Coreless Clip-On & Clamp-On Current Probes for Test Stand & In-Vehicle Current Monitoring

GMW Associates

Presented by:

Ian J. Walker
Senior Applications Engineer
GMW Associates
ian@gmw.com

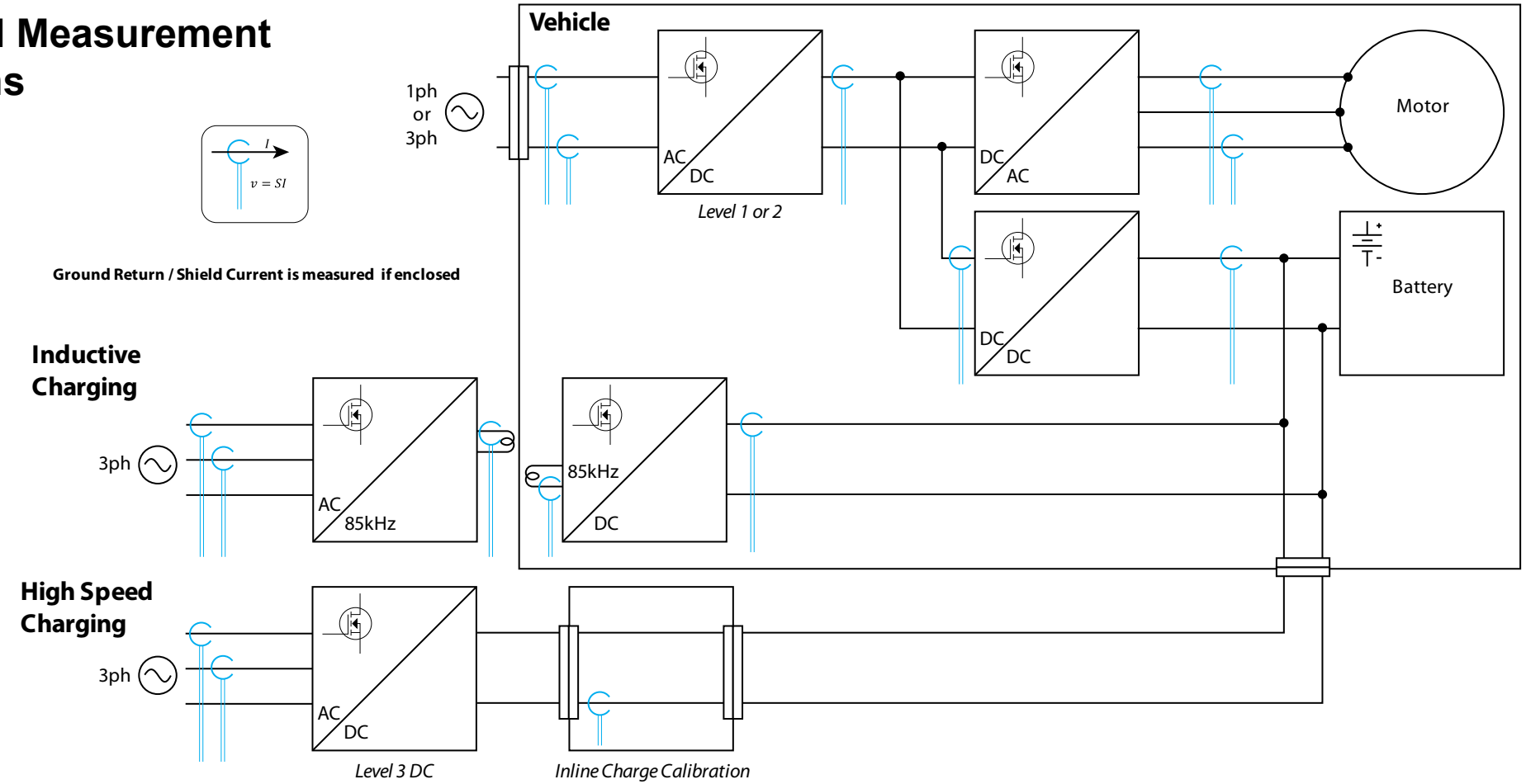
Overview & Specifications

Coreless Clip-On & Clamp-On Current Probes

GMW Associates

Coreless Clip-On & Clamp-On Current Probes

Potential Measurement Locations



Coreless Clip-On & Clamp-On Current Probes

The potential locations for current measurement in a modern electric or hybrid vehicle are difficult to access.

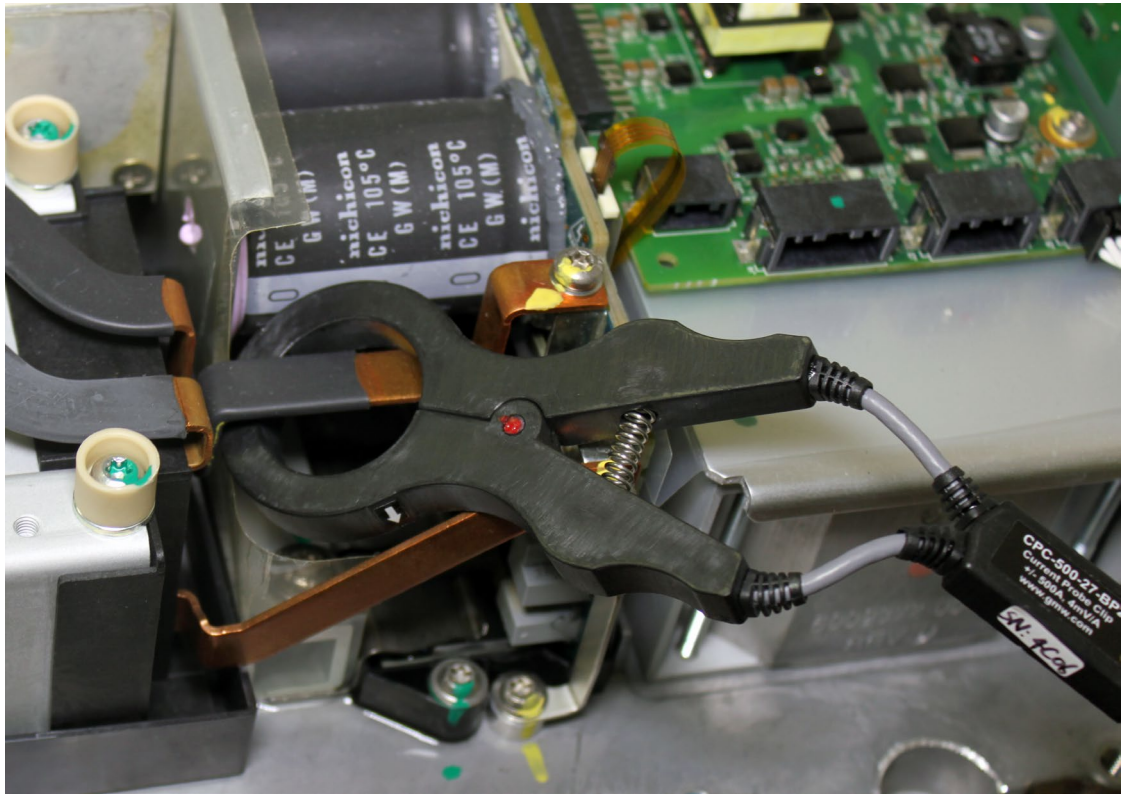
A Clamp-On Current Probe designed for safe, Hand-Held current measurements is typically large and will not withstand vibration, moisture/ice, or temperature cycling from -40°C to +85°C.

Coreless Clip-On & Clamp-On Current Probes

GMW CPC Clip-On DC-AC Current Probes
Current probes with no magnetic core and current ranges from ±250A to ±2000A.

No hysteresis, no damage from primary current overload with recovery to linear operation within 10 µs of primary current within range. The CPC Current Probe can be used to monitor the “low current” recovery after a high current overload.

27mm Aperture Clip-on Current Probe



Small size enables installation in difficult locations

GMW Associates

Coreless Clip-On & Clamp-On Current Probes

Specifications: GMW CPC Clip-On DC-AC Current Probes

Signal Output	0±2V
Current Sensitivity	8mV/A to 1mV/A
Current Ranges	±250A, ±500A, ±1000A, ±2000A
Frequency Range	DC to 75kHz (-3dB)
Sensitivity Error	<±1%
Output Change, Magnetic Field	<0.2% of range for 40mT(1)
Response Time	<2µs
Insertion Impedance	<1pH
Operating Temperature	-40°C to +100°C
Moisture Resistance	Sealed, NEMA 5
Aperture	27mm (1.06”)
Mass	<30g (1 oz)
Power Supply	3.5V to 5.5V, <85mA, USB Port

(1) A current of 10kA generates a field of 40mT at a radius of 0.05m (~2”).

Coreless Clip-On & Clamp-On Current Probes

GMW CPCO Clamp-On DC-AC Current Probes
Large aperture Current Probes with no magnetic core and current ranges from ±500A to ±16kA. Suitable for earth moving, marine and aerospace high current applications.

77mm (3.03”) or 160mm (6.3”) aperture with a full 180° opening short 19mm (0.75”) axial length enables installation on cables or bus bars with close spacing.

Small cross-section and sealed enclosure enables long-term, reliable operation in harsh environments.

GMW Associates

Coreless Clip-On & Clamp-On Current Probes

Specifications: GMW CPCO Clamp-On DC-AC Current Probes

Signal Output Options	5V±5V, 05±5V, 0V±10V, 12mA±8mA, RMS 0-3V
Current Ranges	±500A, ±1kA, ±2kA, ±4kA, ±8kA, ±16kA
Frequency Range	DC to 40kHz (-3dB)
Sensitivity Error	<±1%
Output Change, Magnetic Field	<0.2% of range for 18mT to 267mT (range dependent) (1)
Response Time	<10µs
Insertion Impedance	<1pH
Operating Temperature	-40°C to +85°C
Moisture Resistance	Sealed, NEMA 5
Aperture	77mm (3.03”) or 160mm (6.3”)
Mass	120g (0.26 lb) or 300g (0.66 lb)
Power Supply	±11V to ±31V, <0.8W

(1) A current of 10kA generates a field of 40mT at a radius of 0.05m (~2”).

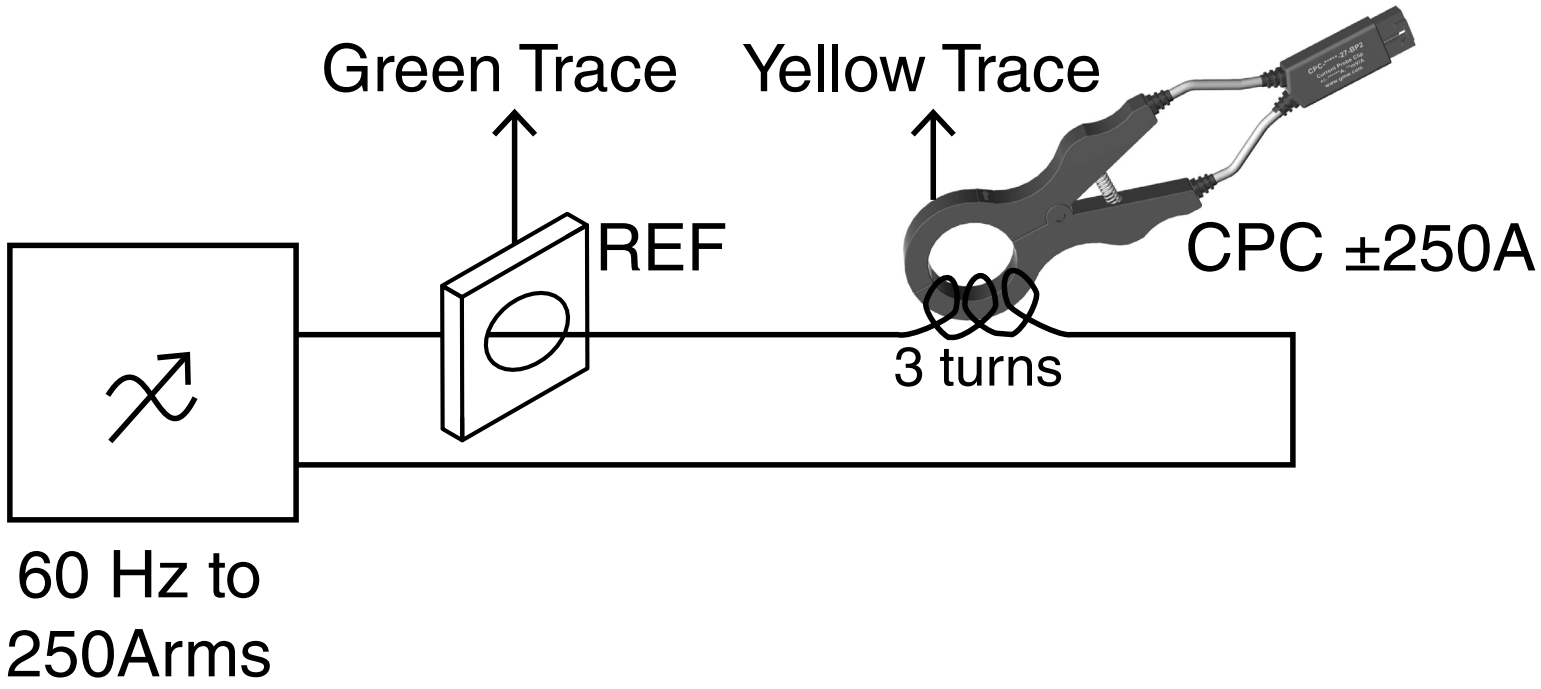
Test Data

Coreless Clip-On & Clamp-On Current Probes

GMW Associates

Coreless Clip-On & Clamp-On Current Probes

Recovery from Overload Current – Test Setup



Coreless Clip-On & Clamp-On Current Probes

With 4x primary overload current the CPC shows:

