1

Isolation, Grounding, and Protection

Identifying the Myths and Confusion

Paul Nylander, imc DataWorks, LLC

Franz Hillenbrand, imc Meßsysteme GmbH

www.imcDataWorks.com

2

Abstract

Isolation pertains to how an external sensor is electrically connected to a data recording system. It is commonly used to solve grounding problems and to provide protection to the input amplifiers (the "front end"), but neither of these are a correct use, and in some cases if not handled correctly, isolation can lead to unexpected behaviors.

In this seminar we will talk about how front end isolation works in multi-channel systems, and it's proper use in dealing with common-mode problems (common-mode = voltage reference difference between a sensor and the measurement system). A field experience based (practical) approach to solving grounding, common mode, and protection problems will be discussed.

Appropriate for test engineers involved in in-vehicle testing, as well as anyone in vehicle sub-system instrumentation and testing.

imc offers both isolated and non-isolated front end amplifiers in both the CRONOS-PL and CANSAS products. All SPARTAN inputs are isolated.

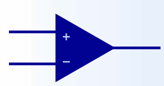
www.imcDataWorks.com

Goals for this session

Explain...

- What is an isolated system?
- Why is isolation useful?
- Where is isolation often unnecessarily used?

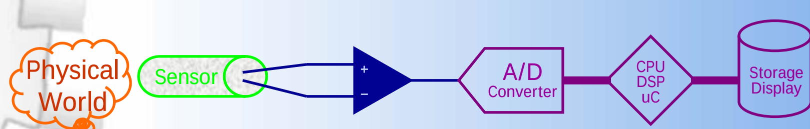
Symbols and Terms



An Amplifier

Can be configured as buffer (1:1), step-up, step down, and/or filter

The amplifier(s) is/are the key component of any instrument's front end

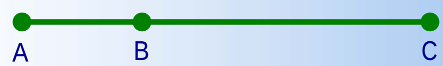


Front end: bandwidth, linearity, impedance, noise, isolation, ...
All influence our ultimate goal: a voltage measurement

Why "+" and "-" inputs?

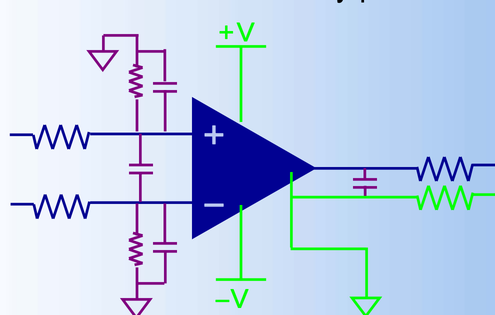
- Voltage is a Potential Difference!
- Potential difference means a measurement ALWAYS takes place between two points

- Voltages are cumulative: If from A to B is 5 V; and from B to C is 2 V; then from A to C is 7 V.



But in a real world...

- Amplifiers need power and connection to ground
- Every wire has some resistance
- Capacitance exists between every pair of elements



But in a real world...

We often ignore these real world effects

- Effects are often small enough to ignore
- Or just to simplify the discussion

Nevertheless, these real effects have an influence on

(and challenge our simplifying assumptions of...)

- Design
- Operation

www.imcDataWorks.com

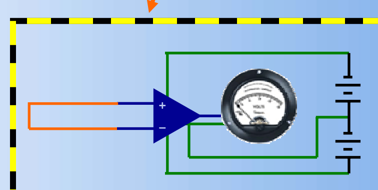
7

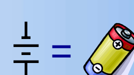
"Ideal" Measurement System

<u>Natural Isolation</u>

- Battery operated
- Single Channel
- Non-conductive case
- Measurement probe isolated from system being measured

Entire System is self contained (Isolated)



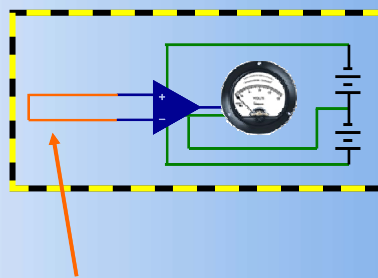


www.imcDataWorks.com

8

"Ideal" Measurement System

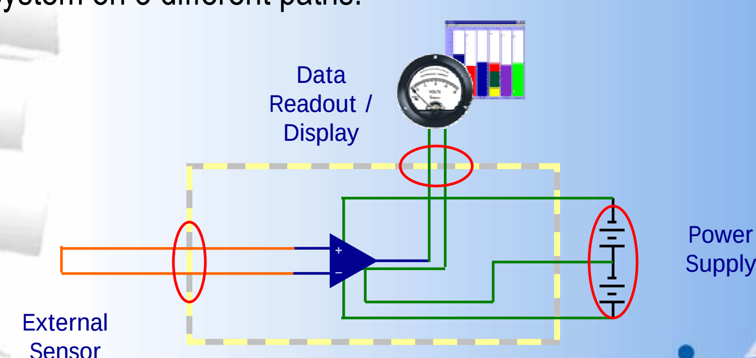
- System is self contained
- No electrical path into, or out of the system
- "Isolated" sensors:
  - thermocouple probes
  - mylar backed strain gauges
- Energy is still exchanged (otherwise we wouldn't be measuring anything!)



