The Effects of High Frequency Noise on the HCTL-1100

Application Brief M-018

Introduction

In 1990 Agilent Technologies obsoleted the HCTL-1000 and replaced it with the HCTL-1100. The HCTL-1100 is a pin for pin compatible enhanced replacement for the HCTL-1000. Among the enhancements was the process change from low speed NMOS to a high-speed, low-power CMOS. The speed of this new process is on the order of 10 to 30 times faster than the old process. This speed difference makes the HCTL-1100 much more susceptible to high speed noise glitches such as those generated by brush type motors. The HCTL-1000 was considerably less susceptible to this noise as a result of its low speed process. Figure 1 shows an example of the response of the HCTL-1000 and HCTL-1100 to this type of noise.

This Application Note describes two different approaches to dealing with HCTL-1100 noise problems. The first approach deals with how to reduce the noise susceptibility of the HCTL-1100 and the second approach deals with common sources of high frequency noise and how to eliminate it at the source.

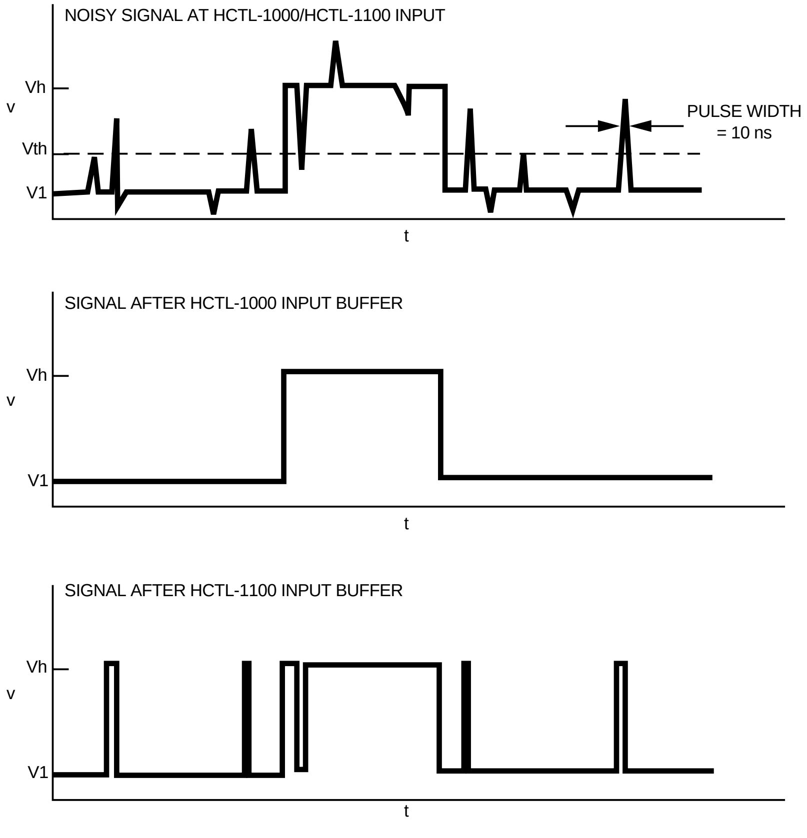


Figure 1. Effects of Noise on the HCTL-1000 and HCTL-1100.

Effects of Noise on the HCTL-1100

There are six inputs on the HCTL-1100 that are particularly susceptible to noise. These inputs are the edge triggered signals and bus control signals. They are CLK, RESET, OE, CS, ALE, and R/W. The typical effects of noise on each of these lines are described below.

CLK

1) The HCTL-1100 intermittently

drops out of control mode back to initialization idle mode.

2) The position counter freezes.
3) The sample timer freezes.
4) The HCTL-1100 completely fails and can only be revived with a hardware reset.

RESET

1) The HCTL-1100 completely fails and can only be revived with a proper hardware reset.
2) The HCTL-1100 will intermittently reset and return to initialization idle mode.

OE

1) The HCTL-1100 intermittently crashes the host processor as a result of the HCTL-1100's tri-state data bus buffers being enabled at the wrong time.