- No electrical saturation and the correct sign with no overshoot
- No ringing
- No zero-crossing phase shift after overload
- No damage

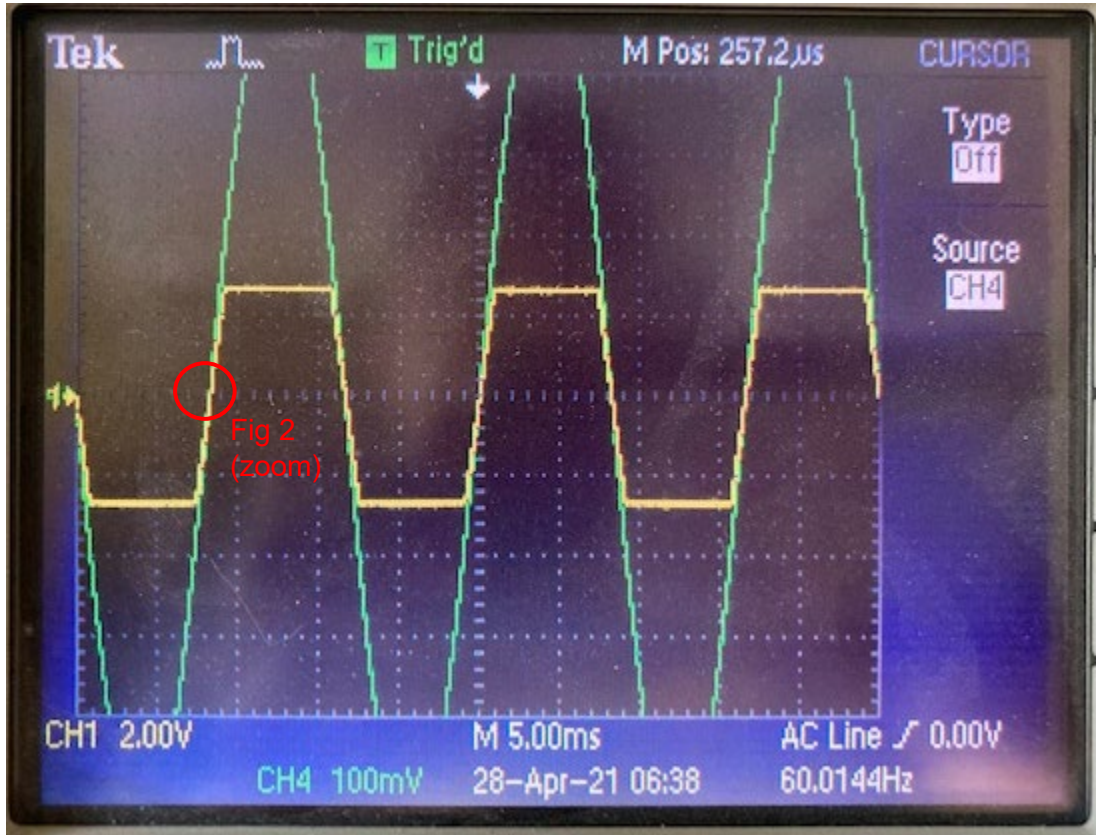


Fig 1: CPC ±250A fs with 750Arms Primary Current (yellow trace), or ±1060A. Approx. 4x full scale.

GMW Associates

Coreless Clip-On & Clamp-On Current Probes

With 4x primary overload current the CPC shows:

- No electrical saturation and the correct sign with no overshoot
- No ringing
- No zero-crossing phase shift after overload
- No damage

Fig 2: CPC ±250A fs as in Fig 1 but with high vertical sensitivity. No measurable zero crossing shift at 5µs/div.

GMW Associates

Coreless Clip-On & Clamp-On Current Probes

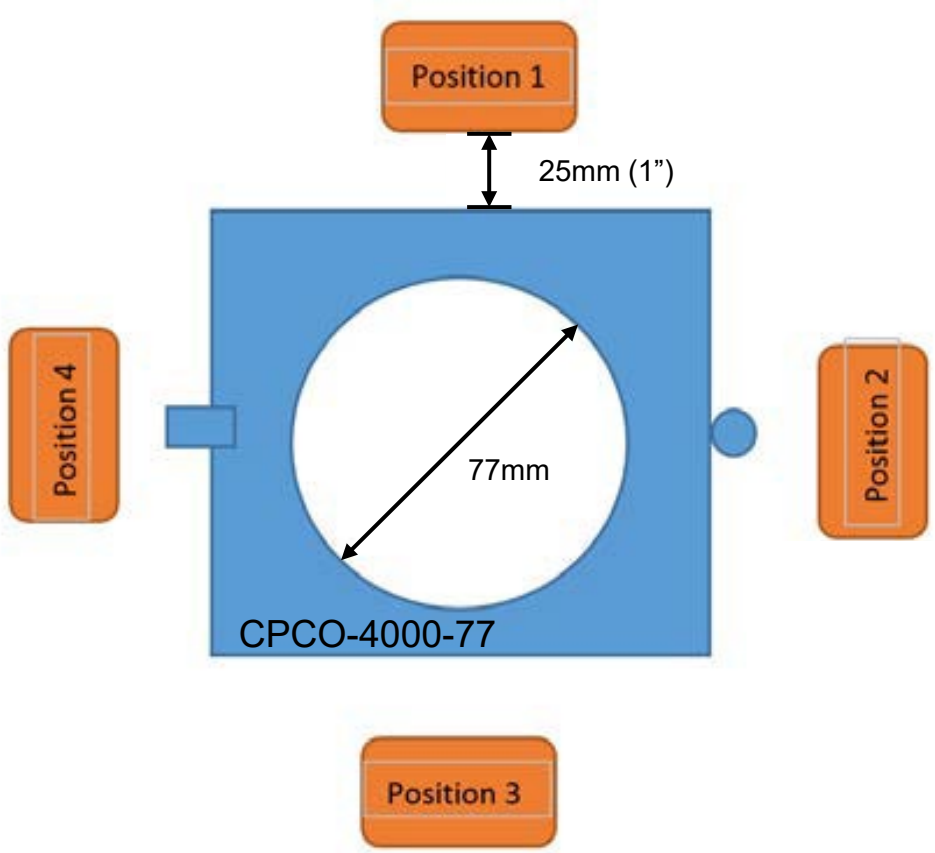
High rejection of external magnetic fields arising from external currents or steel cabinets.

Test arrangement:

- GMW CPCO-4000-77 (±4000A, 77mm aperture)
- External Conductor 1000A at 25mm from surface

Change in Zero Offset:

Position 1: 0.5% full-scale
Position 2: 0.52% full-scale
Position 3: 0.61% full-scale
Position 4: 0.25% full-scale



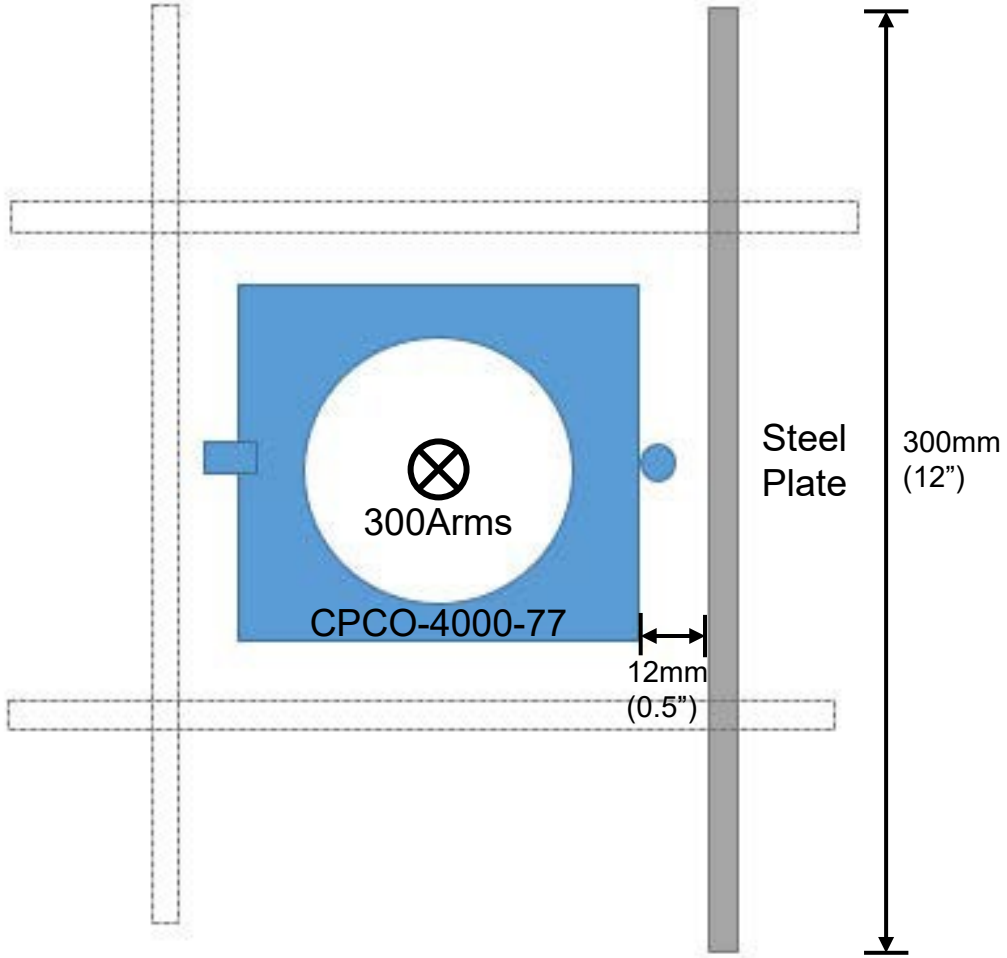
GMW Associates

Coreless Clip-On & Clamp-On Current Probes

High rejection of external magnetic fields arising from external currents or steel cabinets.

Test arrangement:
Steel place 100mm x 300mm x 6mm (4” x 12” x ¼”) placed about 12mm (0.5”) from the outer surface of the CPCO at four positions. The output signal for a 300Arms, 60Hz was measured.

The change in the output signal was <0.1% of the signal for the steel place in any position.

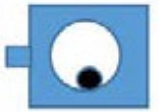
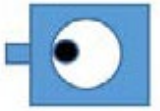
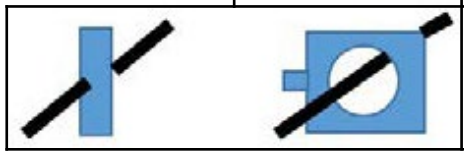


GMW Associates

Coreless Clip-On & Clamp-On Current Probes

Signal Output essentially independent of current position within aperture.