E.g. Current Loop = Transformer: Magnetically coupled

Isolation Challenges

What is "the system"? Connections can violate the isolated system on 3 different paths:



Isolation Challenges

- Data Display: PC or Network Connection – own ground
- Power Supply: External AC, Shared DC Source – own ground
- Sensor: external sensor with exposed reference point – own ground

Only one of these 3 external connections can provide

The Reference Point

The Reference Point

What happens if 2 (or all 3) are at different potentials?

- Current flows between references
- Current is (basically) limited only by the wire resistance
- Ohm's Law: V = I R
- Current continues until potentials are equal

So what? This potential difference can

- corrupt the signal
- damage the system

13

Measurements Applied

Common Approach

- Define power supply reference to be the True Reference →The Ground
- Measurement is referenced to the power supply ground
- (For now we ignore the data display)
- Often used as the output of a signal conditioner rack or a 3-wire "active" sensor

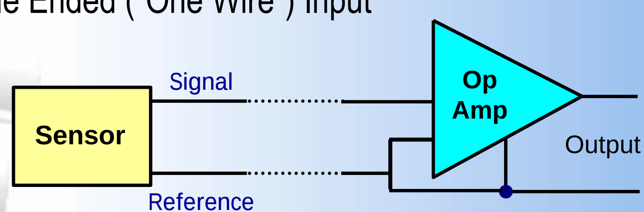
➔ Known as a single ended input

www.imcDataWorks.com

14

Input Types Defined

Single Ended ("One Wire") Input

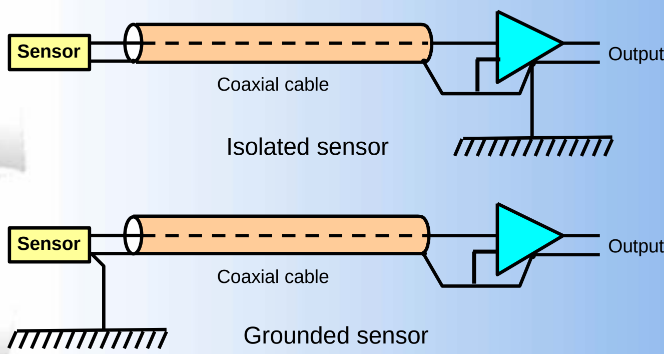


Singled-ended – "Operational Amplifier" Input

But watch out! The Sensor and Measurement references may be different!

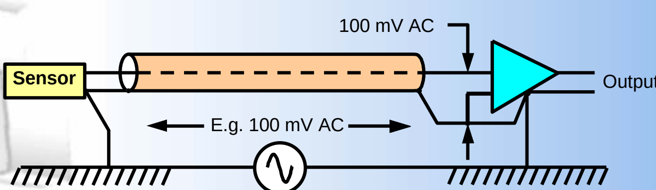
www.imcDataWorks.com

Single Ended at Work

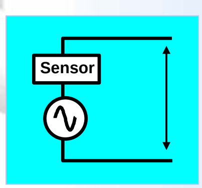


For best results, a single-ended channel should be grounded *only at one end.*

Danger of Single Ended



Grounded sensor *and* input



What the amplifier "sees”

This “ground loop” picks up this difference – directly influence your signal!

Reference Differences

Reference Potentials can be different for many reasons

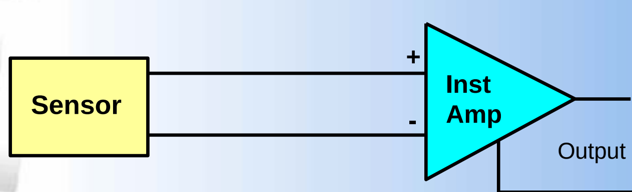
- Spatial loading differences
- Voltage source (battery, generator, ...)
- Electromagnetic pickup
- Inductive Loading

These differences can be static or time dependent, and can range over several orders of magnitude

A Solution to Differences

Differential Input [Diagram]