CS

1) Intermittent read and write errors occur during HCTL-1100 bus operations.

ALE

1) Intermittent read and write errors occur during HCTL-1100 bus operations. This is due to an invalid address being latched as a result of a noise spike.

R/W

1) Intermittent read and write errors occur during HCTL-1100 bus operations.

In extremely noisy environments, D7-D0, SYNC, LIMIT, and STOP may also be susceptible to noise; however, if the noise is severe enough to affect these lines, the host processor would more than likely be affected as well. In this situation it would be necessary to shield and isolate all of the control electronics from the source of noise.

Detecting high frequency noise glitches without the proper test equipment is very difficult. It is recommended that an oscilloscope having a bandwidth of 300 MHz or greater be used when tracing these types of problems. If an inadequate scope is used for this application, the sharp noise spikes will appear to be of a much lower amplitude and spread out in time. In many instances they will be invisible to a low speed oscilloscope.

If a 300 MHz or greater oscilloscope is unavailable it is still possible to debug these types of problems. The best way to do this is to try each of the solutions offered in this application note until the problem disappears. The most effective solution is to place filters in line with each sensitive input. The details of this solution are described in the next section.

In addition to noise coupled from external sources, the HCTL-1100 is also susceptible to other phenomenon such as ringing on signals. The line which is most susceptible to ringing is the clock line. Make certain that all ringing that occurs on sensitive signals such as the clock line remains outside the HCTL-1100 input threshold range (0.8 V to 2.0 V). Figure 2 shows an example of what the HCTL-1100 sees when unacceptable ringing crosses its input threshold.

The HCTL-1000 was less susceptible to this problem due to the slow response time of the old NMOS process.

In many instances the ringing may be so fast that it would be undetectable by a low bandwidth oscilloscope. It is also recommended for this test that an oscilloscope having a bandwidth of 300 MHz or greater be used.

Reducing the Noise Susceptibility of the HCTL-1100

The following is a list of solutions that help reduce the noise susceptibility of the HCTL-1100.

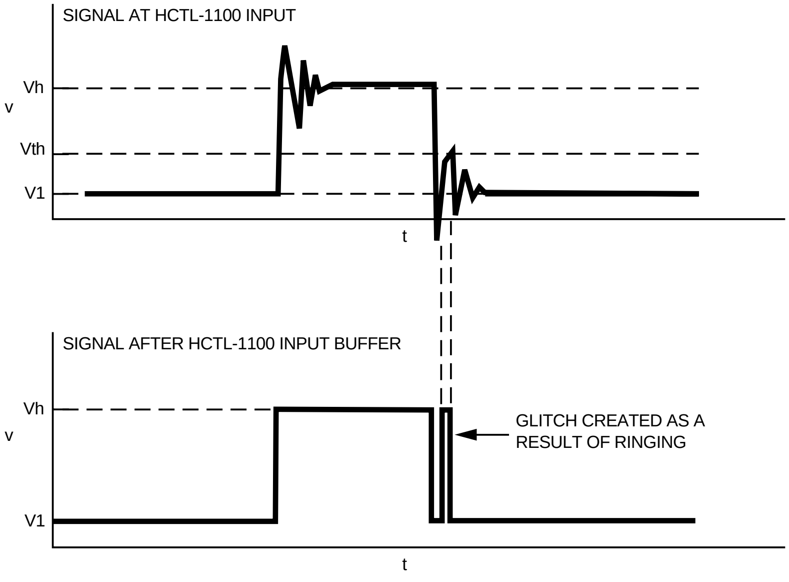


Figure 2. The HCTL-1100's Response to Excessive Ringing.

1) Place Filters on Sensitive Inputs

The most successful way to reduce the noise susceptibility of the HCTL-1100 is to protect the sensitive inputs from high frequency noise glitches. The best way to protect these inputs is to place a low pass filter in line with each of the inputs. Figure 3 shows the connection of these filters. The filters should be placed as physically close as possible to the protected input to minimize the amount of noise coupled onto the line after the filter. It is also important to minimize the trace length between the filter's ground terminal and the system's ground plane.

