

# EMC For Servo Drives and Motors

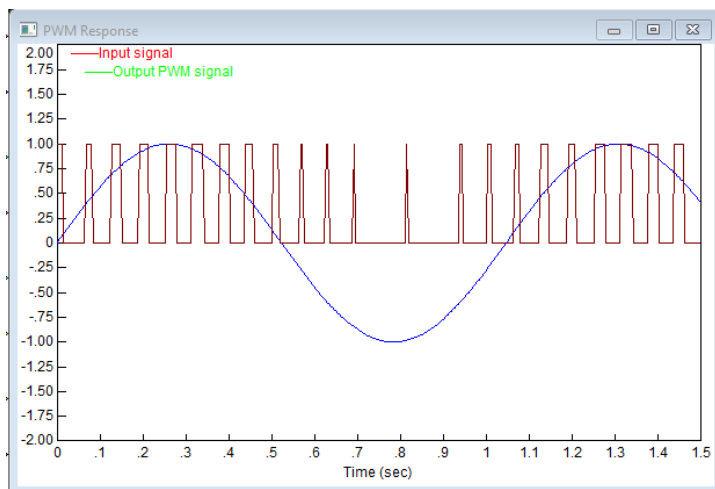
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*The purpose of this is to explain the source and reduction of Electro-Magnetic Interference (EMI) event or Compliance to standards when a Pulse Width Modulated servo drives are the source. This treatment will be limited in scope to conducted and radiated emissions relating to servo amplifiers as opposed to the many facets of Electro-Magnetic Compatibility and Compliance (EMC) and testing.*

## What Does EMI Look Like and Cause?

There is time domain (oscilloscope) and frequency domain (Spectrum Analysis) for reference. views intended to explain the phenomena. Some pitfalls and avoidance as well as post intervention will be discussed. In red on the figure 1 below, the pulse train of a signal going to a phase of a motor is displayed. The blue is the resultant current to the motor.

**Figure 1:** Quick Reference of PWM

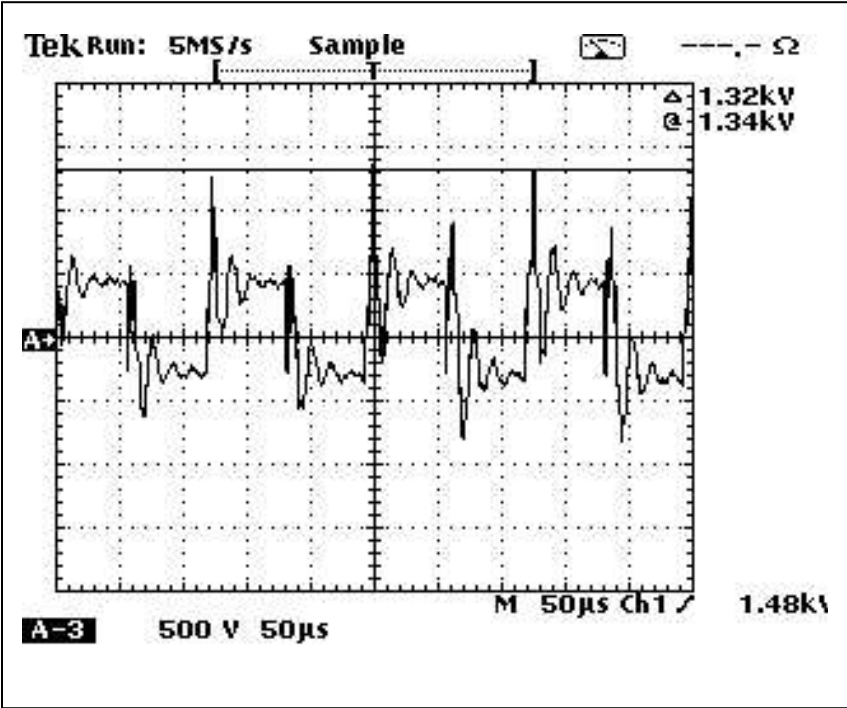


# Differential Measurement

Differential noise is measured in each individual phase. When you have noise that is coupling in the system differentially, one of the most common indicators is ringing on the PWM.

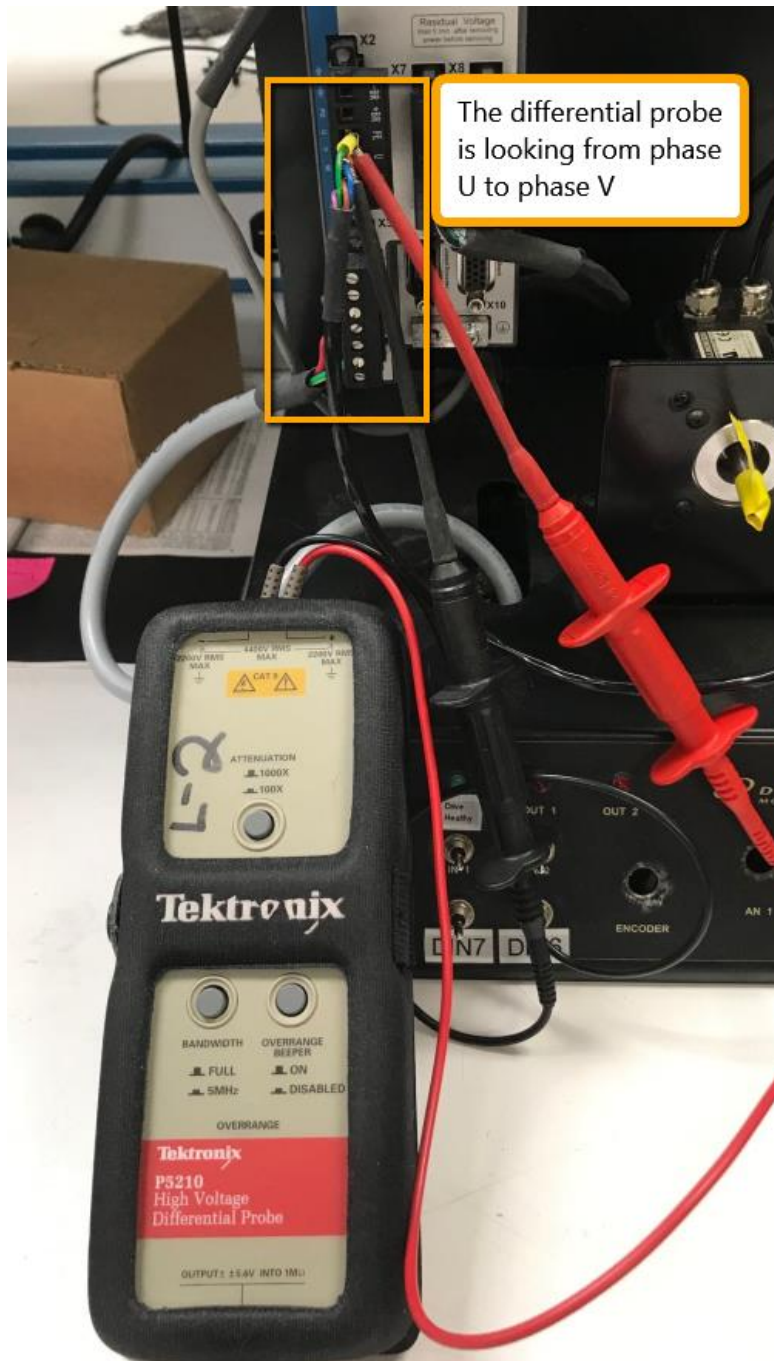
Monitoring PWM on individual phases for Differential Current