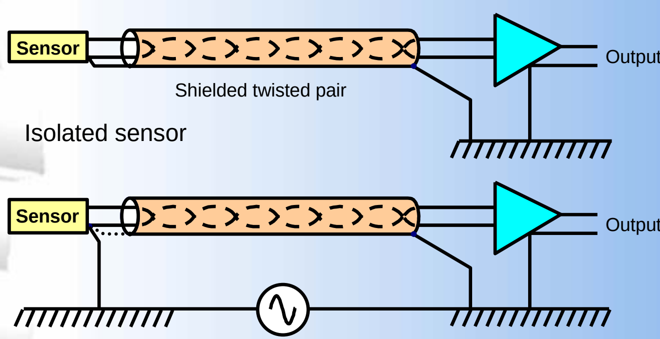
- Signal = difference between “+” and “–” inputs
- Independent of amplifier – sensor reference differences



Differential - Instrumentation Amplifier Input

19

Differential Inputs and Ground



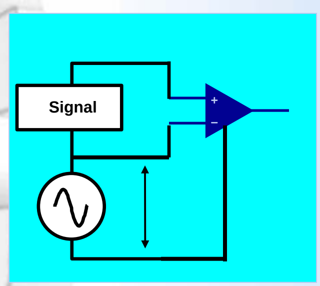
No problems!

Differential Amplifier avoid the ground loop because of the high impedance (to ground) of the differential input.

www.imcDataWorks.com

20

Common Mode



Common Mode

Voltage on both "+" and "–" inputs relative to DAS ground. All differential inputs have an upper limit to this common mode difference.

CMRR – the common mode rejection ratio – is commonly used in conjunction with the common mode range to indicate the ability of an amplifier to suppress influences from common mode, input to ground potential differences.

Example: thermocouple atop a 1000V battery; or measurement of voltage and current (via shunt) on an electric motor

www.imcDataWorks.com

Differential Inputs

What have we accomplished?

- Eliminated current flow between reference potentials, effectively isolating the sensor from the measurement system
- Eliminated the effects of the common mode potential difference on the measured signal

But amplifier common mode typically limited to $\pm V_{amplifier}$

- What if we need more?

Limitations on Differential Measurements

Amplifier Common Mode Range:

- Defines the maximum common mode which can exist at the amplifier inputs without causing signal corruption.
- Typically quoted only for one frequency (e.g. 60 Hz), but depends on (and decreases with) frequency.
- For static signals, common mode range ≤ supply rails

How do we increase the common mode range?

www.imcDataWorks.com

Isolation Revisited

Isolated Measurement implies:

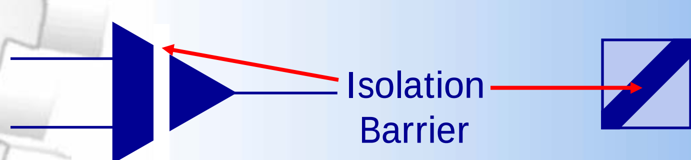
the reference of the measurement can be connected to another arbitrary reference (e.g. sensor reference) without implying current flow (references are floating)

Isolation Voltage: Threshold below which no electrical current path exists; ideally this is the common mode range

Isolation is achieved two ways

Isolated Sensor – the sensing element is not electrically contacting the thing being measured.

Isolation amplifier – input is electrically disconnected from the rest of the measurement system



25

Common Isolation Methods

Capacitive?

- Both "+" and "–" leads must be "AC coupled"; no DC measurement possible
- Not *really* isolated:
  - Isolation broken for all but DC measurements
- less than ideal for most situations with physical speed measurements (10 Hz – 1 kHz)

www.imcDataWorks.com

26

Common Isolation Methods

Why not RF?

- analog transfer, even over long distances.
- But because RF signal must be generated, and signal must be conditioned to produce radio signal, a power supply is necessary
  - HF Carrier must be generated
  - Very low power transfer; amplitude distortions likely
  - Shifts the problem, doesn't solve it (except for battery)
- Only solves problem of data transfer isolation