A variety of options are available in choosing a filter type. Some of these options are listed below in the order of most effective to least effective.

a) Ferrite Bead/Ceramic Capacitor EMI Filter Networks: These networks were originally designed for applications where it was necessary to reduce the amount of electromagnetic interference radiated from a high speed circuit. However, these networks are also very effective at removing fast noise glitches and transients. These devices are third order low pass filters. The schematic for this network is shown in Figure 4.

It is important when doing timing calculations to keep in mind that the additional capacitance will introduce timing delays in the circuit. In isolated cases it may be necessary to use a network with a

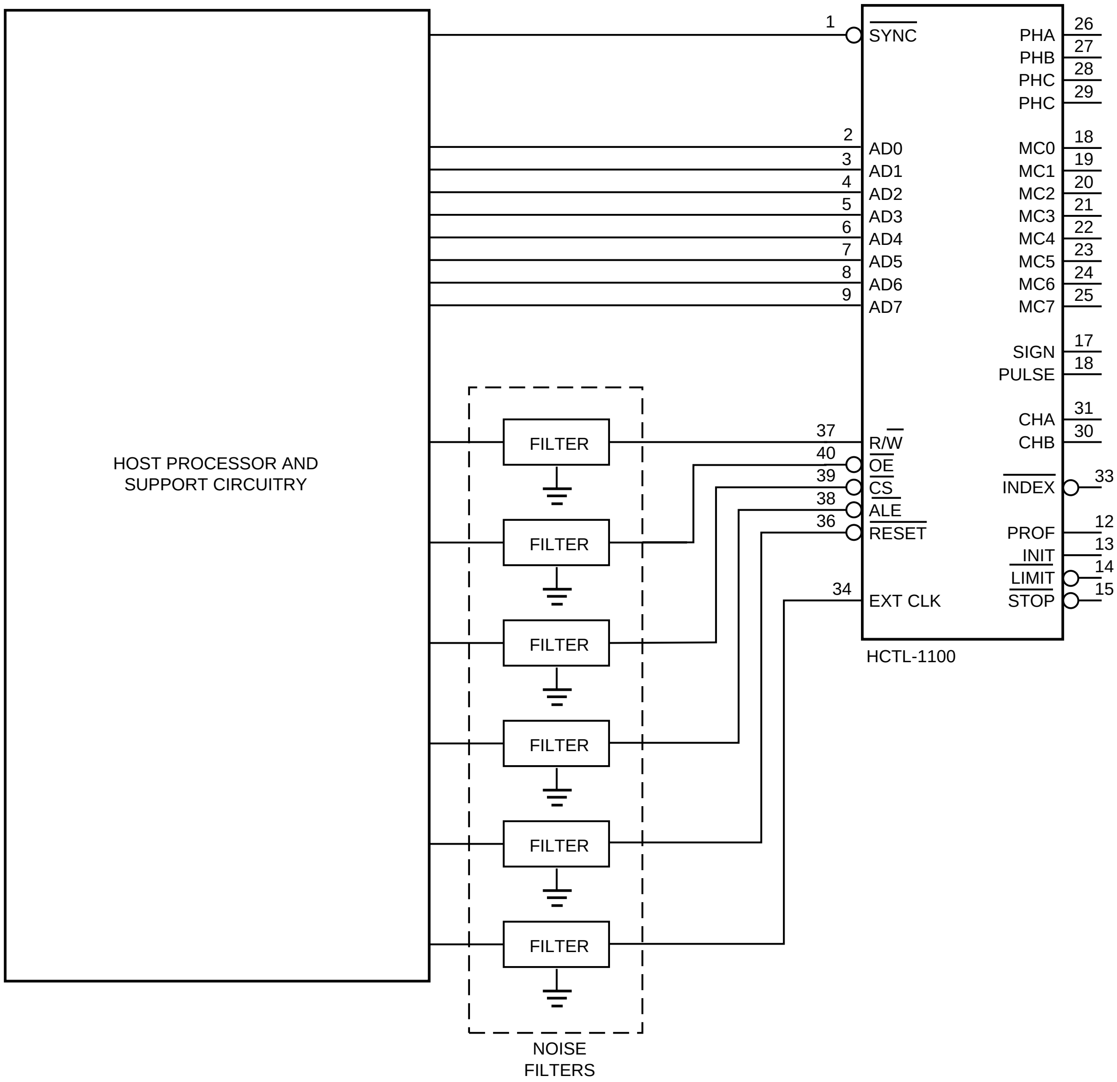
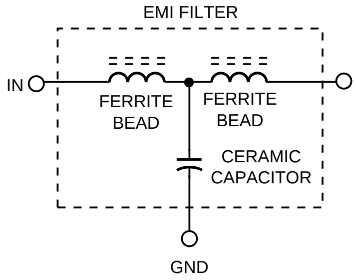