- 1. Idle Currents as well as driving currents should be monitored and documented.
- 2. **Figure 2:** The ringing on both the leading and trailing edges will be transmitted magnetically as well as radiatively. The system can be affected by the unintended paths of the magnetic field and results in voltage spiking.



- 3. Taking the measurement in figure 2. Using a differential probe on the voltage of phase U to Phase V.

# Taking the Differential Voltage Measurement

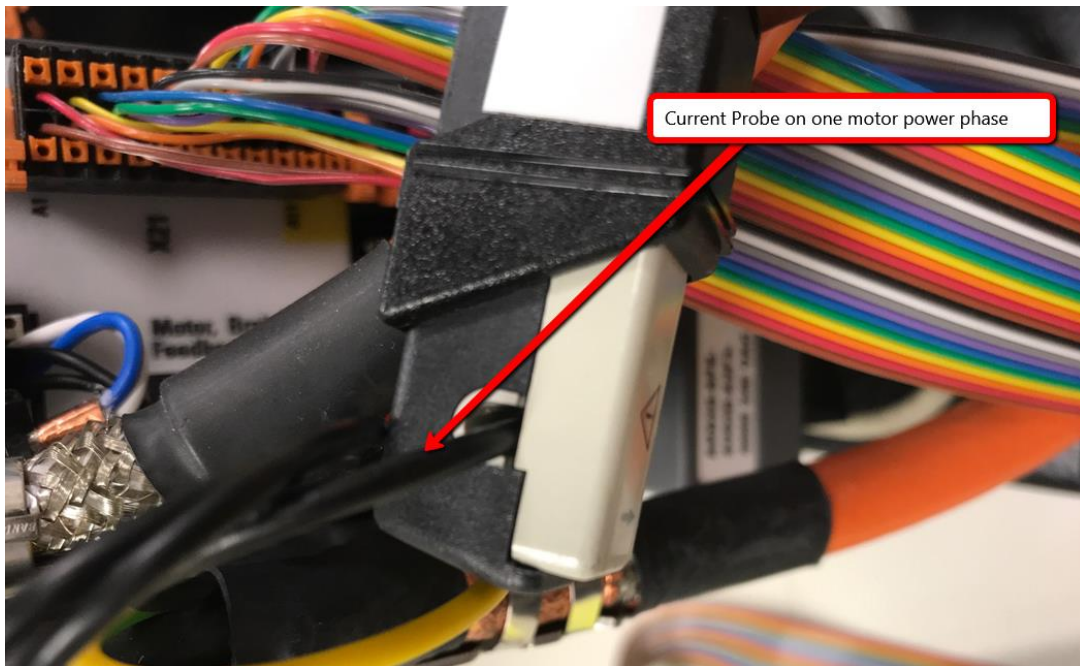


**Figure 3:** The high frequency and high voltage requires a high-speed differential probe. In this case, a Tektronix P5210 is a good choice.

# Taking Differential Noise Currents

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When measuring the PWM Voltages and spikes, the differential current noise will be measured with a current probe on one phase. It should show similar characteristic ringing, and this represents the magnetic potential noise. Remember that magnetic noise represents enough power to turn on devices without voltage as they can generate a voltage from the field itself.