The output signal for a CPCO-4000-77 (77mm aperture) is measured for a 60Hz 230Arms current in a 10mm diameter conductor with variations in the measured current as shown.

Conductor Position	Measured Current (Arms)	Deviation (%)
	230	0.%
	228	-0.9%
	228	-0.9%
	232	0.9%
	233	1.3%
	233	1.3%

GMW Associates

Coreless Clip-On & Clamp-On Current Probes

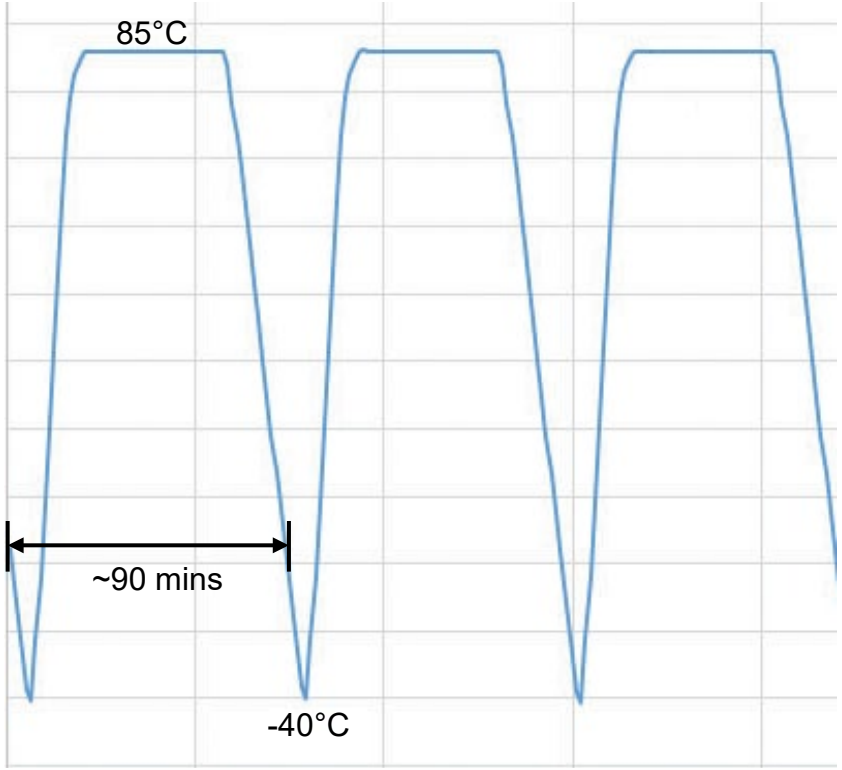
High Stability with thermal cycling.

Several different CPC and CPCO models with different current ranges have been temperature cycled for 50 cycles over 70 hours.

The maximum changes observed:

Zero Offset: ±0.2% of full-scale

Sensitivity: ±0.5%



1 cycle ~ 90 minutes, -40°C to +85°C.
Repeated for 50 cycles.

GMW Associates

Operating Principle

Coreless Clip-On & Clamp-On Current Probes

GMW Associates

Coreless Clip-On & Clamp-On Current Probes

Operating Principle:
Ampere's Circuital Law

In SI units:

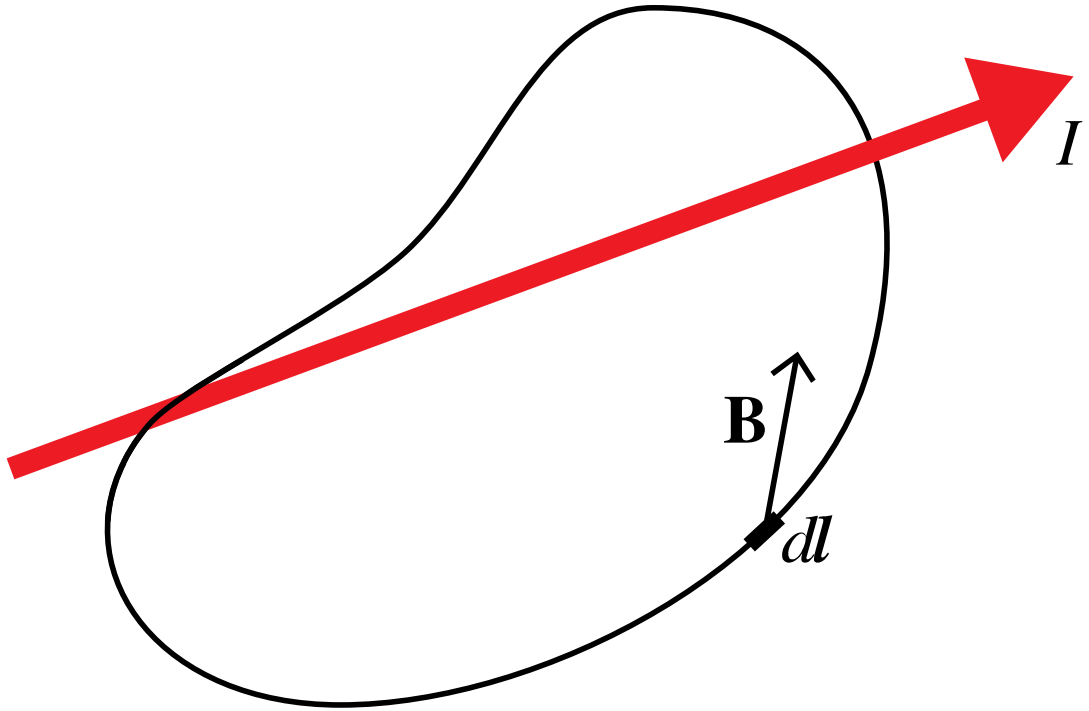
$$\oint_C \mathbf{B} \cdot \mathrm{d}\boldsymbol{l} = \mu_0 I_{enc}$$

B is the magnetic flux density in Tesla.

μ_0 is the permeability of a vacuum.

I is the current enclosed in Ampere.

Note that the line integral is independent of the position of the current.



GMW Associates

Coreless Clip-On & Clamp-On Current Probes

Operating Principle:
Ampere's Circuital Law

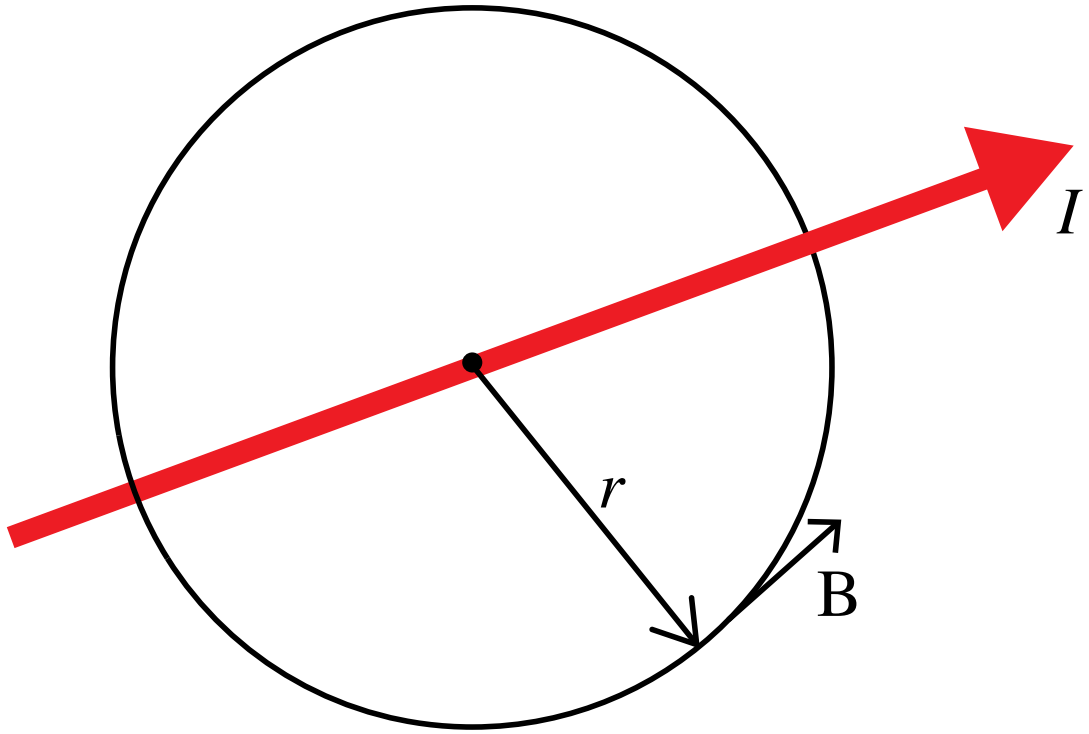
For a circle of radius r enclosing a current I with the current perpendicular to the plane of the circle, **B** is tangential to the circle at all points on the circle and the relationship becomes:

$$\mathrm{B} \cdot 2\pi r = \mu_0 I$$

or

$$I = \frac{2\pi r \mathrm{B}}{r}$$

Only in the absence of any other currents or magnetic fields can the current be determined by measuring **B** at one point.



GMW Associates

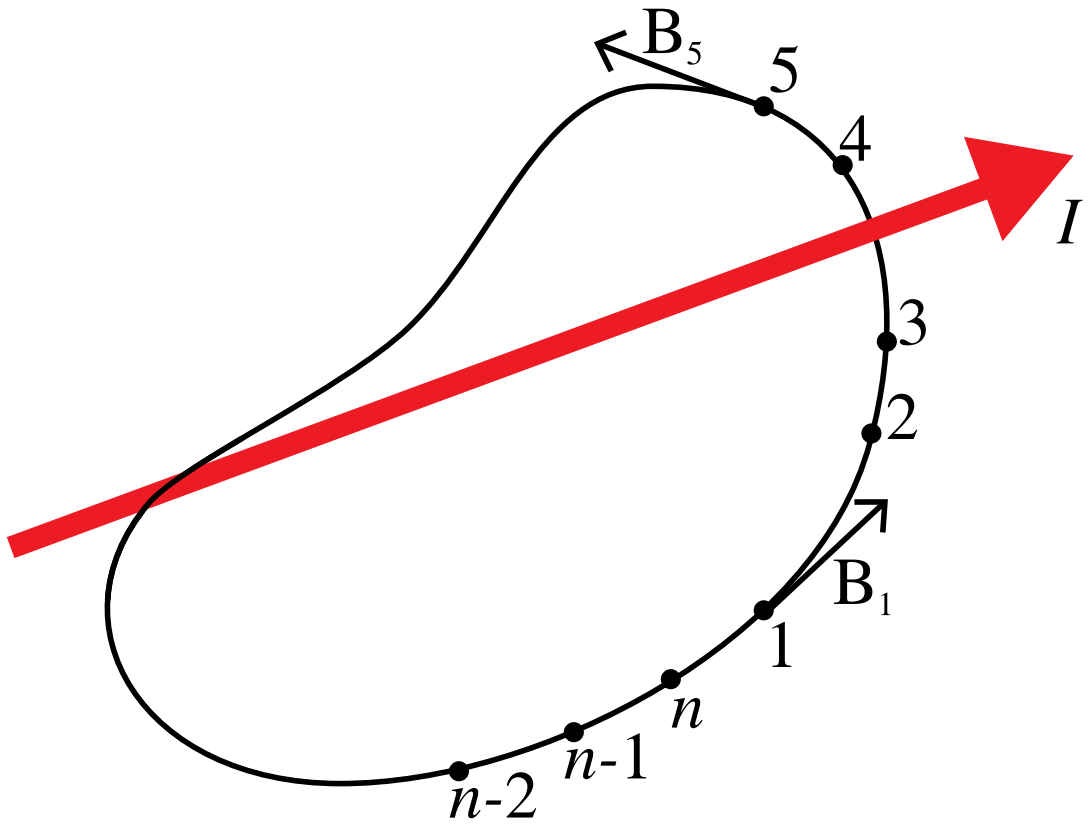
Coreless Clip-On & Clamp-On Current Probes

Approximating Ampere's Circuital Law with a Summation instead of a Line Integral

For "point" magnetic sensors providing an output signal proportional to **B**, the Line Integral can be approximated by a summation:

$$I = \frac{1}{\mu_0}\int \mathbf{B}\cdot d\boldsymbol{l} \sim \frac{1}{\mu_0}\sum_{r=1}^{n} C_r \cdot B_r$$

Where B_r is the field component along the tangent to the enclosing line and C_r are constants that can be determined by magnetic modeling.