Figure 3. Noise Filter Placement for the HCTL-1100.



RECOMMENDED CAPACITANCE VALUE = 100 pF

RECOMMENDED TDK PART NUMBER =
ZJSR 5101-101R (100 pF)

RECOMMENDED MURATA PART NUMBER =
DSS306-55Y5S101M (100 pF)

Figure 4. EMI Filter Network.

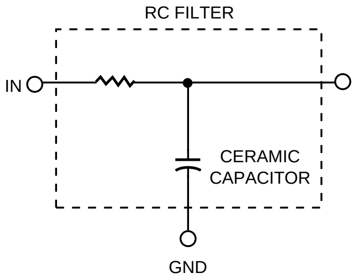
lower capacitance in order to reduce this delay. To determine the additional delay due to the capacitive loading consult the data book of the part driving the HCTL-1100's inputs. For an LS TTL output the additional 100 pF capacitance will contribute a delay that is on the order of 5-10 ms.

b) RC Low Pass Filter Networks:

This filter type is a single pole filter which is fairly effective at reducing high frequency noise, but not as effective as the LC EMI suppressor described above. This network has a much slower roll-off characteristic than the EMI suppressor; however, this network would introduce less ringing in the signal than the EMI suppressor. Once again the delay introduced by this network should be taken into account when doing timing calculations. The diagram for this filter is shown in Figure 5.

c) Ceramic Capacitors:

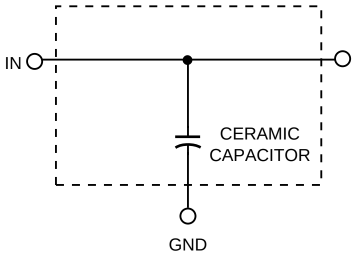
This solution is the simplest and cheapest of all the solutions and in many applications this solution will suffice. The recommended capacitance value for most applications is on the order of 100 pF.



RECOMMENDED RESISTANCE VALUE = 100 Ω

RECOMMENDED CAPACITANCE VALUE = 100 pF

Figure 5. RC Filter Network.



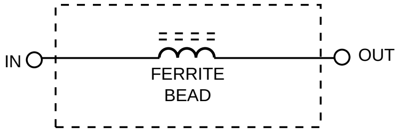
RECOMMENDED CAPACITANCE VALUE = 100 pF

Figure 6. Capacitive Filter.

The aditional delay introduced by this method should be computed the same way as described for the EMI filter.

d) Ferrite Beads:

This solution is the least effective of all for this application due to the high impedance nature of the HCTL-1100's inputs. A more effective solution would be to use a capacitor to ground after the ferrite bead. This would give the same level of protection as the EMI filter described in section (a). Ferrite beads are much more effective in applications such as power supply filtering where the input and output impedances are much lower.



RECOMMENDED TDK PART NUMBERS:
ZBF503D-00 (TA)
ZBF504D-00 (TA)
ZBF506D-00 (TA)

Figure 7. Ferrite Bead.

The delay contribution for the ferrite bead is in most cases negligible.

2) Power Supply Filtering

a) Place a ceramic bypass capacitor between V_{DD} and GND.

b) Use a ferrite bead on V_{DD} in conjunction with a ceramic capacitor. Figure 8 shows the placement of these components.