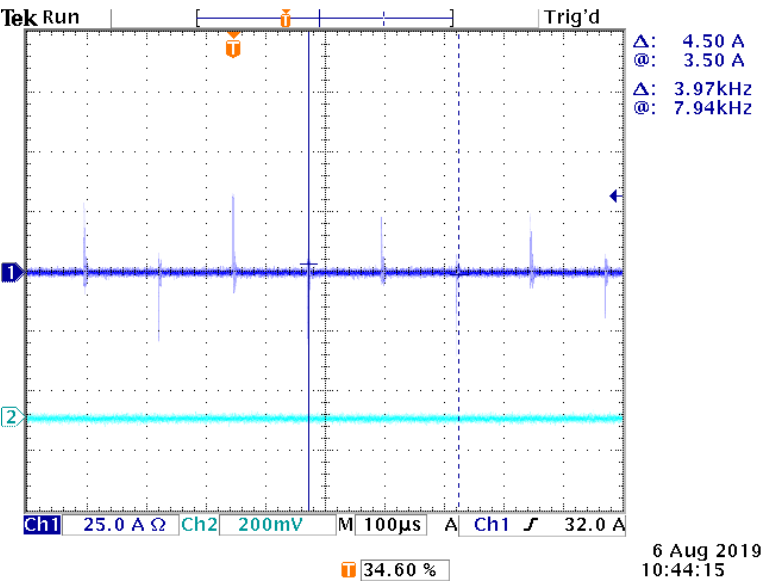


**Figure 4:**

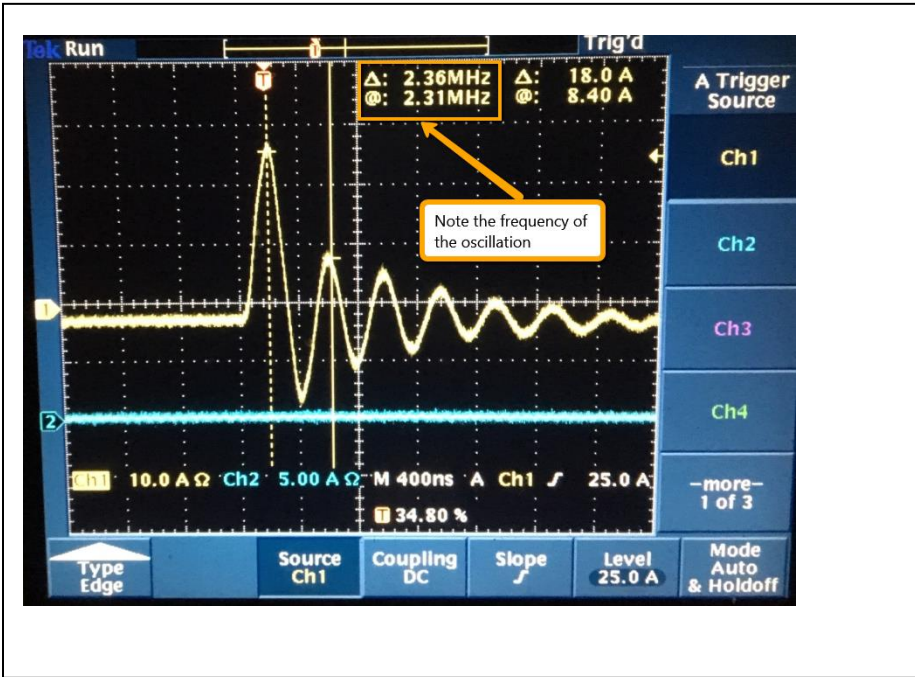
The expected PWM currents when ringing will also show overshoot and ringing if there is any. Using the current probe will indicate the presence of voltage spikes as well, dealt with later in this

# PWM Differential Noise

Using an oscilloscope and current probes, a time domain snapshot can be taken of both common mode and differential mode currents. Since this treatment is referencing three phase brushless DC motors, the common mode currents will represent those unintended currents caused by imbalance of the actual motor to an ideal motor.



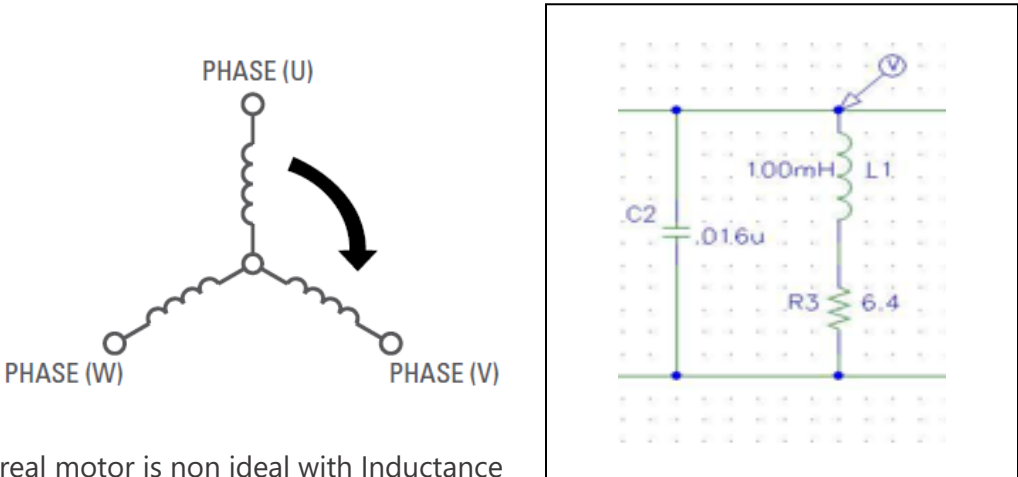
**Figure 5 and 6: Noise and expanded view**



# Common and Differential Mode Noise

Common Mode noise is when there are recirculating currents in the motor. These currents are due to the parasitic capacitance of the motor as opposed to an ideal model. These parasitic capacitance paths are from the winding and insulation and are not part of the normal specifications of a motor and often, not controllable. The layout of the windings causes differences.

This Y-wound motor has only inductance



The real motor is non ideal with Inductance Resistance (R), and Capacitance (C) that affect the currents and voltages of the motor.

(L), would

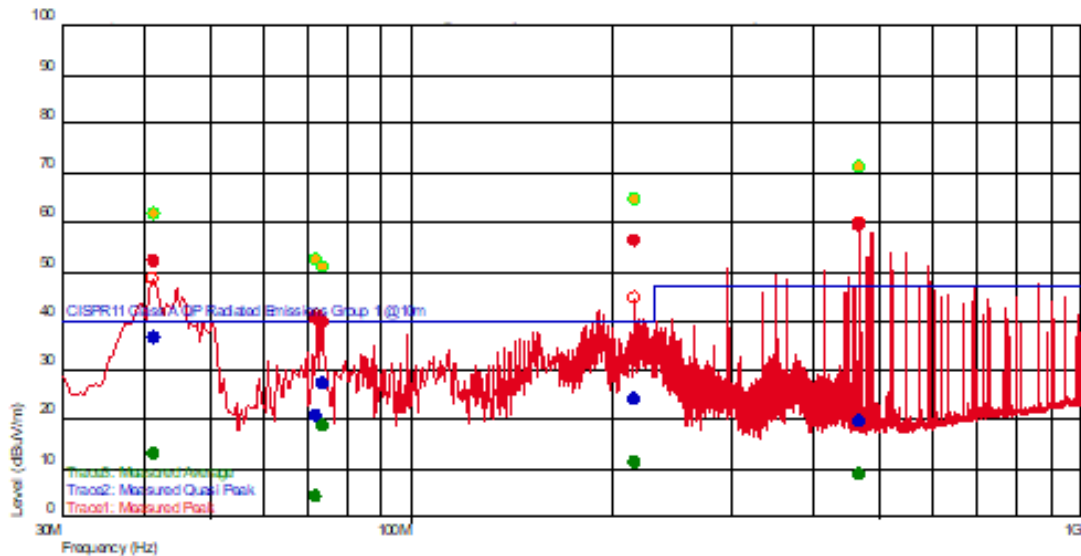
**Figure 7:** The ideal and real models of a motor.