GMW Associates

Coreless Clip-On & Clamp-On Current Probes

Approximating Ampere's Circuital Law with a Summation instead of a Line Integral

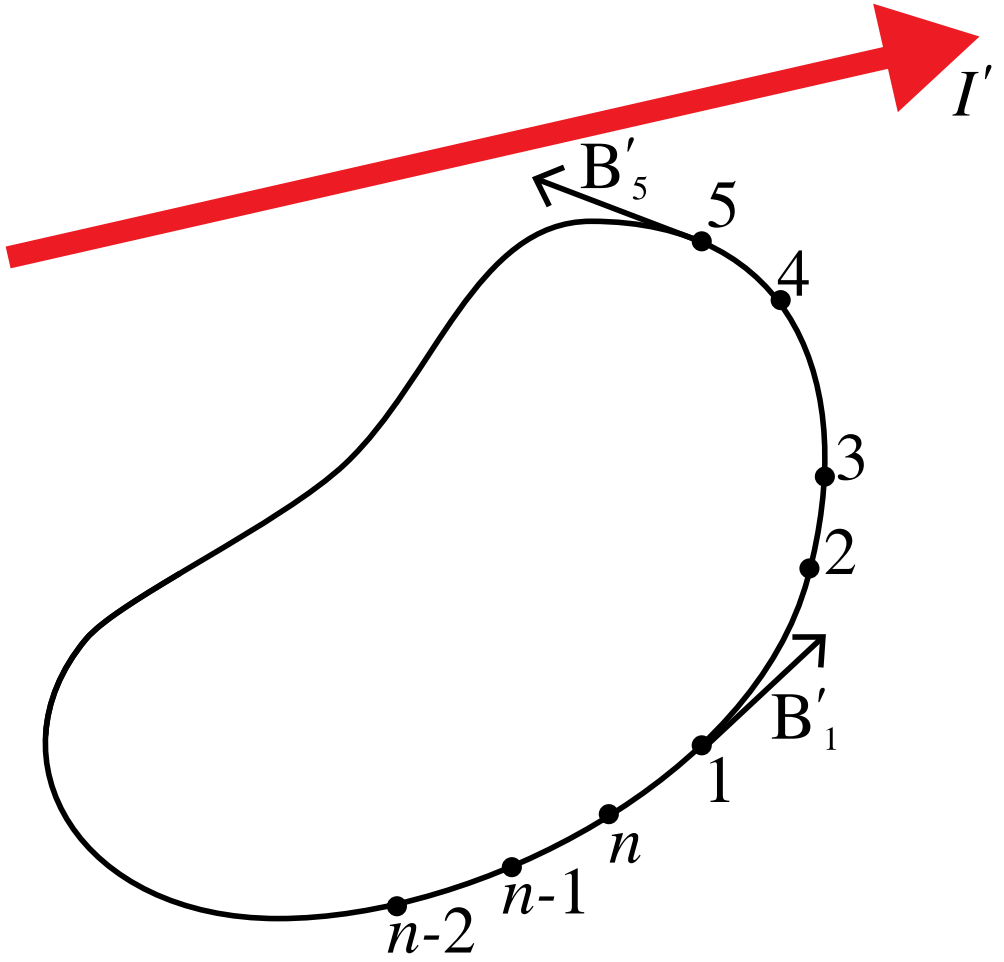
For a current I' outside the loop:

$$\frac{1}{\mu_0}\int \mathbf{B}' \cdot d\boldsymbol{l} = 0$$

and

$$\frac{1}{\mu_0}\sum_{r=1}^{n} C_r \cdot B'_r \sim 0$$

External currents and magnetic fields are rejected by the summation approximation.



US Patents: 9952257, 10690701
European Patent: 2972425

GMW Associates

Coreless Clip-On & Clamp-On Current Probes

Ampere's Circuital Law applies to any closed line. The CSS-SO DC/AC "Slip-on" Current Probe can measure the current of any shape conductor that can fit within the open U-shape.

Signal Output	0±2V
Current Sensitivity	4mV/A to 0.166mV/A
Current Ranges	±400A, ±1kA, ±2kA, ±4kA, ±8kA, ±12kA
Frequency Range	DC to 1kHz (-3dB)
Sensitivity Error	<±1%
Response Time	<2µs
Insertion Impedance	<1pH
Operating Temperature	-40°C to +85°C
Moisture Resistance	Sealed, NEMA5
Aperture, U-shape	102mm x 30.2mm (4.0" x 1.2")
Mass	<65g (2.3 oz)
Power Supply	3.5V to 5.5V, 150mA, USB Port

A U-shape, "Slip-On" Current Sensor with a relatively narrow opening works well.

CSS-SO-xxxx-BP2

GMW Associates

Thank You!

Ian Walker

ian@gmw.com

www.gmw.com

(650) 240-1134

GMW Associates

Current Measurement for Electric Vehicle Charger Test

GMW Associates

Presented by:

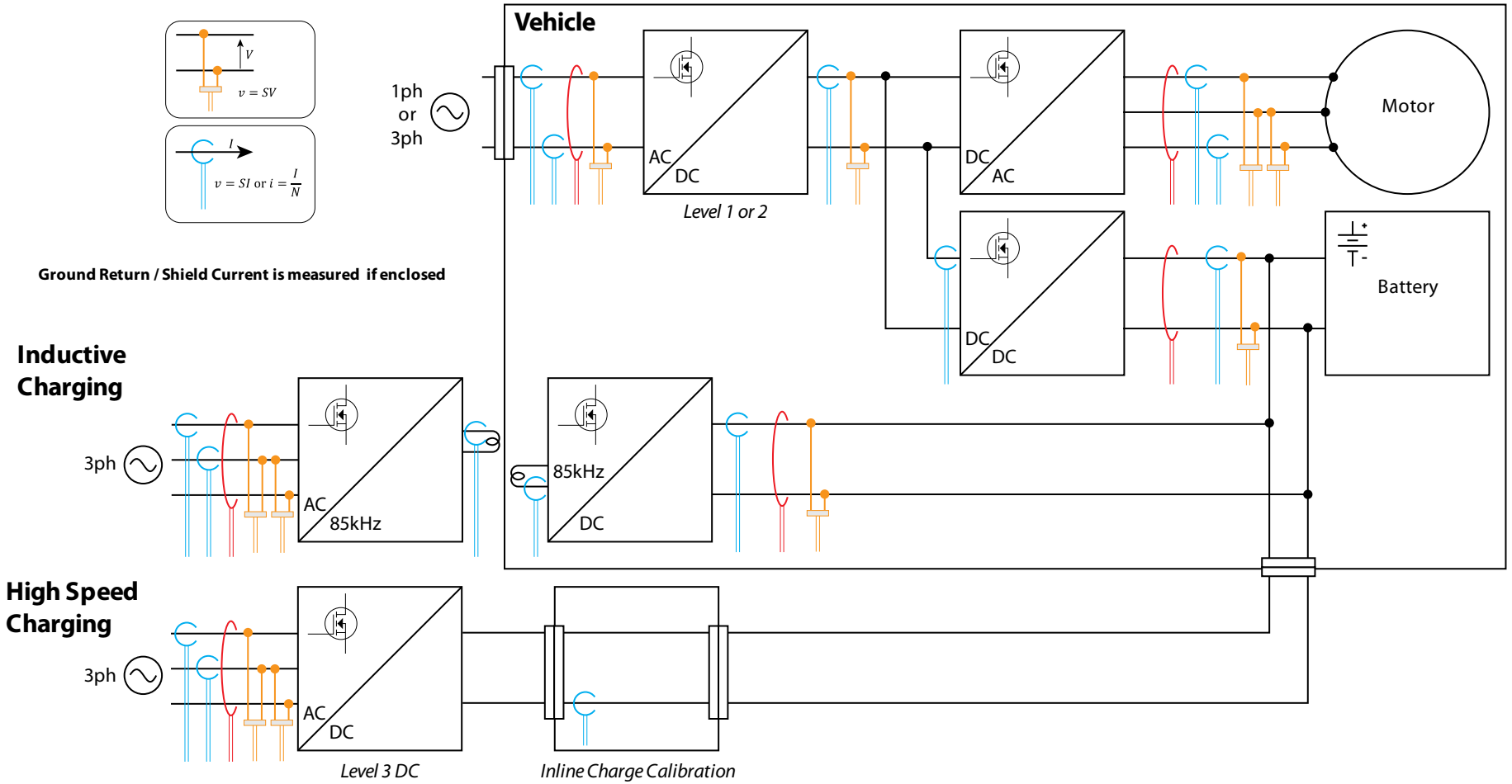
Ben Hartzell
VP Marketing
GMW Associates
ben@gmw.com

Overview

Current Probe Connections in Electric Vehicle Chargers

GMW Associates

Current Probe Connections in Electric Vehicle Chargers



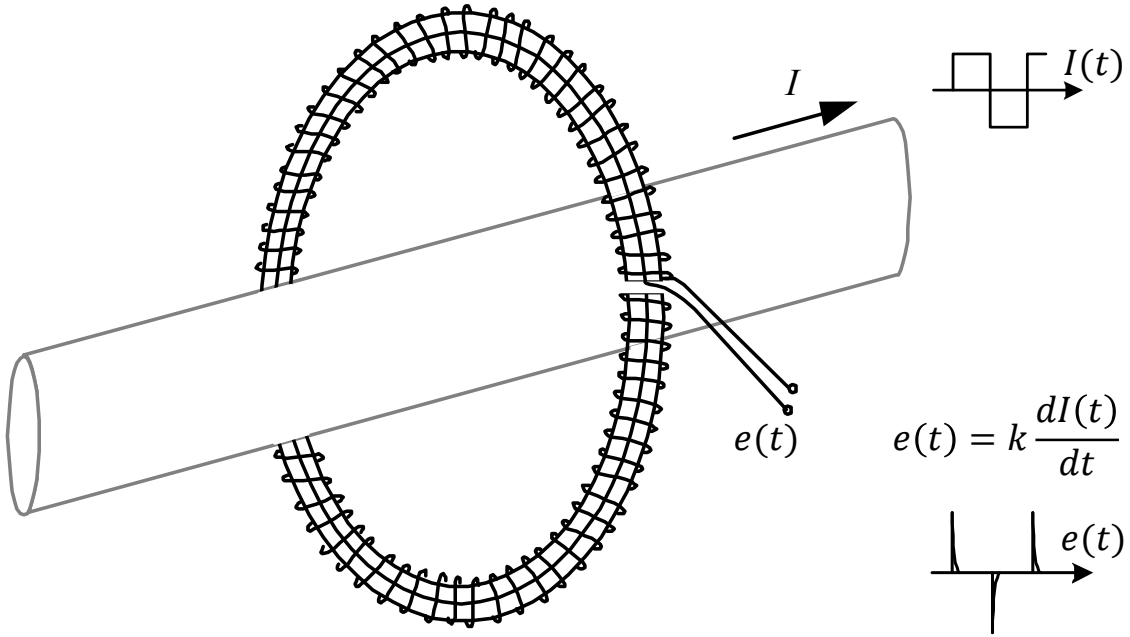
GMW Associates

PEM Rogowski Coils

Flexible, Clip-around AC Current Probes with Analog Integrator

GMW Associates

PEM Flexible, Clip-around AC Current Probes
Rogowski Coil with Analog Integrator

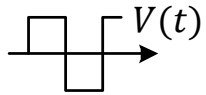


Rogowski Coil with no magnetic core

Current Sensitivity (S):	200mV/A to 0.02mV/A
Current Range:	±30A to ±300kA
Frequency Range:	0.03Hz to 50MHz
Amplitude Accuracy:	~±1%
Phase Shift:	< 1°at mid-range
Insertion Impedance:	<1pH
Operating Temp (coil):	-20°C to +100°C (can be wider range)
Sensitivity Temp Coeff:	-150ppm/°C to -200ppm/°C

