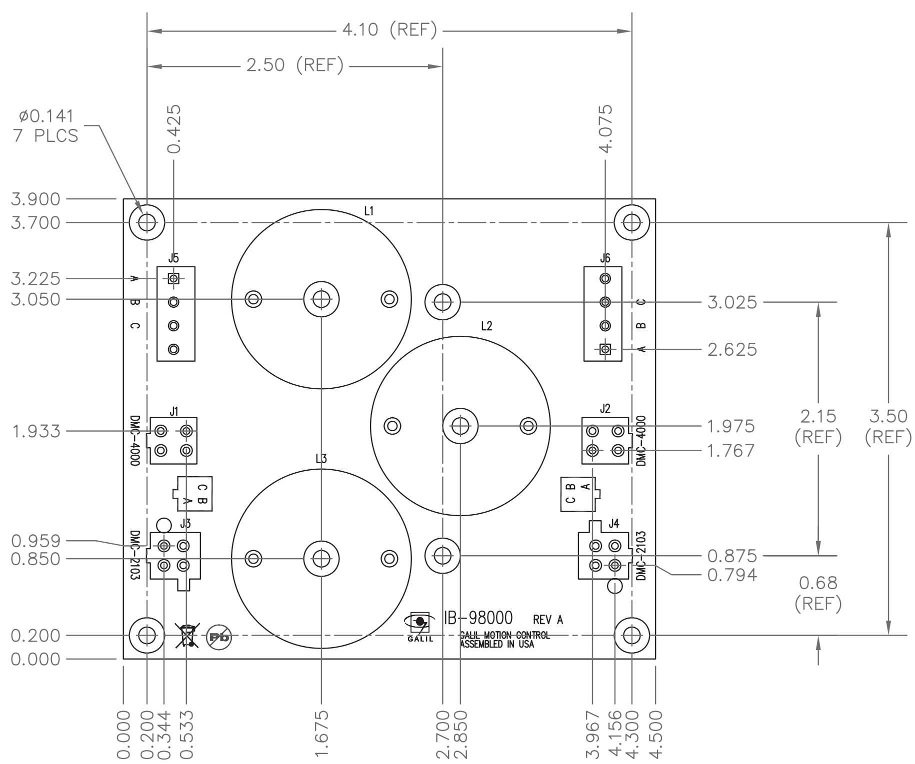

Figure 1. Dimension Drawing of Galil IB-98000

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The IB-98000 can be ordered with connectors compatible with all Galil Amplifiers:

Amplifiers by controller	**Example Amp**	**Part Number**
DMC-4xxx	AMP-43040	IB-98000-4K
DMC-21x3, DMC-18x2, DMC-18x6, CDS-3310	AMP-20540, AMP-19540	IB-98000-2K
Generic (screw terminals)	Third party amplifier	IB-98000-ST

Electrical Explanation for the Role of Inductance

A typical Galil switching amplifier has a switching frequency of *66.6 kHz*, or a switching period of *15us*. With a switching amplifier running inverter mode (default Galil operation), 0 net current is attained by switching +V to the motor half of the time (7.5us), and –V to the motor for the other half (7.5us). To create a nonzero current through the motor, this 50-50 balance can be changed to, for example, 60-40. Carefully controlling the on time of each voltage allows for precise control of the current through the motor. In the discussion below, we'll assume the on time of each voltage is 50%, providing zero net current. This is a common state for an idle servo.

The electrical equation of a motor is given by

$$v = L\frac{di}{dt} + IR + K_e\omega \qquad \text{(a)}$$

where:
L is the inductance of the motor (H)
di/dt is the rate of change of the current (A/s)
R is the resistance of the motor (Ω)
I is the current through the motor (A)
K_e is the motor voltage constant (v/kRPM)
w is the speed of the motor (RPM)

For simplicity, we assume the motor is not moving and equation (a) becomes

$$v = L\frac{di}{dt} + IR \qquad \text{(b)}$$

The power loses in a motor due to current are given by

$$p = I^2R \qquad \text{(c)}$$

Note that equation (c) is a power law. As current increases by a factor of n, power loses increase by a factor of n^2.

For the purpose of discussion, imagine a motor that has zero inductance. We see that the entire voltage drop across the motor is attributed to the motor resistance,

$$v = IR \qquad \text{(d)}$$

For an amplifier power bus of 24v and a motor resistance of 1 ohm, the current through the motor is +/- 24 A. The power loss in the motor is 576w!

The reason a switching amplifier does not cause such staggering power loses is that the inductance of the motor limits the current through the motor on a switching amplifier. The current switching characteristic in a switching amplifier is also called the "current

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ripple.” Note that equation (b) is an “RL”-type circuit. From circuit analysis, it can be shown that the time-dependent current relationship of an RL circuit is

$$i(t) = \frac{V}{R}\left(1 - e^{-\left(\frac{R}{L}\right)t}\right) \qquad \text{(e)}$$

where: *V* is the amplifier supply voltage.

Figure 2 shows the current response for various values of L. For lower values of L, the rise to the max current is faster. This will cause a larger current ripple, and therefore a larger loss of power through motor heating due to equation (c). For larger values of L, the current rise is slower; however this slowness means that the bandwidth of the motor is reduced. With a properly sized inductance, a motor experiences low power loses due to switching, while still maintaining a high-performance current bandwidth. For example, in the 1mH case, peak torque of 10 Amps is achieved in just half a millisecond.