The model of a motor ideally and the true model differ in the fact that there are parasitic elements such as the internal capacitance and the added cable parasitic elements that must be accounted for.

The typical capacitance of a motor is not a known specification as it may vary with the type of wire insulation and layout of conductors within the motor, some of which are not able to be controlled.

# Spectrum of PWM

In Radiated Emissions, the area of 30 – 60 MHz is significantly affected by the rise time of the PWM. As devices get faster and rise time reduces, expect higher frequency interference.

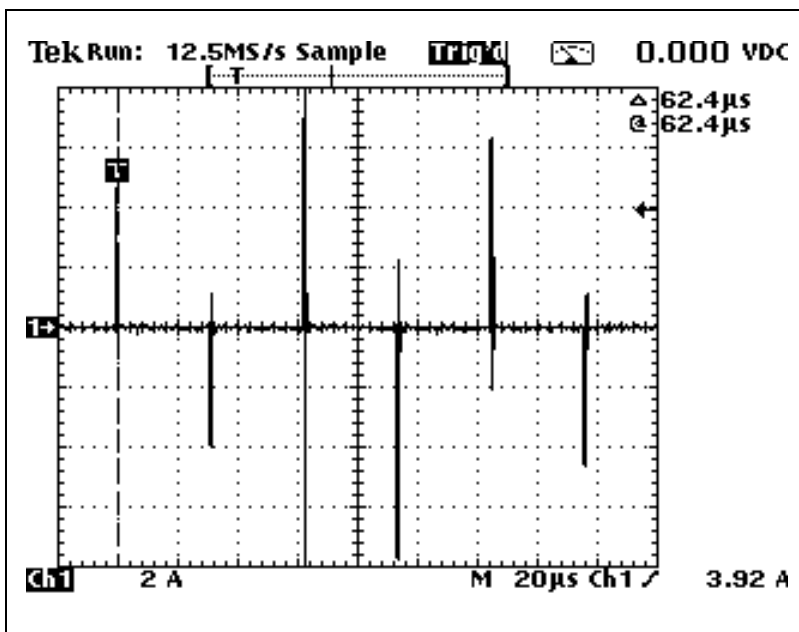
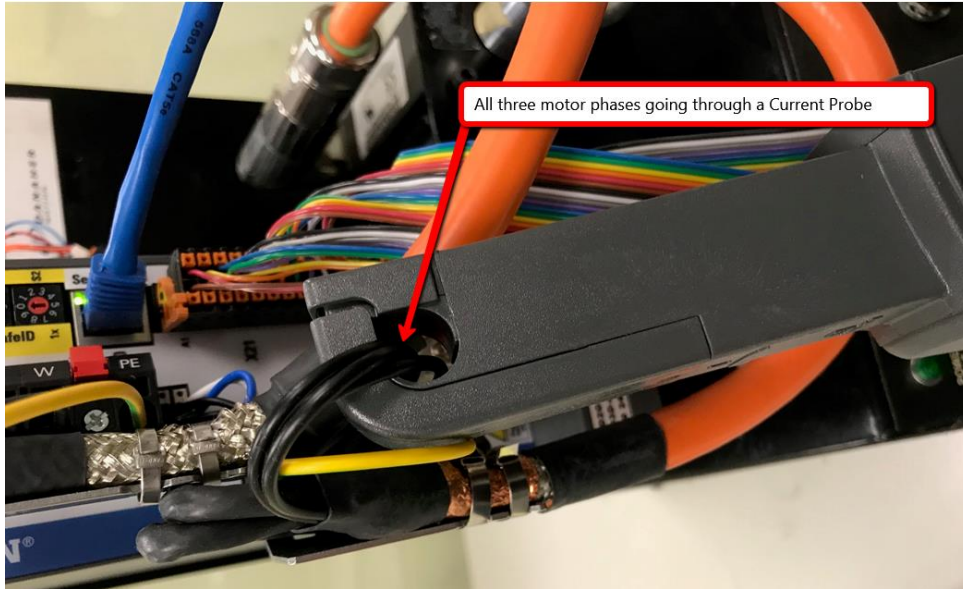


**Figure 8:** This is the spectrum taken in an EMC Lab of a servo systems. The levels of passing are exceeded in the 40 MHz area as well as some high frequency areas above 300 MHz. The PWM is a magnetic noise responsible for less than 100 MHz. The high frequency are often due to clocks and power supply issues that are capacitively coupling when it's above 300 MHz.

## The mechanism of the noise

## Taking the measurements with an Oscilloscope

This shows a current transformer measuring the common mode noise. The current probe has all three phases of the drive passing through for measurement without the ground or shield. Notice that the plot shows very symmetrical noise about zero volts. This is characteristic of common mode as opposed to differential mode noise at idle.



**Figure 9 and Figure 10:**  
Making the measurement –  
Drive Enabled Only



# Shield and Ground Noise

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Often, noise on the shield lines if sufficient in length, may transmit. Looking at the ground and shields is often helpful. A typical transmission antenna for radiated noise is set at  $\lambda/20$  which means that it is  $1/20$  of the wavelength. Although not likely responsible for any errors with in the drive, radiating outward can interfere with other parts of a large installation. Why is this? To receive a signal in the voltage field, you must be  $1/2$  wavelength away from the source. At 30 MHz, that would be 5 meters. Applications with 25m cables could easily be an issue however.