After Analog Integration: $V(t) = \int k \cdot \frac{dI(t)}{dt} \cdot dt = k \cdot k' I(t) = S \cdot I(t)$

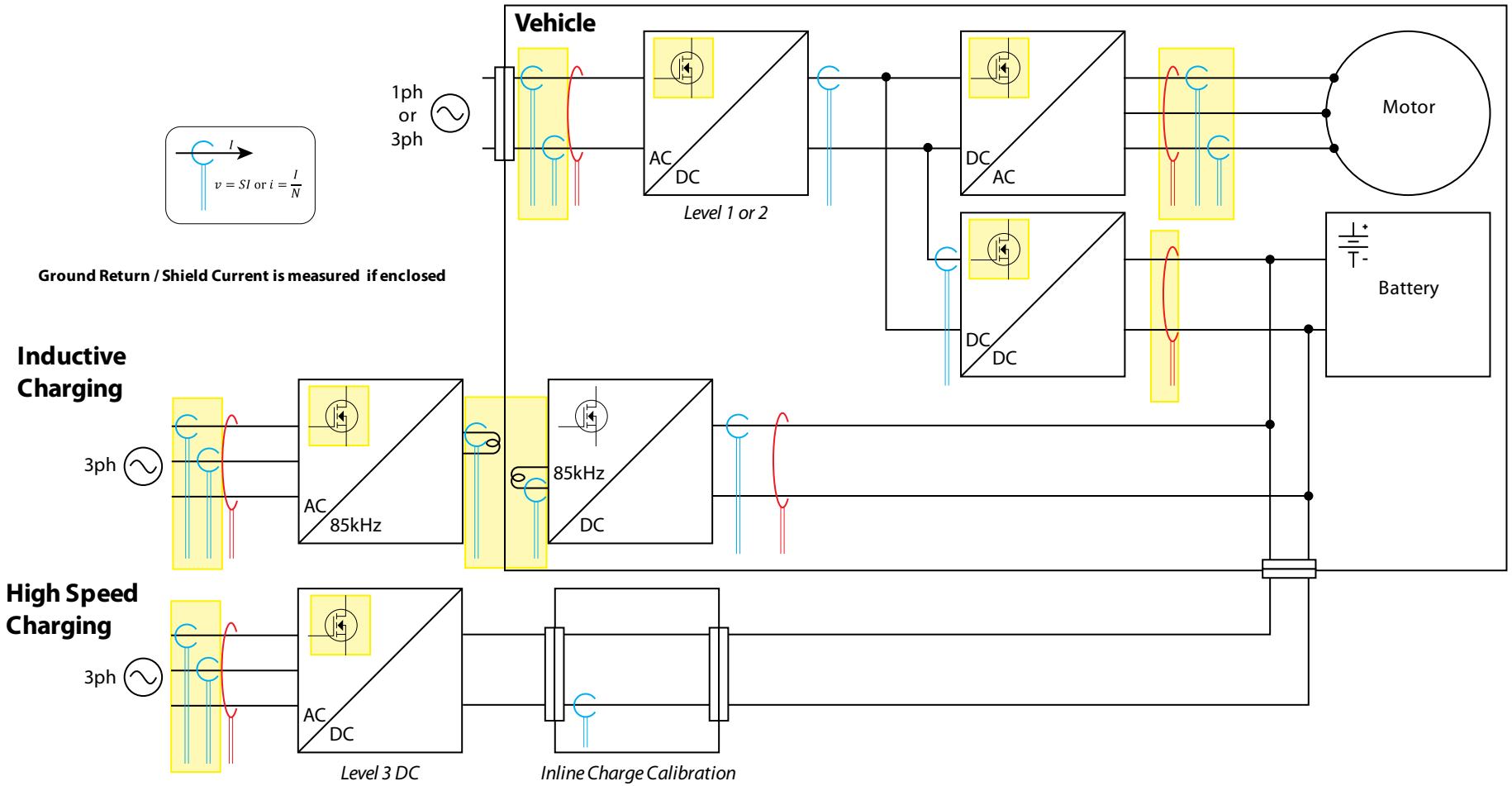
$S = Sensitivity$



Source: PEM

GMW Associates

Current Probe Connections in Electric Vehicle Chargers - PEM CWT Rogowski Coils

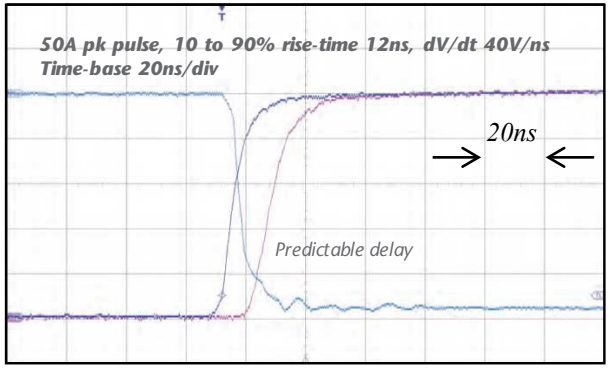


GMW Associates

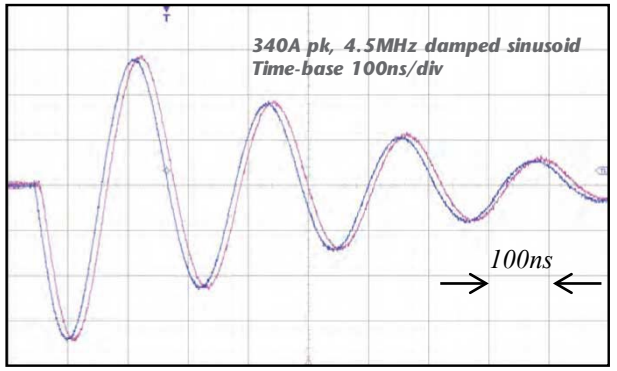
PEM Current Probes - CWT Mini50HF

Clip-around, shielded Rogowski coil

Current Sensitivity (S):	10mV/A	5mV/A
Current Range:	±0.6kA	±1.2kA
Noise (primary current):	1.5Ap-p	3Ap-p
Frequency Range (LF):	12Hz	6Hz
(HF):	50MHz	50MHz
Coil Lengths:	100mm or 200mm	
Coil Cross-section:	3.5mm	
Current Sensitivity (S):	10mV/A	5mV/A



Ch1 - (2GHz) Co-axial shunt (10A/div)
Ch2 - CWTMini50HF/3 /B/1/100/2 - 10mV/A, peak current 600A (10A/div)
Ch3 - Voltage close to the coil - 100V/div

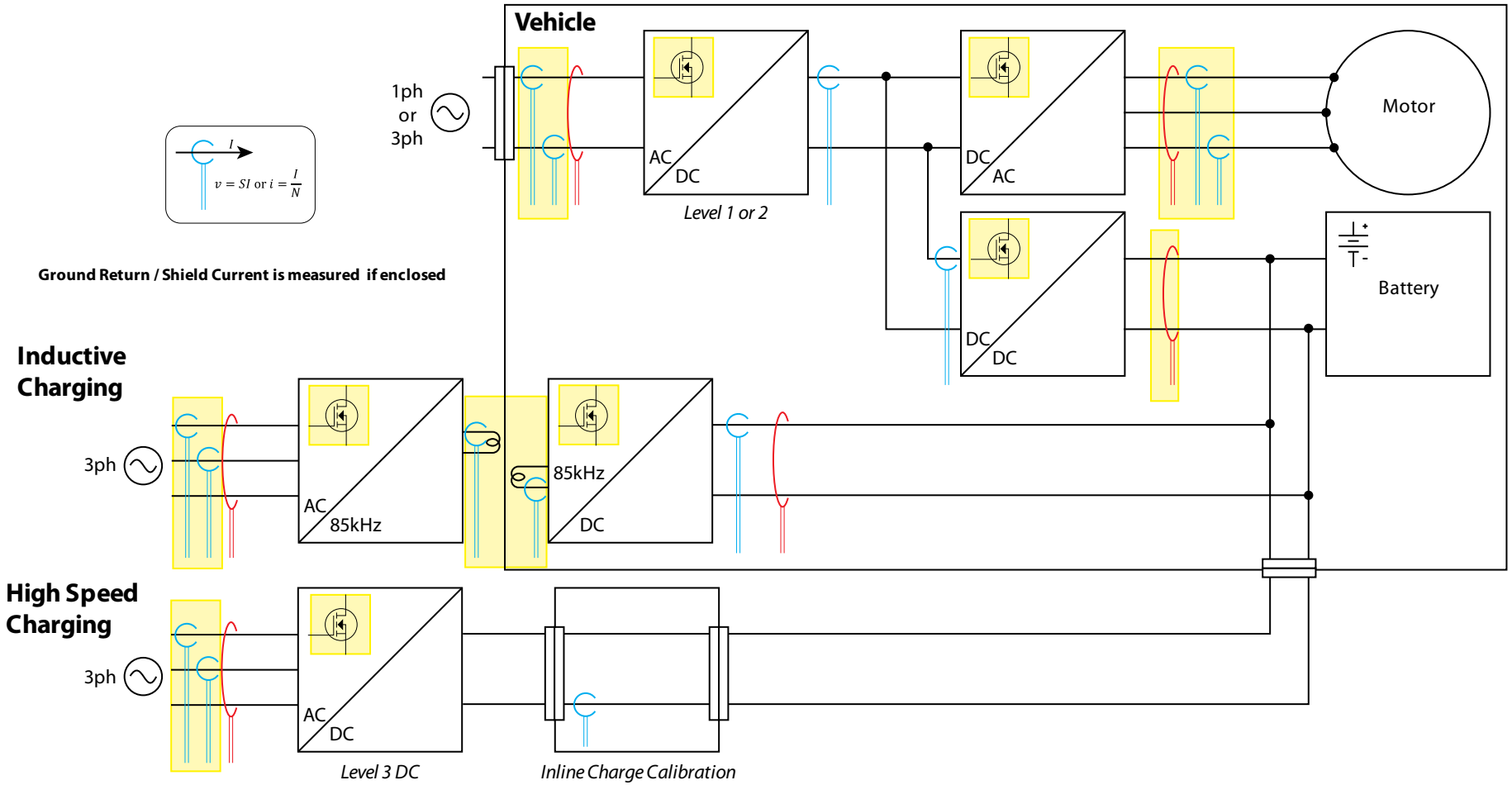


Ch1 - (2GHz) Co-axial shunt (100A/div)
Ch2 - CWTMini50HF/3/B/1/100/2 - 10mV/A, peak current 600A (100A/div)