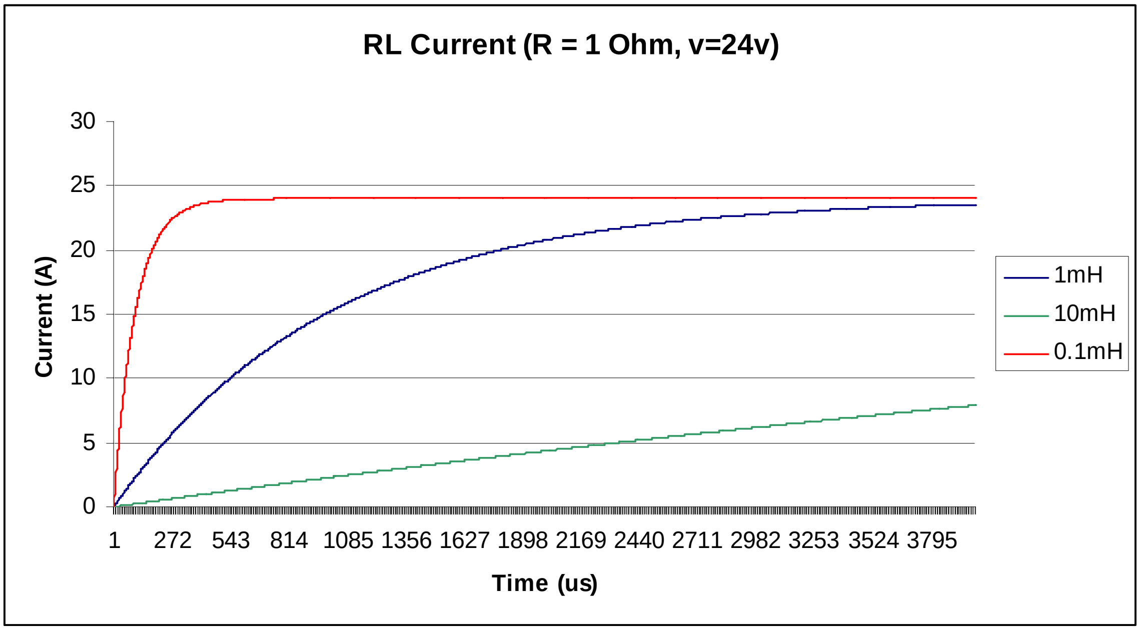

Figure 2 RL current responses for various value of L

If the voltage across the motor is left on indefinitely, the current will approach the maximum according to equation (e). A switching amplifier inverts the voltage rapidly, preventing current saturation.

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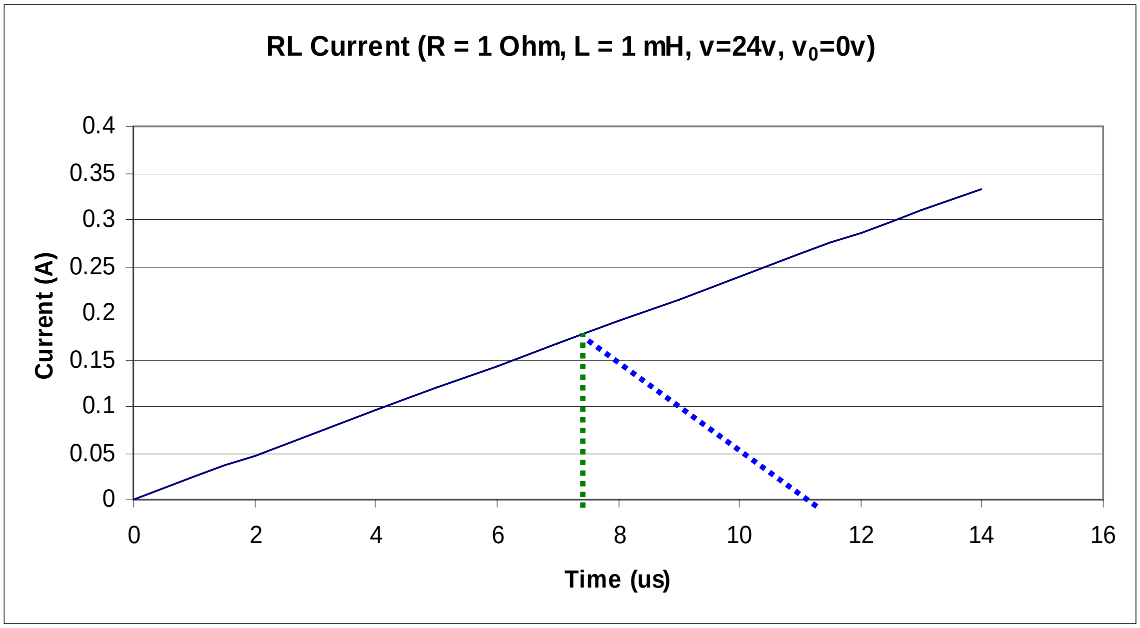

Figure 3. RL current ripple when switching every 7.5us

Figure 3 shows a zoomed view of the 1mH curve in Figure 2 from t=0 to 14 us. After 7.5us from the time the amplifier is enabled (SH), the current has reached ~0.179 A. At this time, the voltage is switched from 24v, to -24v, providing for a total change in voltage of 48v, and leading to the steeper decay of the current as it switches. After 14us, the current would be ~-0.179A. The current ripple with these conditions is +/- 0.179A and the power dissipation is just 0.03w.

Switching amplifiers offer an efficient and high-performance method for controlling motor current, but rely on the inductance of the motor phases. If the motor does not have sufficient inductance on its own, the IB-98000 is a simple way to add inductance making a motor compatible with a switching amp.

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