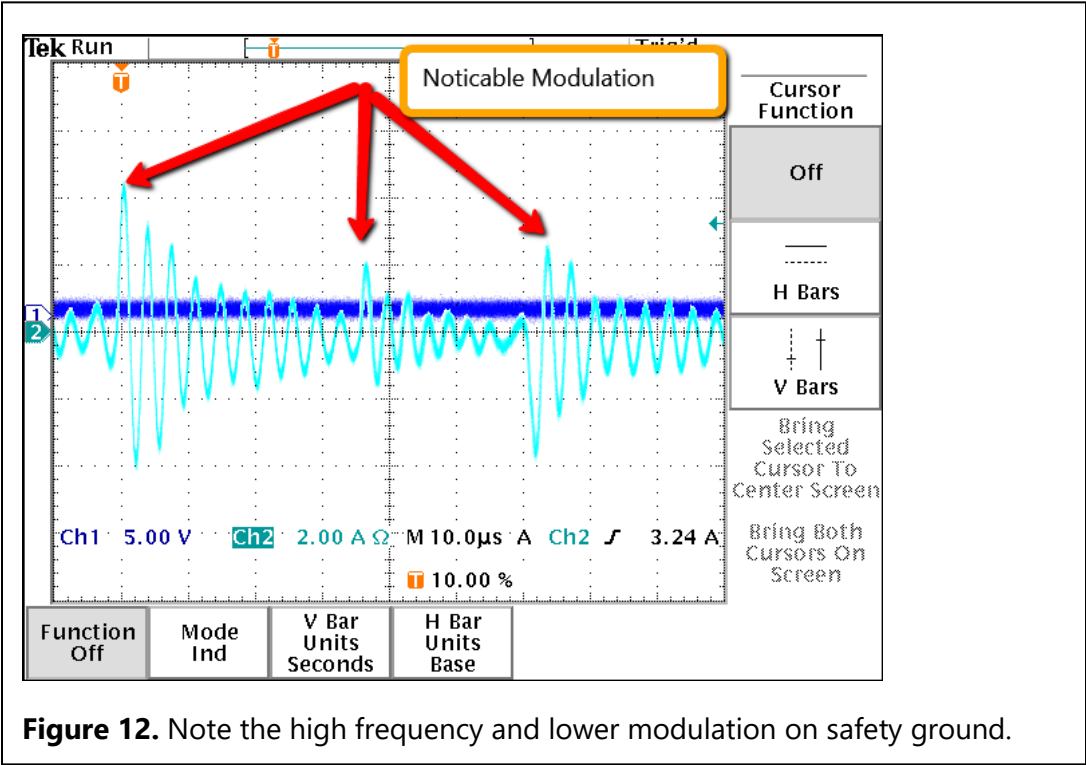


**Figure 11:** Using a current probe to monitor the safety ground.

Often ground noise will result in common mode noise. When looking at the ground noise however, it gives you an indication that perhaps the ground reference is insufficient for the currents. If the ground noise is dominated by the fundamental power frequencies like 50, 60, 150 or 180 Hz, then it is likely that the earthing of the drive is insufficient. If it is dominated by the PWM, then reviewing the common mode noise of the PWM, the common mode noise must be reduced. Identifying the source can help determine if you have a conducted noise issue, one where a reference, ground or signal is connected to the wrong intended signal. If you were to see 60 Hz noise or 180 Hz noise in the case of three phase connections, it would be an indication that the ground reference for the power is not right.

# Shield and Ground Noise

Modulation on the ground indicates that there is significant amounts of noise that has an incorrect path to ground. The safety ground is by definition: " a Non-current carrying conductor except under fault conditions". Thus, we should not see the currents in this following figure 9. We have an interaction of the current draw on drives as well as the PWM and some sort of modulation. The solution in this case was to clamp shields to the drive, ensure that the back plane was uncoated and conductive to the drive base and add an LRC EMI filter to the power for the drives.



**Figure 12.** Note the high frequency and lower modulation on safety ground.

# Damage from Noise

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## The mechanism of the noise

Large swings in current or voltage can cause multiple issues. One is a standing wave problem. This is when the noise can double or triple because the reflection is in time with another input pulse. Line reflections are dangerous because they can cause insulation breakdown. Servo motors are typically high pot or dissipation (called PD Test) tested to twice the rated voltage plus 1000 VAC. There for, a typical 480v systems will be tested to at least 2000v for some time-based test, perhaps 1 minute. That does not indicate that this motor is intended for multiple hits of that voltage for each PWM cycle, perhaps at 20 – 62.5  $\mu$ s.

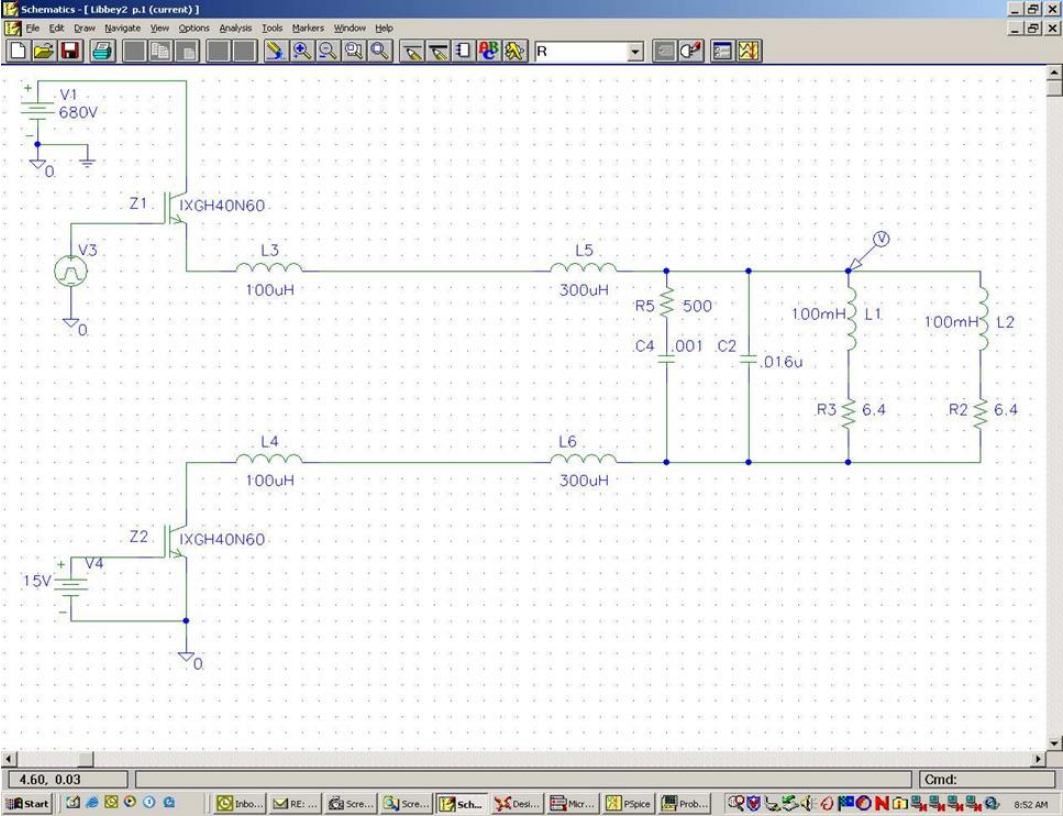
The oversimplified standing wave equation will not work reliably with the complex impedance of the cable and motor. Although the motor is an inductor, it has parasitic capacitance. Other complications are the fact that the cable has capacitance, inductance and resistance from phase to phase, phase to shield, and common phases to shield that create a complex lump mode that is easier modeled than calculated.