3) Resistive Termination of Long Traces

Resistive termination gives the noise a much lower impedance path to be coupled onto and greatly reduces ringing. As mentioned earlier, ringing can also cause problems if the amplitude is sufficient enough to cross the TTL threshold.

4) Shielding

a) Use shielded cables to carry sensitive signals. Do not mix high power signals with sensitive signals within the same shield.

b) Shield the HCTL-1100. In extreme situations it may be necessary to enclose the control electronics (including the HCTL-1100) in a shielded metal enclosure.

c) Use a multi-layer PC board with ground and power planes.

5) Cabling Techniques

a) Minimize cable lengths for sensitive signals.

b) Separate sensitive cables from cables carrying noisy signals or high power signals.

c) Shield cables carrying sensitive signals.

6) Isolation

In extremely noisy environments it may be necessary to isolate the HCTL-1100's encoder and motor control signals from the external world. An example of such an environment is in automatic welding machinery where very high levels of EMI are present. The most economical way to isolate the encoder and motor control signals would be to use optocouplers.

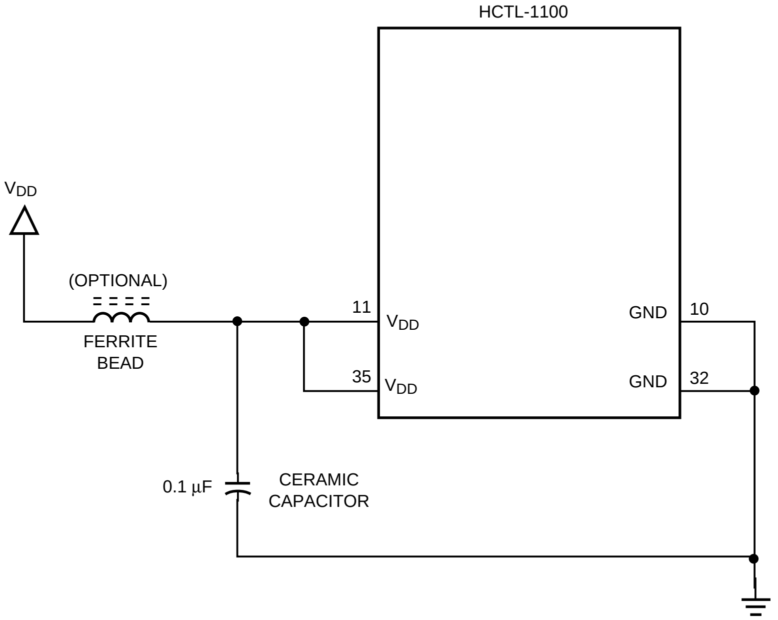


Figure 8. Power Supply Filtering.

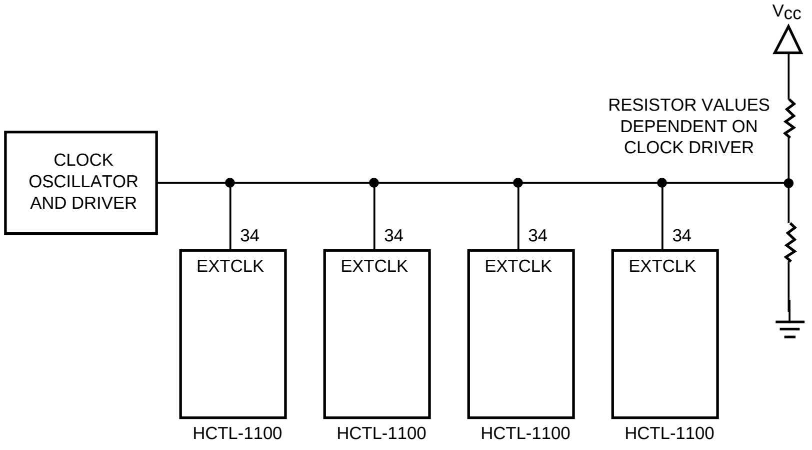


Figure 9. Example of Resistive Termination on the Clock Line.