Source: PEM

GMW Associates

Current Probe Connections in Electric Vehicle Chargers - PEM CWT Mini50HF



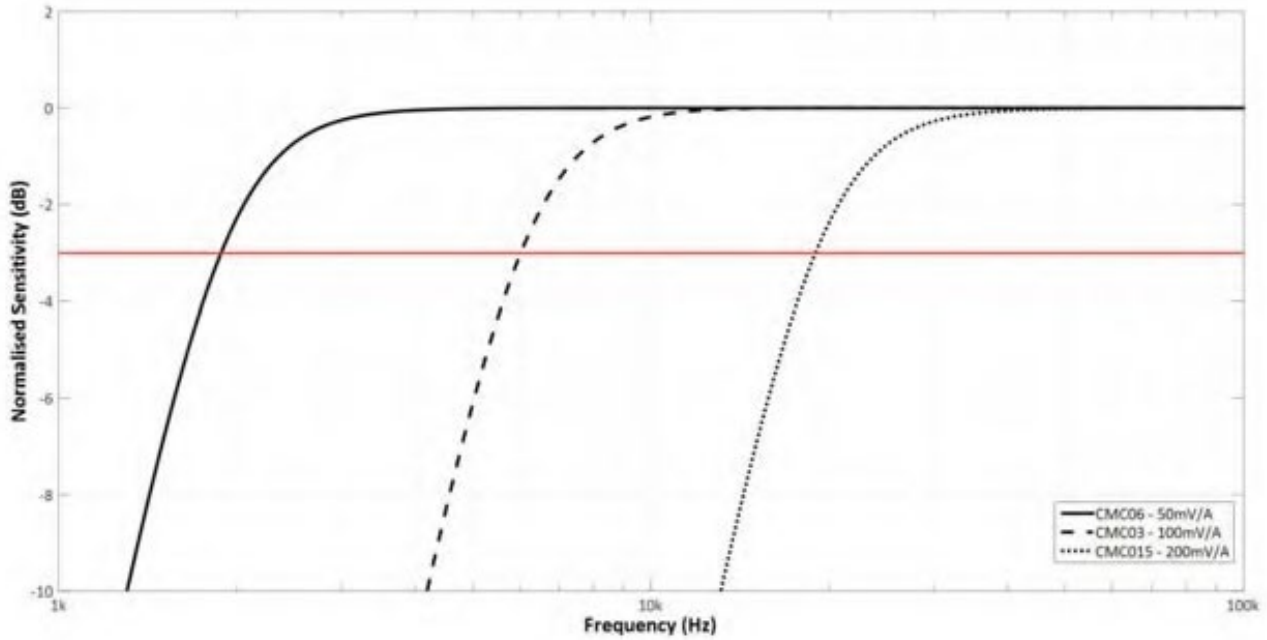
GMW Associates

PEM Current Probes with Tailored Frequency Response

CMC Common-Mode AC Current Probe

Optimized for high S/N for the high frequency current generated by the Variable Speed Drive Voltage Spikes

Current Sensitivity (S):	200mV/A	100mV/A	50mV/A
Current Range:	±37.5A	±75A	±150A
Frequency Range (LF):	19kHz	6kHz	1.9kHz
(HF):	11MHz	13MHz	14MHz



CWT MiniHF 85kHz AC Current Probe

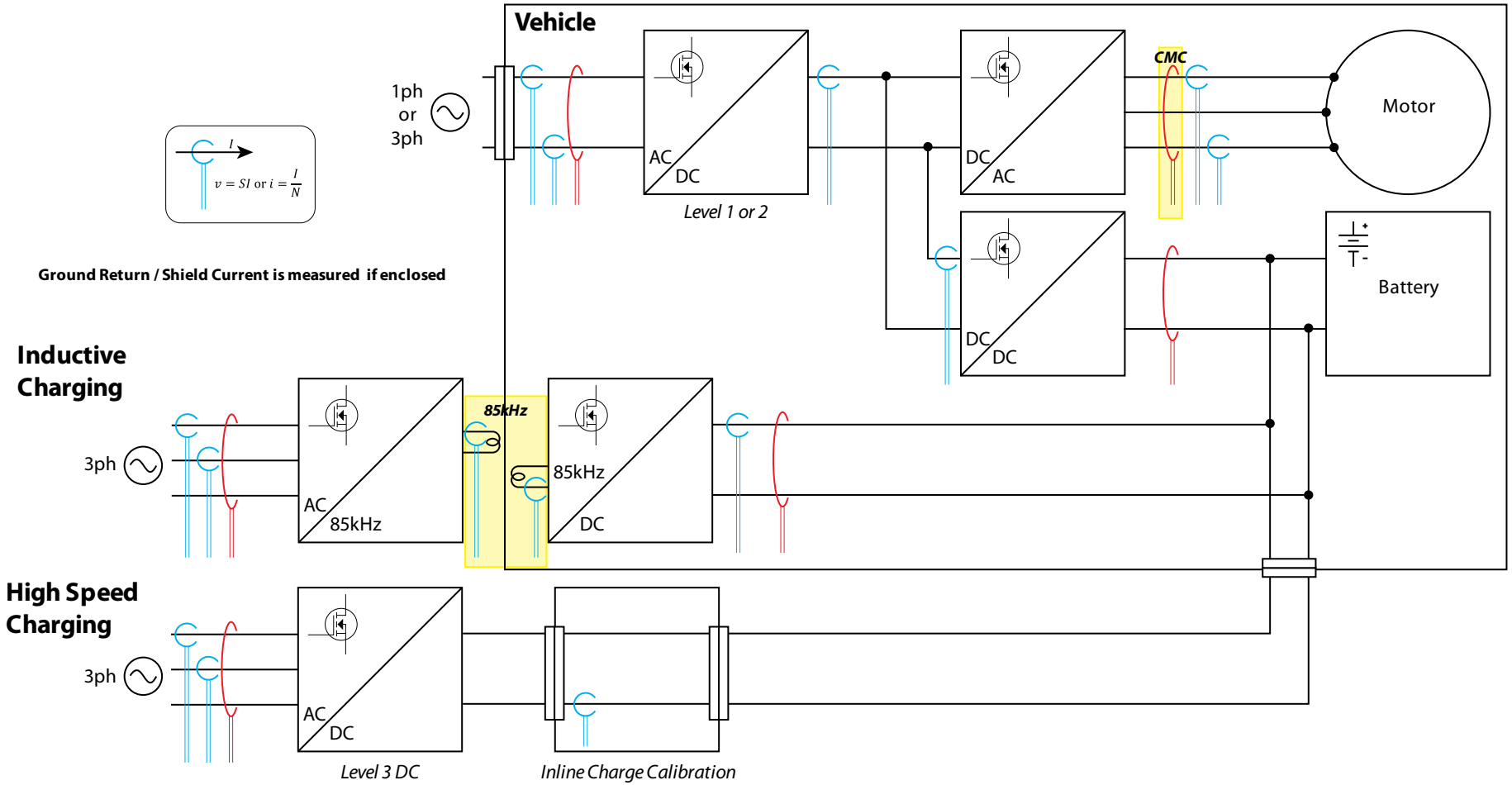
Optimized for 85kHz inductive power transfer measurements

Current Sensitivity (S):	20mV/A
Current Range:	±300A
Frequency Range (LF):	530Hz
(HF):	30MHz
Amplitude Accuracy (85kHz)	±0.5%
Phase Accuracy (85kHz)	<±1°

Source: PEM

GMW Associates

Current Probe Connections in Electric Vehicle Chargers – Tailored Frequency Response (CMC, CWT MiniHF 85kHz)



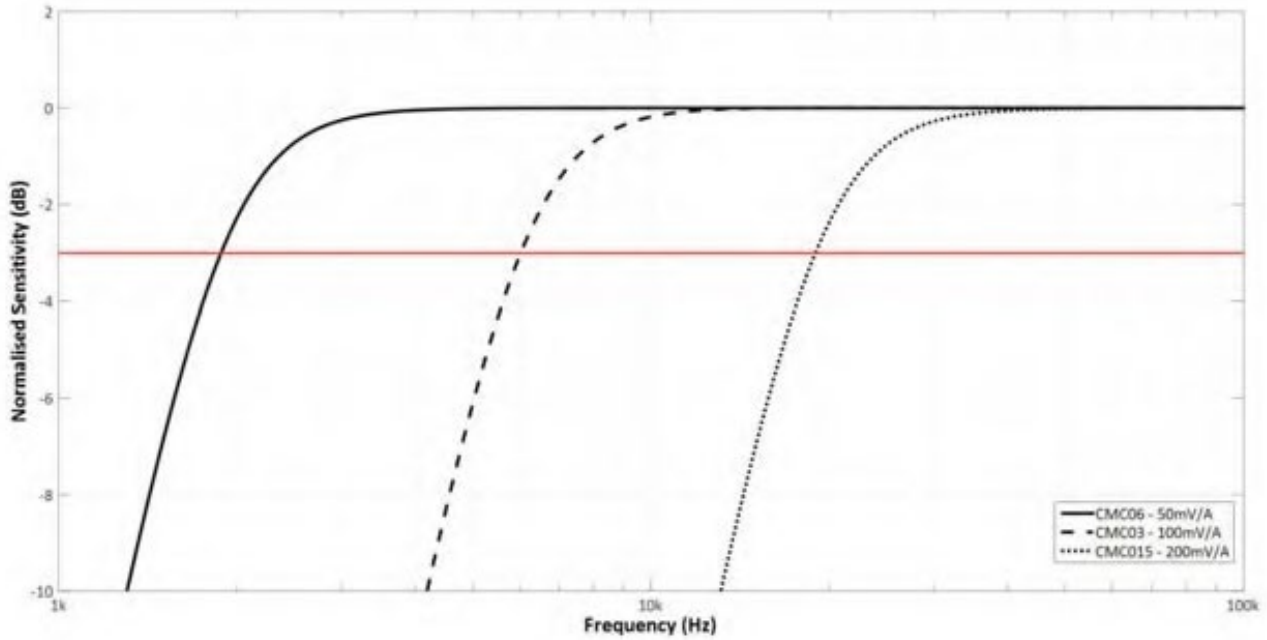
GMW Associates

PEM Current Probes with Tailored Frequency Response

CMC Common-Mode AC Current Probe

Optimized for high S/N for the high frequency current generated by the Variable Speed Drive Voltage Spikes

Current Sensitivity (S):	200mV/A	100mV/A	50mV/A
Current Range:	±37.5A	±75A	±150A
Frequency Range (LF):	19kHz	6kHz	1.9kHz
(HF):	11MHz	13MHz	14MHz



CWT MiniHF 85kHz AC Current Probe

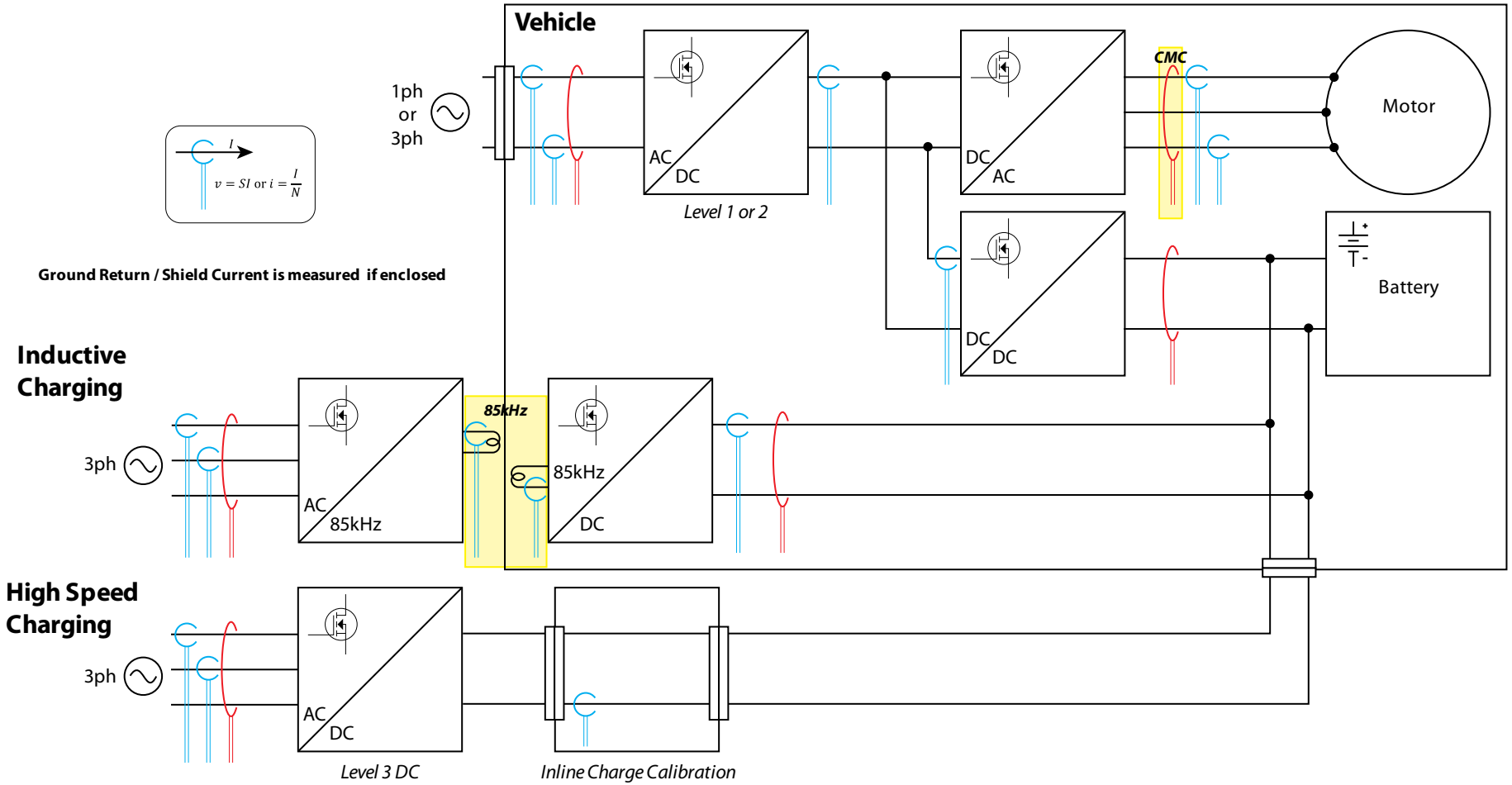
Optimized for 85kHz inductive power transfer measurements