After modeling, you can compare actual results with the empirical tests and correct the model accordingly. The difficulty will be the internal capacitance of the motor and cable are very difficult to measure. It streamlines the testing to see what the basic values are at first.

Instability in current loops caused by reaction to unexpected loads can also contribute to the potential issues. Insulation breakdown, over=heating, arcing and corona effects can result. You cannot change the current in an inductor instantaneously and you cannot change the voltage in a capacitor instantaneously. Because of the fast risetimes, you are bordering on this area. Should you mis-commutate, trying to dump the current in the winding of the motor may result in a fly-back in excess of the insulation ratings.

# Damage from Noise .... continued

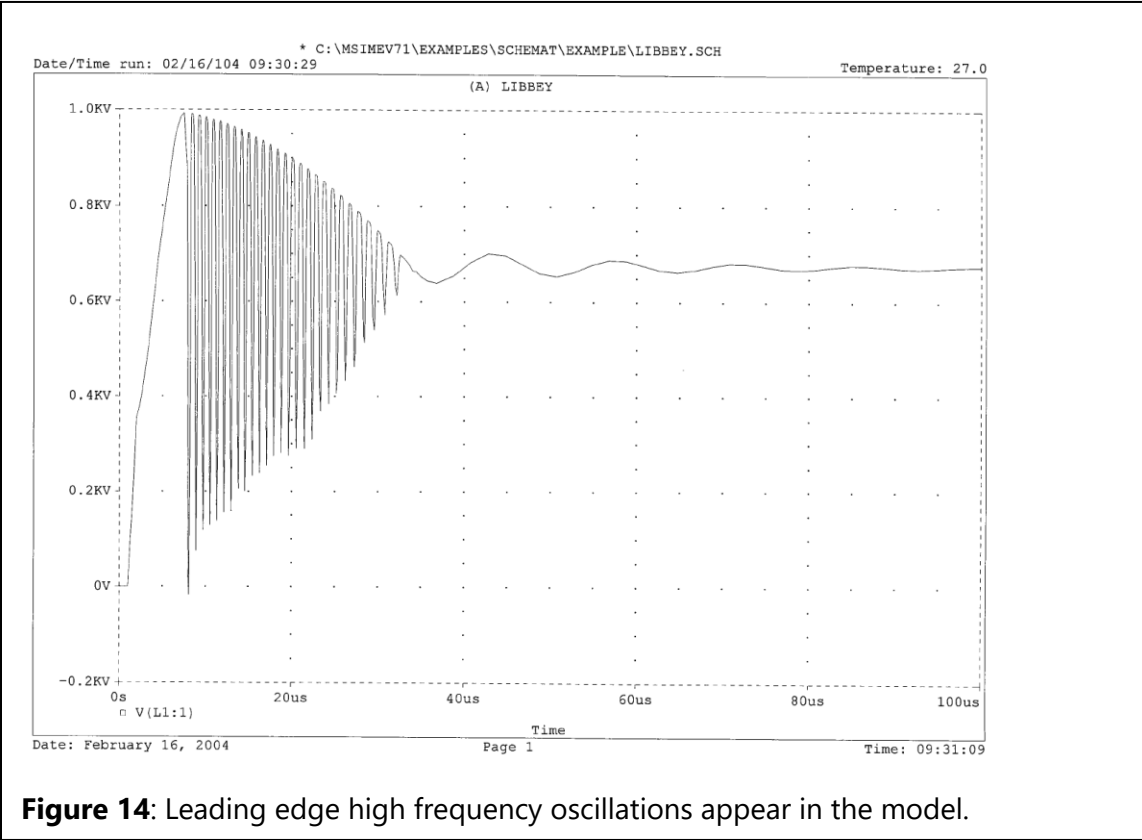
In the following figure, we have a schematic representation of a motor with a 100m cable. If you were to define long cables as anything above 25m, then you would expect to model whatever length you have accordingly. Say you have 160 to 180pf/m you would have as much as .016uF parasitic capacitance being seen by the emitter of the IGBT.



**Figure 13:** A simplified model from a simulation package that allows for voltage and current monitoring. Although this is also simplified, it has the major parasitic components. Assuming that the parasitic capacitances and resistance of both the motor and cable are accurate, a reasonably accurate result can be expected.

# Damage from Noise

The simulation results below show that the parasitic oscillation can occur because the load is putting undue stress on the emitter of the IGBT. This noise is differential and with the switching going unstable, would result in reflections and high frequency waves that could cause spurious voltage fluctuations.