www.imcDataWorks.com

Common Isolation Methods

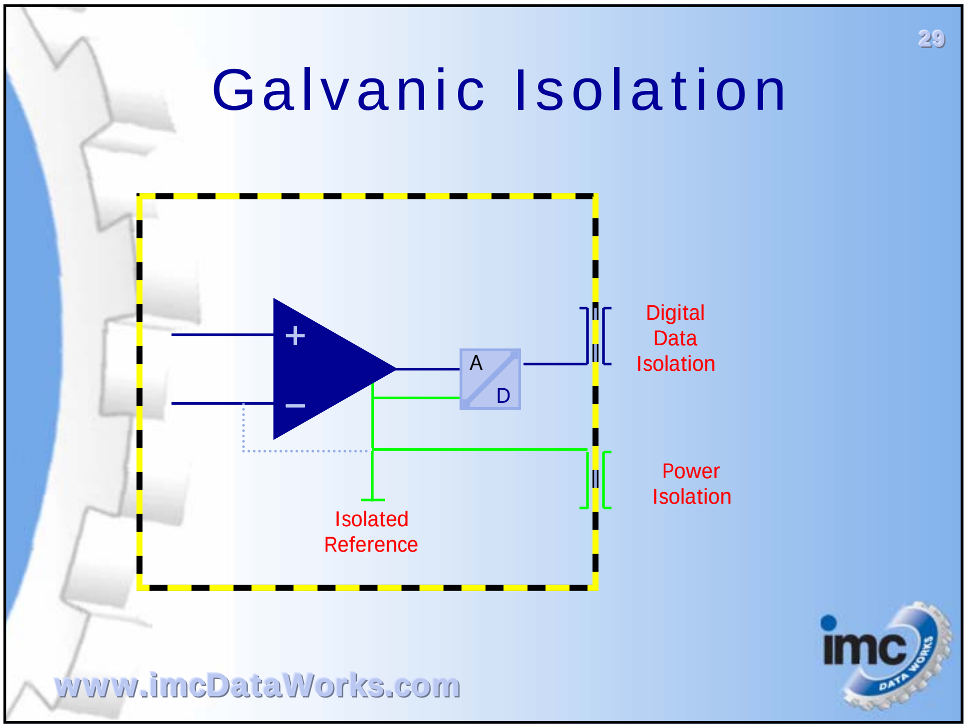
Optical – analog LED and photo receptor pairing.

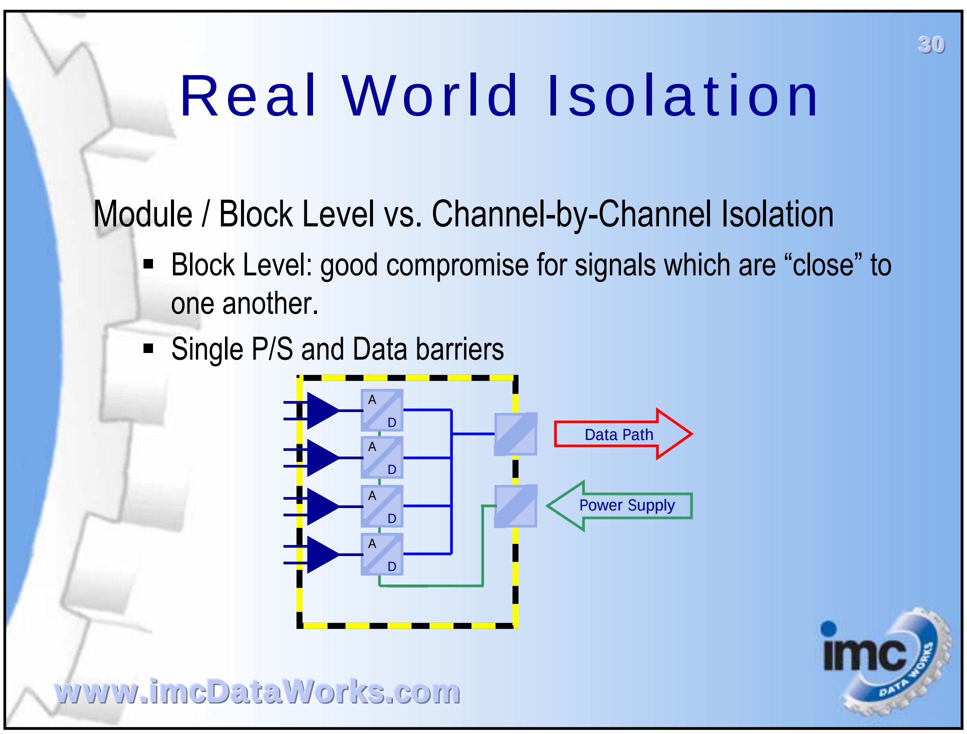
- Can be used without modulation
  - But requires much more power, especially at high frequency
- Best used for digital or threshold-only types of signals
  - Amplitude unstable with varying temperature
  - Optical efficiency very poor compared to other methods
  - Still requires isolated power – usually magnetic
- Typically more expensive than galvanic

Common Isolation Methods

Galvanic (transformer)

- Magnetic but not electric coupling.
- Transformers commonly used for isolation in audio amplifiers, network interface, power supplies, etc.
  - o Stray capacitance can be kept low
  - o Bulky compared to other methods
    - – core saturation limits size
  - o Higher voltage isolation can be reached (air gap → bulk)
  - o Requires modulation to transfer ~static analog signals
    - – perform digitization first!