Eliminating Noise at the Source

This section describes the most common sources of noise in an HCTL-1100 based servo system and the most effective ways to deal with them. This section is divided into three parts:

1) Motor Brush Noise
2) PWM Switching Noise
3) External Noise Sources

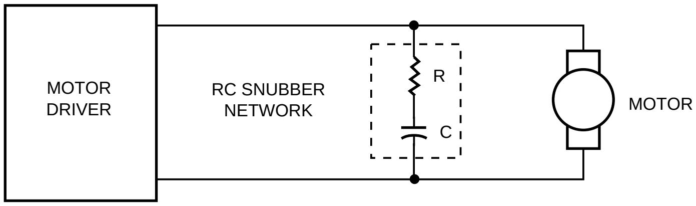


Figure 10. Application of an RC snubber Network to Reduce Motor Brush Noise.

1) Motor Brush Noise

If a servo system is using a brush type motor and the system is suffering from noise problems, the most likely cause is the motor brushes. A majority of the noise is generated from the breaking of the contact between the motor's brushes and the rotor contacts. This disconnection is done in series with the highly inductive rotor windings which causes a high voltage/high frequency noise spike to be generated every time the contact is broken. The radiated energy from this spike is transmitted from both the rotor windings and the wires leading to the motor. The energy radiated from the rotor windings is very effectively blocked by the metal motor housing, however, the energy radiated from the motor terminals and the wires leading to the motor are not. It is very easy for this noise to couple onto sensitive control signals such as those leading to the HCTL-1100. The most effective way to reduce this noise is to block it right at the motor terminals.

One effective way to block this high frequency noise is to place a capacitor across the motor terminals. The capacitor looks like a short circuit to this noise. One problem with this method is that a resonant circuit is formed with the capacitor and the inductance of the motor lead wires. This arrangement can produce long periods of ringing at the resonant frequency of this high Q circuit causing strong RF emissions at that resonant frequency. A second problem with this solution occurs when it is used in conjunction with PWM motor driver circuits. The capacitor causes excessive current spikes during switching times and may cause the PWM driver circuit to eventually fail. These spikes may also cause noise problems just as severe as the motor brush noise was itself.

A more effective way to eliminate motor brush noise is to place a series type RC snubber network across the motor terminals. Figure 10 shows the connection of this network. The resistor greatly reduces the level of current spikes and ringing that a capacitor alone would cause. It is recommended that a ceramic capacitor be used for this application.

In a DC drive system, component values are not critical. The larger the capacitor the more effective the snubber will be. The constraints are usually the cost and size of the capacitor and the effect it will have on system stability. The resistor may be optional in this application. This can be determined by viewing the duration of ringing at the motor terminals. If the ringing is less than a couple of cycles the resistor may not be necessary. In many DC drive applications it is not required.

In a PWM driven system there may be several constraints on component values and the series resistor will always be necessary. The two dominant constraints are the peak and average current through the snubber network. You can choose the optimal values based on these constraints using the equations below.

$$I_{AVG} = \frac{2CV_P}{T}\left(1-e^{\frac{-T}{2RC}}\right)$$

Where:

$$V_P = \left(\frac{1}{1+e^{\frac{-T}{2RC}}}\right)V_{PWM}$$

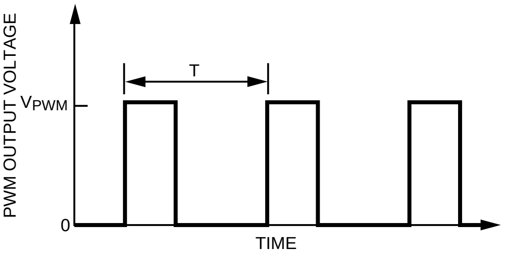


Figure 11. Average Current Through the Network.

Peak current through snubber network:

$$I_{PEAK} = \frac{V_{PWM}}{R}$$

The following three steps outline a procedure for determining the RC values for the network based on the peak and average current through the network.