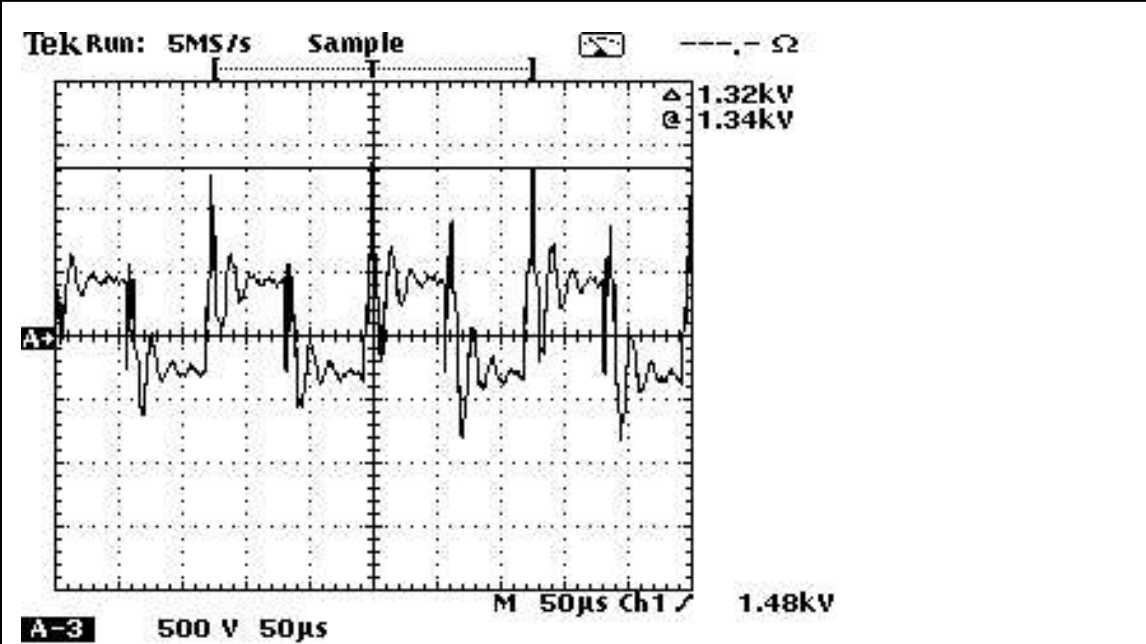


**Figure 14:** Leading edge high frequency oscillations appear in the model.

As can be seen from Figure 11, the oscillations are rising to 1000v even though the bus voltage is 680 VDC in the model. The reason is the parasitic components of the cable, motor, and drive and the rise-time of the PWM. The current loop feedback of the system is not included in this model and could further exasperate the condition. We will take this as a reasonable example of what may happen. So what does the actual signal look like that this model is made to approximate?

# Damage from Noise

Empirical measurements on the 100m system looked like this without any other components added.



**Figure15:** As can be seen, leading and falling edge oscillations nearly matching the model voltage some higher. That could be line reflection not taken in consideration in this model.

Repetitive hits at high voltages is detrimental to the motor life. Looking at the picture, it's obvious that the PWM is going to have an issue. With the voltage and current transitions looking close enough, modeling potential solutions can proceed. Differential mode inductors or perhaps a reactive filter can be used. In this case, adding some differential inductance would appear to slow the risetime sufficiently and result in reduced voltage transients.

# Damage from Noise .... continued

During the modeling, it was discovered that changing the inductance or cable capacitance would result in better performance and a reduced voltage swing. The model results and empirical results are shown below.

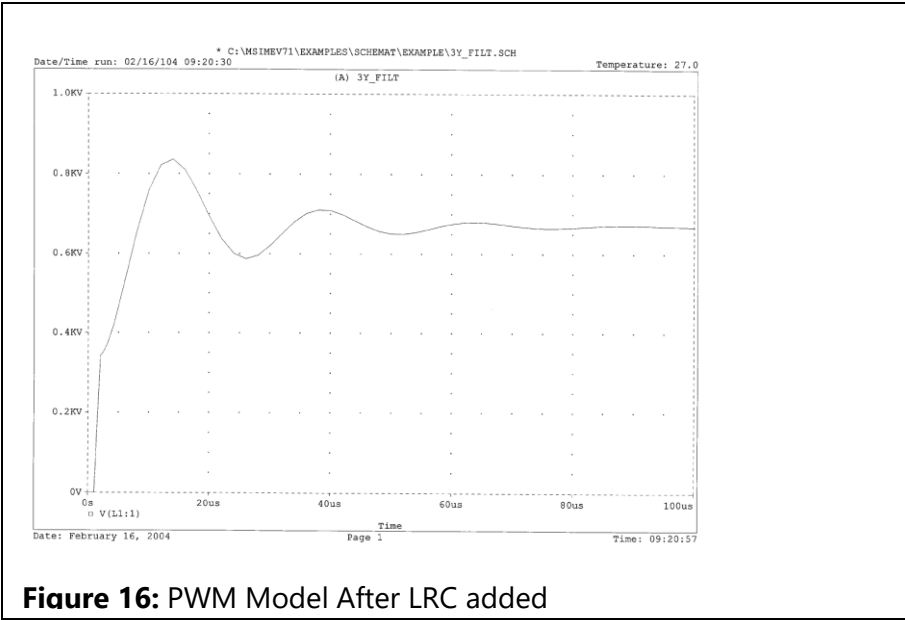


Figure 16: PWM Model After LRC added

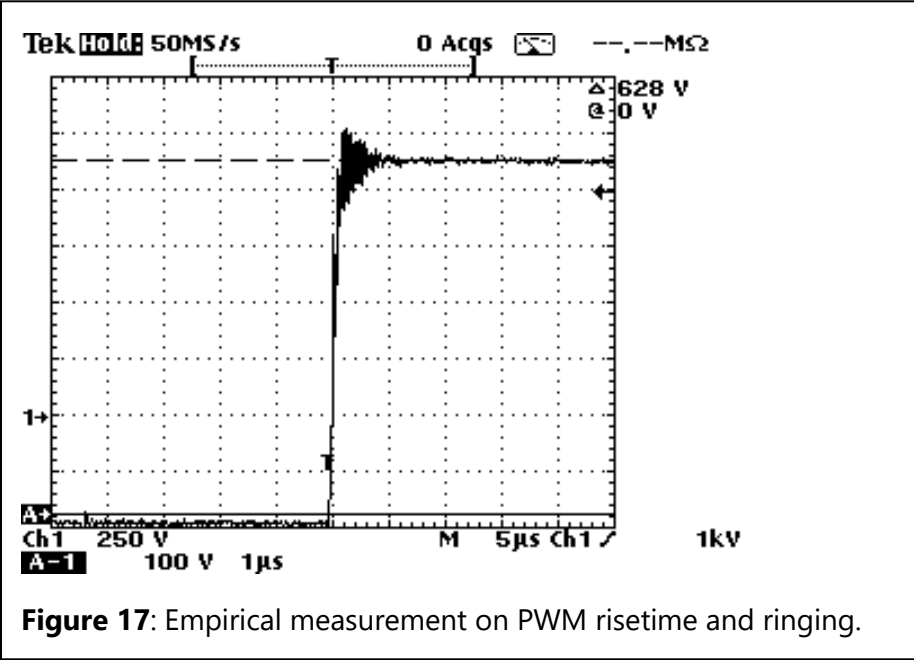


Figure 17: Empirical measurement on PWM risetime and ringing.