29
Galvanic Isolation
+
–
A
D
Digital
Data
Isolation
Power
Isolation
Isolated
Reference
www.imcDataWorks.com
imc
DATA WORKS

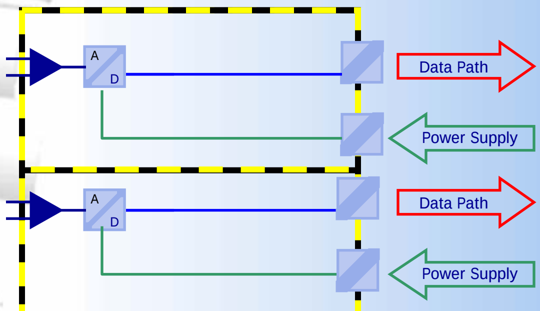

30
Real World Isolation
Module / Block Level vs. Channel-by-Channel Isolation
▪ Block Level: good compromise for signals which are "close" to one another.
▪ Single P/S and Data barriers
A
D
A
D
A
D
A
D
Data Path
Power Supply
www.imcDataWorks.com
imc
DATA WORKS

31

Real World Isolation

Module / Block Level vs. Channel-by-Channel Isolation

- C-by-C is the most expensive, but most effective



32

Is Isolation Ever Bad?

Isolated inputs are physically larger, require more circuitry = more power, more heat. Connectors must be chosen to meet the isolation requirements as well = larger and more expensive connectors.

- Think about this next time you wonder why you data acquisition system cannot be shrunk down to the size of your cell phone…

The "double isolation" problem: revisit differential inputs and grounding. An isolated sensor on an isolated input has NO reference value – it floats. Because it is floating, the common mode voltage (difference between data systems ground reference and that of the object of interest) can exceed the common mode range of even an isolated input.

33

Limitations of Isolation

- Every isolation barrier has a practical limit – a breakdown voltage – beyond which the isolation fails.
- Parasitic Capacitance can lead to high frequency common mode effects, well below isolation voltage limit
  - Suppressed with help of low pass filter

www.imcDataWorks.com

38

Aside: Isolation Classes

IEC takes into account that voltages higher than the nominal maximum isolation voltage can occur.

Classes (1 = weakest, 2, 3, 4...) refer to the level of isolation voltage which does not cause damage in a certain environment

Designed to aid in human safety in dangerous environments

E.g. 600 V Class 3 ➔ 5.2 kV (3.7 kV RMS) maximum voltage for at least 1 minute

www.imcDataWorks.com

39

What isolation is, and is not

Isolation increases common mode range of an amplifier, but it doesn't say anything about the maximum input voltage

By itself, isolation does not give the input amplifier any better range or protection

In particular, an overdriven channel's effect on other channels can be contained without resorting to isolation.

www.imcDataWorks.com

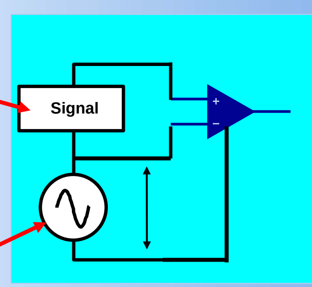
40

Protection vs. Isolation

An overvoltage across signal input

has

Nothing to do with the common mode isolation solution



www.imcDataWorks.com

41

Protection Scheme

Typically an inline resistor (or dual FET transistor input), with diodes to +V and –V (Supplies)

- Voltages beyond rail voltage +/- one diode drop will flow to the respective leg.
- Protection limits are resistive power dissipation (typ. 60V on 5k), or transistor breakdown voltages (200 – 500V)

42

Protection vs. Isolation

When isolation is ok, but doesn't really help or is overkill: over voltage protection, transient voltage spikes

- Protection methods: fuse, breakers, resettable fuses, protection diodes
- Protection from miswiring / short circuit through inputs, etc.

Why do you care? Input protection is often less expensive, less bulky, less power hungry, and less likely to influence the accuracy of your measurement.

43

Summary

- Many testing challenges can be solved with differential inputs and input protection, and do not require isolation
- Isolation does help with high common mode and ground reference issues found in non-isolated inputs... But be careful!
- “Double” Isolation can lead to problems due to the floating common mode reference across the isolation barrier
- High frequency common mode may not be suppressed due to parasitic capacitances, even well below isolation threshold
- Input protection is often incorrectly referred to as isolation, but is actually easier to use and implement.

www.imcDataWorks.com