Current Sensitivity (S):	20mV/A
Current Range:	±300A
Frequency Range (LF):	530Hz
(HF):	30MHz
Amplitude Accuracy (85kHz)	±0.5%
Phase Accuracy (85kHz)	<±1°

Source: PEM

GMW Associates

Current Probe Connections in Electric Vehicle Chargers – Tailored Frequency Response (CMC, CWT MiniHF 85kHz)



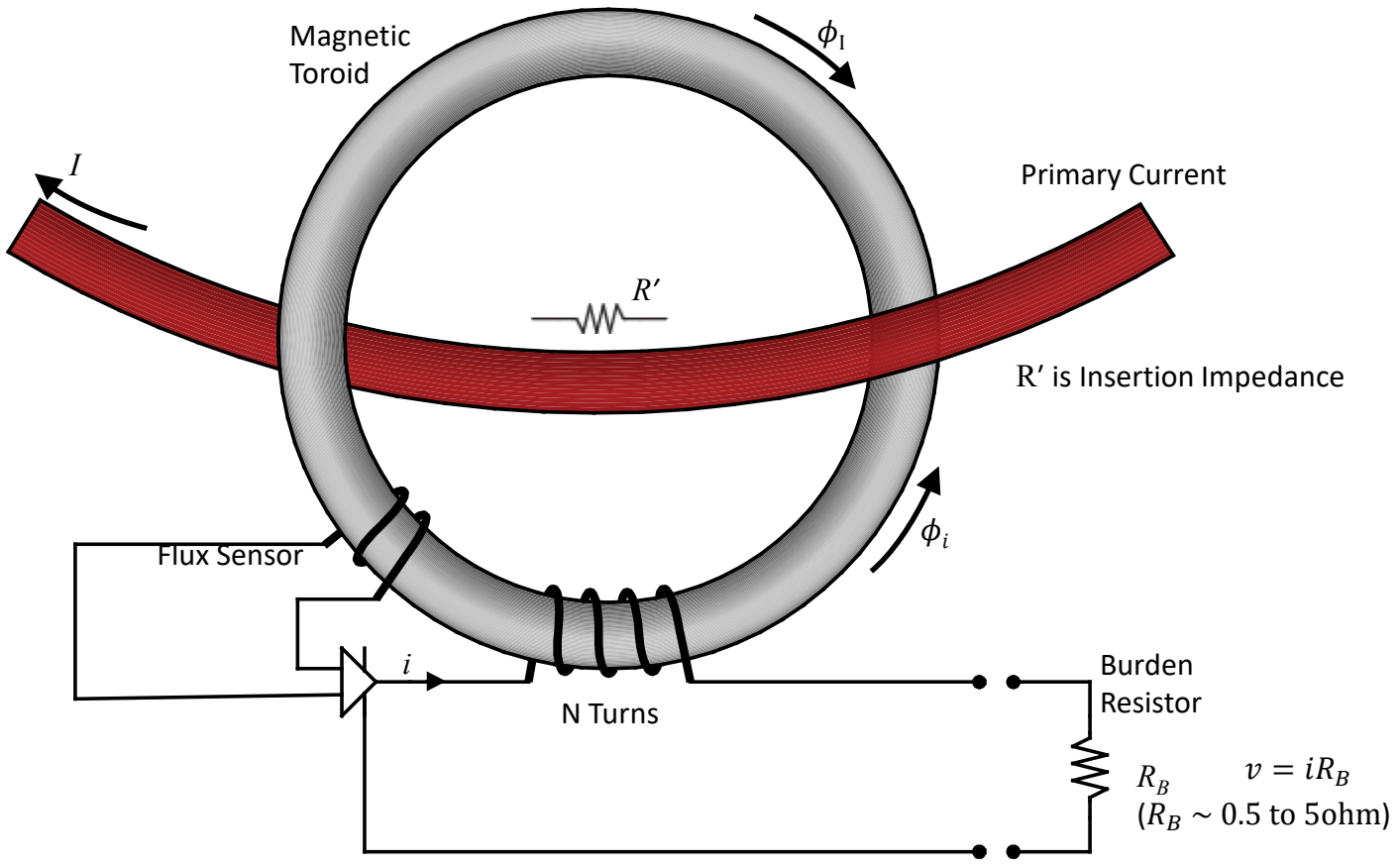
GMW Associates

Danisense Current Transducers

DC-AC Zero Flux, Fluxgate Current Transducers

GMW Associates

Danisense Zero Flux, Fluxgate Current Transducers



If $\phi_i = \phi_I$ (zero flux in the magnetic toroid), $Ni = I$ and $i = I/N$ ($N \sim 200$ *to* 5000).

If there is no power lost in the Current Transducer,

$I^2R' \sim i^2R_B$, $I^2R' \sim \frac{I^2}{N^2}R_B$ or $R' \sim \frac{R_B}{N^2}$

For $R_B \sim 1\text{ohm}, N \sim 1000, R' \sim 1\mu\text{ohm}$.

For $I \sim 1000\text{A}, N \sim 1000, Power \sim 1\text{W}$

GMW Associates

Danisense Zero Flux, Fluxgate Current Transducers

Product Range Overview

Output Type	Product Family	Primary Current (Arms)											
		50	100	200	300	400	500	600	1000	1200	2000	5000	10000
Current	DP	■	PCB Mount, Programmable, 12.5/25/50Arms										
	DT	■	■	■									
	DS	■		■	■	■		■					
	DQ						■	■					
	DC			■									
	DM									■			
	DL										■		
	DR											■	■
Voltage	DS	■		■	■	■		■	■				
	DW						■						
	DM									■			
	DL										■		
	DR											■	■

DP series

DS series

DQ series

DT series

DM series

DR series

DW series

DL series

Unpackaged

DC series

DSSIU System Interface

GMW Associates

Danisense Zero Flux, Fluxgate Current Transducers

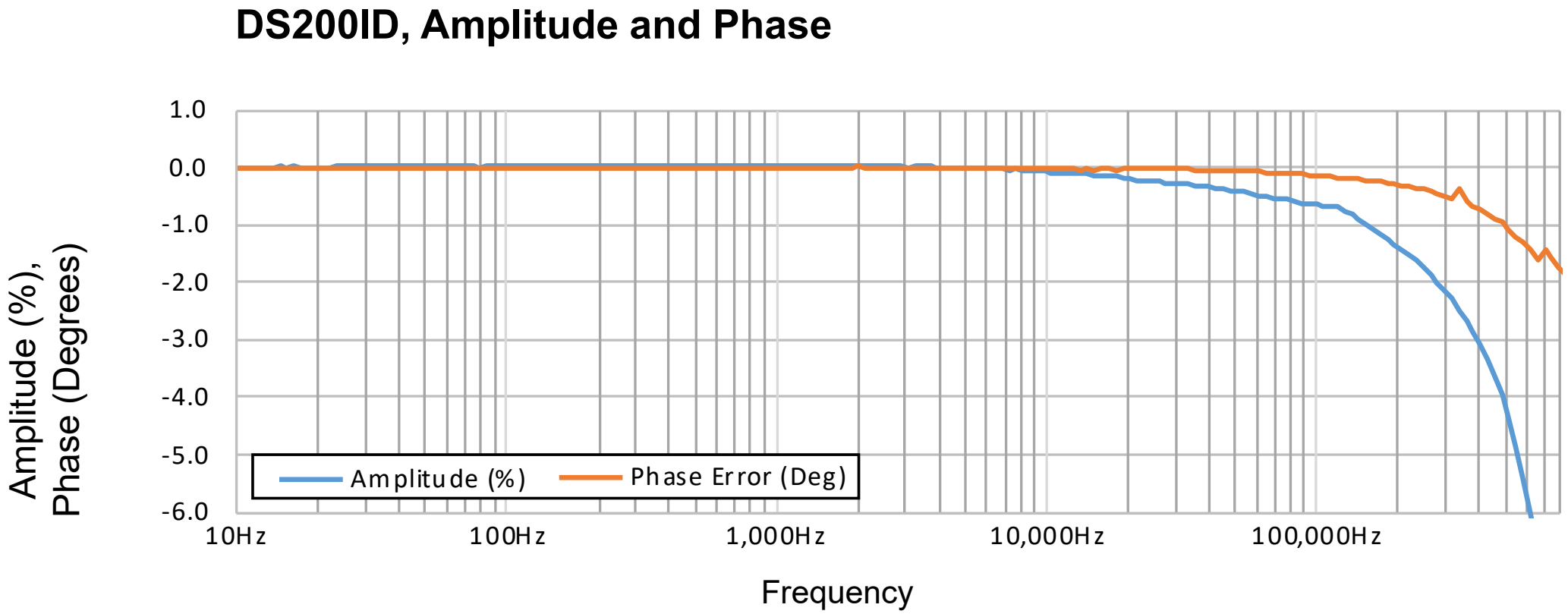
Specifications, selected models

	DS200ID	DS1200ID-CD3000
Current Ratio, N	500	1500
Current Range	±370A	±1500A
Output Signal	2mA/A	0.666mA/A
Zero Offset (equiv. primary)	< ±6mA	< ±18mA
Zero Offset Stability (equiv. primary)	< ±0.06mA/month	< ±0.15mA/month
Offset Change, Magnetic Field (equiv. primary)	< ±3mA/mT(1)	< ±3mA/mT(1)
Amplitude Error, dc to 5kHz	< ±0.01%	< 0.01%(2)
Phase Error, dc to 5kHz	< ±0.1 degree	< ±0.1 degree(2)
Calibration Winding	–	3000 turns(2) $500mA \cdot 3000t = 1500A \cdot t$
Case Type	Al (ES Shield)	Al (ES Shield)
Aperture	27.6mm (~1.1”)	45mm (~1.77”)

(1) A current of 500A generates a field of 1mT at a radius of 0.1m (~4”).
(2) Calibration Winding Option limits AC operation to 1kHz