Step 1:
Solve for R using the equation for peak current. This yields:

$$R = \frac{V_{PWM}}{I_{PEAK}}$$

Step 2:
The second step is to solve for C using the average current equations on the previous page. Since there is no way to derive a closed form solution for C from these equations, an iterative approach or an approximation would have to be used. In this application note, the approximation method is used. The following equation was derived using first order approximations for the average current equations.

$$C = \frac{T}{2} \quad \frac{I_{AVG}}{1.53\ V_{PWM} - 2\ RI_{AVG}}$$

A correction factor was added to guarantee that the actual average current will never exceed the initially specified average current.

Step 3:
Calculate the power rating for the snubber resistor. This can be done by calculating the worst case average current using the equation below. This equation assumes the worst case duty ratio of 50%.

$$P_{AVG} = \frac{CVp^2}{T} \left(1 - e^{\frac{-T}{RC}}\right)$$

The calculations described above assume a PWM driver which is low impedance during the off-state. If the driver is open circuit during the off-state, the equations are no longer valid and the snubber network may have adverse effects on system stability. This potential instability occurs as a result of the capacitor discharging into the motor during the off-state. The additional charge stored in the capacitor can cause the motor and driver to have a non-linear transfer function with a much higher gain at lower duty ratios.

2) PWM Switching Noise
The second most likely source of noise in a PWM driven servo system is the motor power driver. The noise originates from the high speed switching of voltage on the driver's output. Fast current transients are usually minimal due to the inductive nature of the motor. However, if there is sufficient capacitive or parallel resistive loading, there may also be significant current transients as well. These high speed power signals are usually sent over lengthy cables to a motor. These cables can very effectively radiate this energy to the surrounding environment if precautions are not taken. One way to reduce this radiated energy is to route the motor wires as physically close together as possible. A grounded shield could be added to these wires as a second level of protection.

Another effective way to reduce this noise is to place ferrite beads in line with the driver's outputs. The beads slow down the fast switching edges of the PWM's output. The beads should be located as physically close to the driver as possible. A more effective but more expensive way to reduce this noise is to place a more complex low pass filter in line with the motor driver's outputs. Typically this filter would be an LC type filter. An example of this is shown in Figure 12. Keep in mind that this type of filter is only applicable for low impedance off-state drivers.

It is important to design the filter such that the motor in combination with the filter does not exceed the driver's peak current or average current ratings.

Using a motor driver which is high impedance in the off-state may also be a major source of noise in a servo control system. When the driver switches from

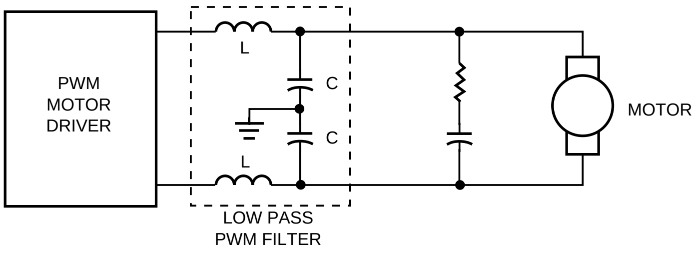


Figure 12. Example of a Low Pass PWM Filter.

the on-state to the off-state, a high voltage spike is generated as a result of the rapid interruption of current through the highly inductive motor windings. This high voltage spike and rapid interruption of current is the primary source of noise. In almost all applications this type of driver is more noisy than the low impedance off-state type driver. Where possible, it is highly recommended that a low impedance off-state driver be used.

3) Other Sources of Noise

In addition to the servo motor and driver, there may be other significant sources of noise in your system. The following is a list of some common sources of noise that may affect your HCTL-1100 based servo control system.

- Switching power supplies
- High power electromechanical actuators
- Noisy switches
- Electrostatic discharge
- Arcing of any sort
- SCRs and TRIACs
- Gas discharge tubes or displays

In general, high power/high speed electrical devices are likely to be a source of noise. The best way to minimize the high frequency RF energy radiated from these devices is to slow down any fast voltage or current transients created by these devices. EMI shielding is also an effective way to reduce this radiated energy.

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