# Mitigation Techniques

Differential noise caused by the leading edge of the PWM ringing must be resolved by differential mode inductance. Common mode inductors do nothing for this as all of the inductance of the choke is cancelled by the opposing magnetic field in the drive.



**Figure 18:** Differential mode cores wrapped with 6 turns over Micrometals 26 powdered iron for 50uH each phase, 100uH in series.

In the case of common mode noise, the effective and accepted method is to use a common mode choke. These can consist of wrapping the three phases of the drive simultaneously around a common core. Pictured here is a Micrometals 250-26 inductor wrapped for common mode noise. Inductors of this size can handle a great deal of current. With 12 or 13 wraps, the inductance will be around 100uH in each phase in common mode. The differential measurement would be near zero.



**Figure 19:** Common mode custom inductor created with the Micrometals powdered iron cores. These or other cores are commonly used for HF noise on the shield caused by common mode noise creating stray currents on the long cables and transmitting magnetically into the surrounding systems.



# Mitigation Techniques – Off the Shelf

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## MTE Corporation products



**Figure 20:** Three phase common mode choke

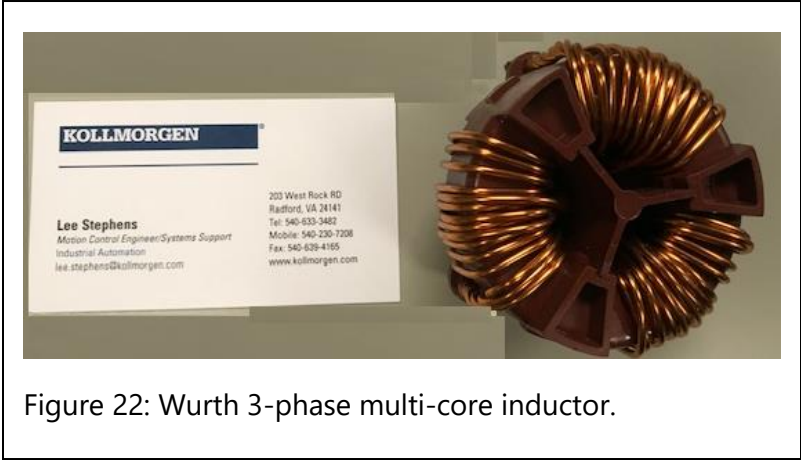
## Kollmorgen 3YL-XX



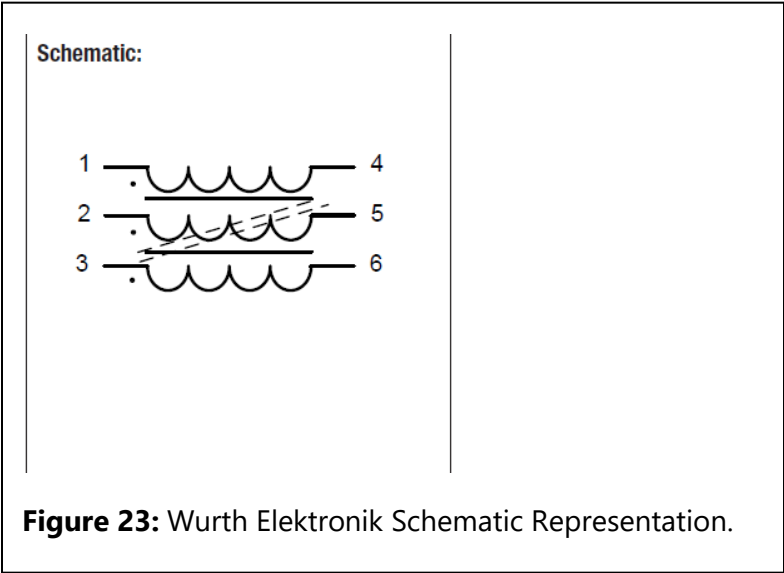
**Figure 21:** Kollmorgen 3YL-20

# Mitigation Techniques – Off the Shelf

## Würth Elektronik



This inductor has both differential and common mode inductance due to the special construction. Note that in the case of common mode noise, a common mode choke is effective but with differential mode noise, a common mode inductor is not effective. The converse however is that a differential mode choke may help with common mode noise due to the fact that the risetime being attenuated will attenuate the coupling factor of the noise. Note the schematic has a diagonal dashed line across the three inductors indicating a complex core.



# Conclusions

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- EMI Noise is not just a phenomenon causing faults, it can cause damage.
- Attacking the grounding and shielding of systems is the first step in mitigation.
- Do not ignore cable lengths shorter than 25m. There can be motor and drive combinations that can cause higher than expected common mode or differential mode noise.
- A common mode choke will do nothing to attenuate differential mode noise.
- A differential mode choke may help reduce common mode noise though perhaps not the most efficient method.
- Standing waves can add more to the ringing of the PWM, effectively doubling and tripling the voltages.
- Inductance is the main method for compensating for parasitic capacitance in the servo system which includes the motor and drive.
- Since the capacitance of a motor is not one of the specified parameters, variances may be unknown. Empirical measurement of the noise is necessary.

## Ref:

- Grounding and Shielding of Existing Equipment – L. Stephens
- Eliminating EMI in Control Systems – Machine Design au: L. Stephens
- Understanding and Eliminating EMI in Microcontroller – Texas Instruments
- Shielded Cables Tame Servo System EMI – Control Engineering – L. Stephens
- Noise Reduction Techniques in Electronic Systems (2<sup>nd</sup> Edition) - Ott