GMW Associates

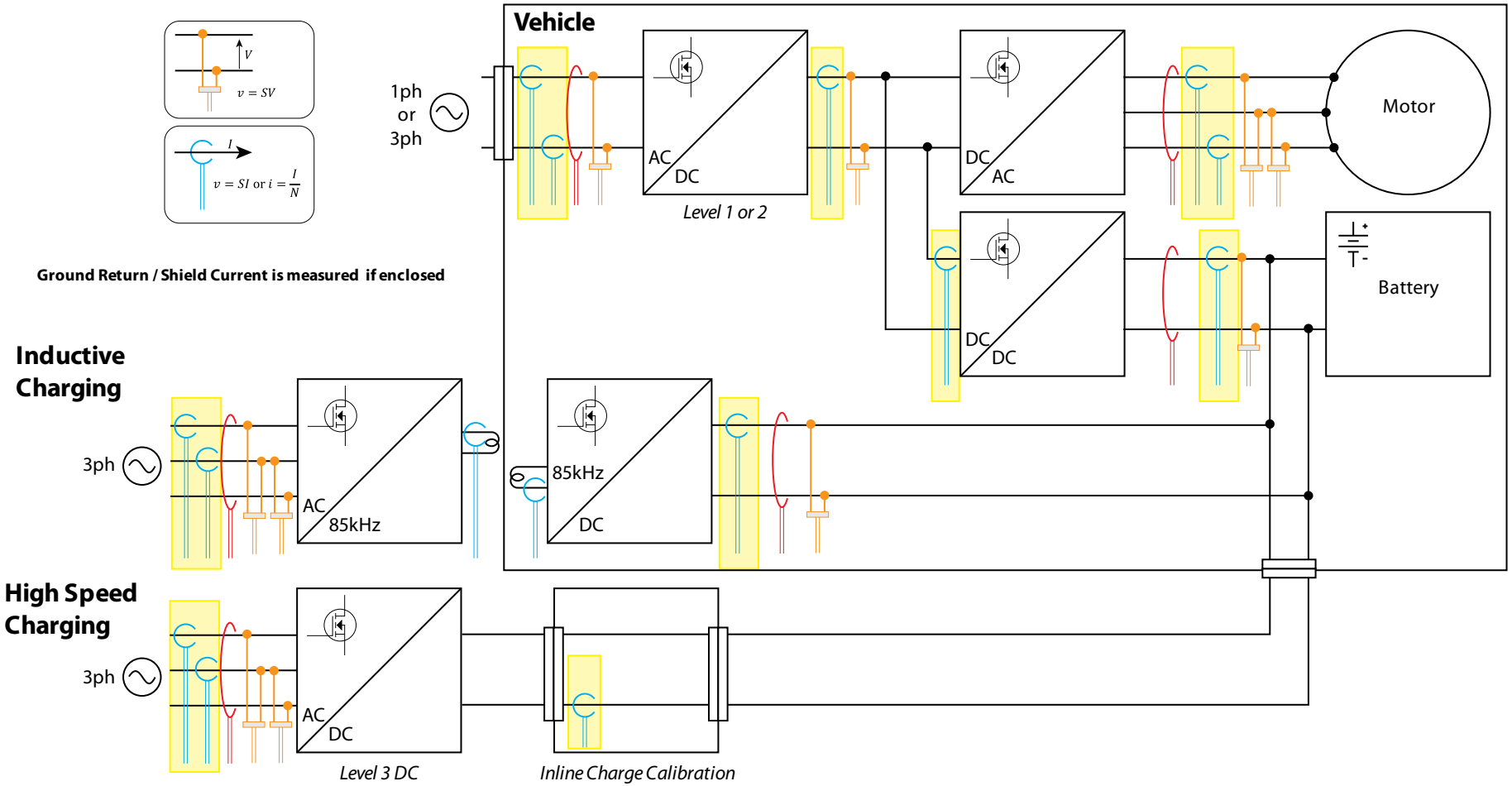
Danisense Zero Flux, Fluxgate Current Transducers



- Excellent amplitude and phase response to 10kHz
- No resonant behavior in amplitude or phase response at high frequency

GMW Associates

Current and Voltage Probe Connections in Electric Vehicle Chargers – Danisense Current Transducers



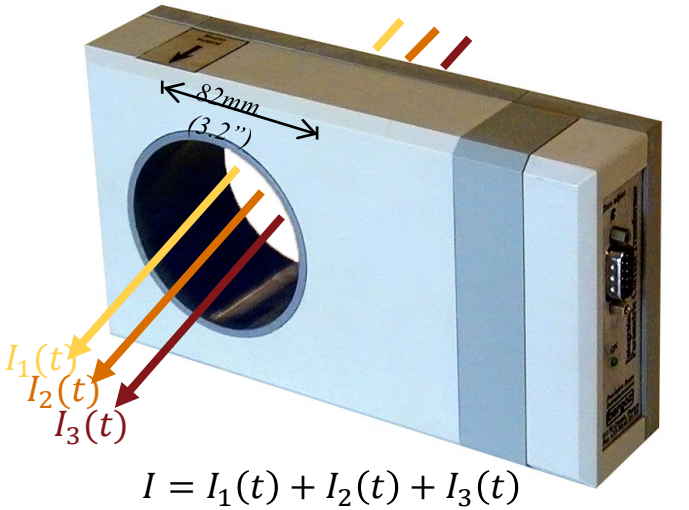
GMW Associates

Bergoz IPCT

DC-AC High Resolution Current Transducer

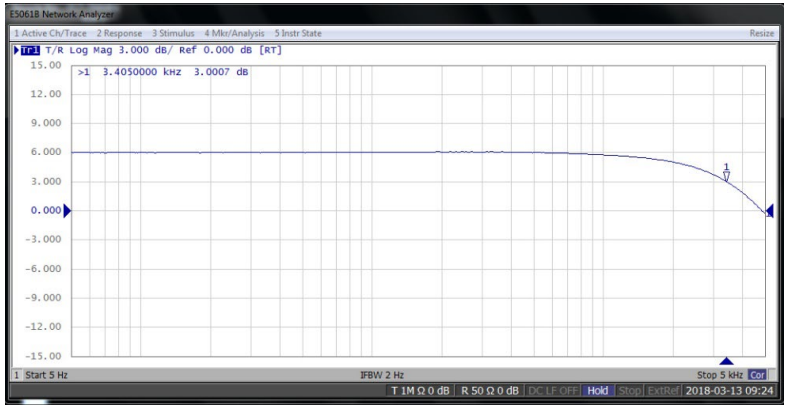
GMW Associates

Bergoz IPCT –
DC-AC High Resolution Current Transducer



$$I = I_1(t) + I_2(t) + I_3(t)$$
$$V(t) = S \cdot I$$

IPCT-0100mA-82 Amplitude v. Frequency

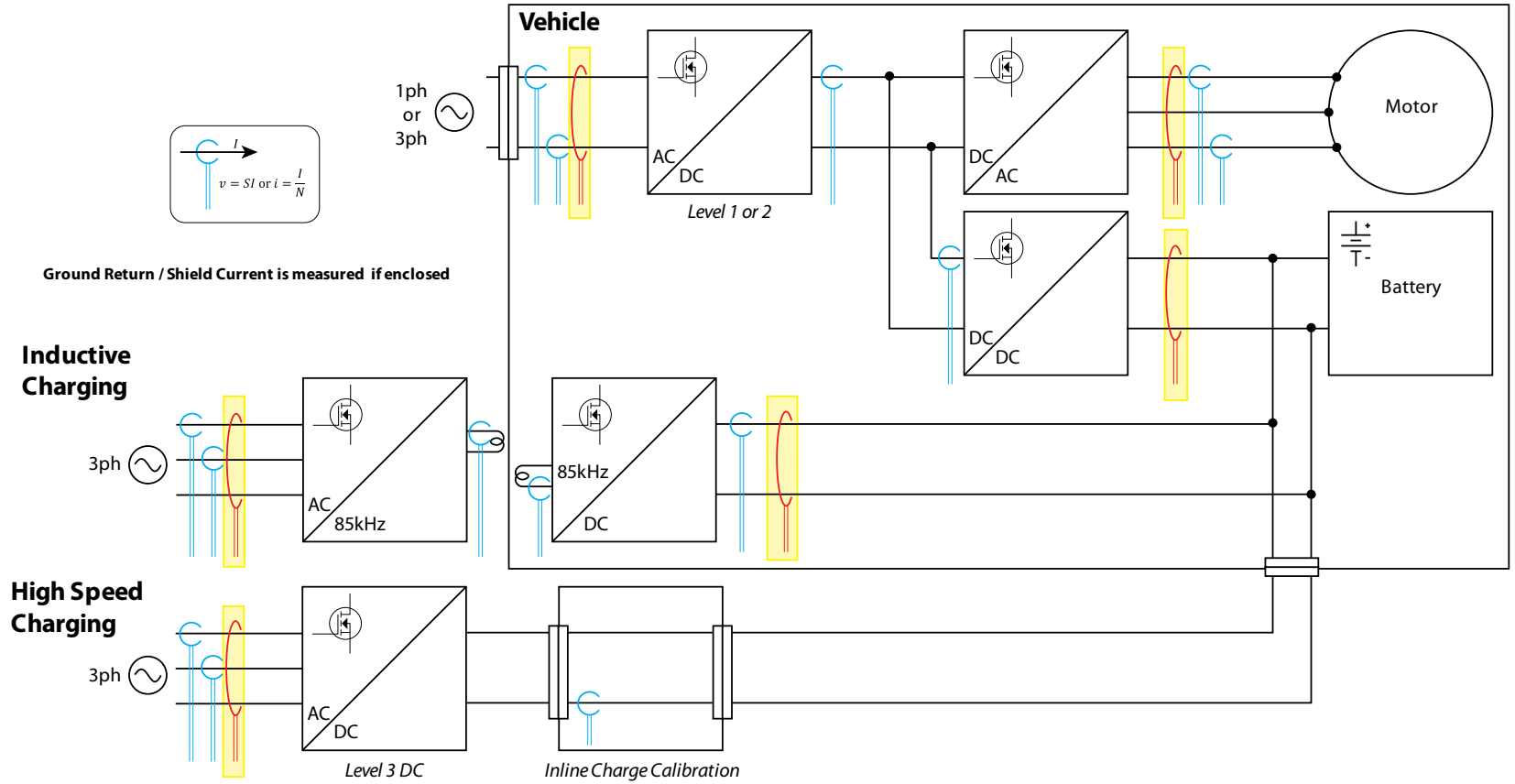


	IPCT	LP-IPCT
Current Range	±1mA to ±20A	±1mA to ±2A
Output Signal, $V(t)$	±10V	±10V
Zero Offset	Adjustable, 20 turn pot.	Adjustable, 20 turn pot.
Frequency Response	DC to 2.5kHz (-3dB)	DC to 1kHz (-3dB)
Noise (equiv. primary)	1µArms/$\sqrt{Hz}$ to 50µArms/$\sqrt{Hz}$	—
Resolution	30µA at ±2A Full-Scale	3µA at ±2A Full-Scale
Recovery after overload (1000x)	< 10ms	< 20ms
Aperture	82mm (3.2")	30mm (1.18")
Mass	0.5kg	0.2kg
Dimensions	200 x 112 x 50mm	105 x 52 x 55mm

(1) A current of 500A generates a field of 1mT at a radius of 0.1m (~4").

GMW Associates

Current Probe Connections in Electric Vehicle Chargers – Bergoz IPCT



GMW Associates

GMW CPC

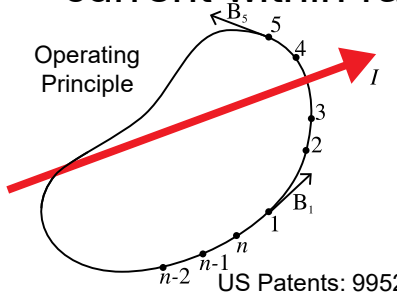
Clip-on DC-AC Coreless Current Probes

GMW Associates

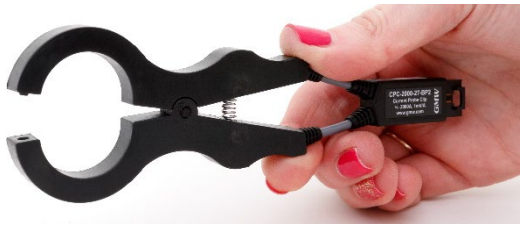
GMW CPC –
Clip-on DC-AC Coreless Current Probes

For System diagnostics and long-term monitoring, Current Probes with no magnetic core.

No hysteresis, no damage from primary current overload with recovery to linear operation within 10 µS of primary current within range. The CPC can be used to monitor the “low current” recovery after a high current overload.

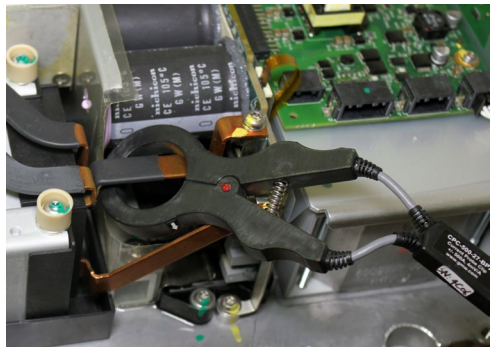


US Patents: 9952257, 10690701
European Patent: 2972425



CPC-xxxx-27

CPCO – Current Probe, Clamp-on Probe based on same technology and design with larger aperture, in use at an electrochemical plant.



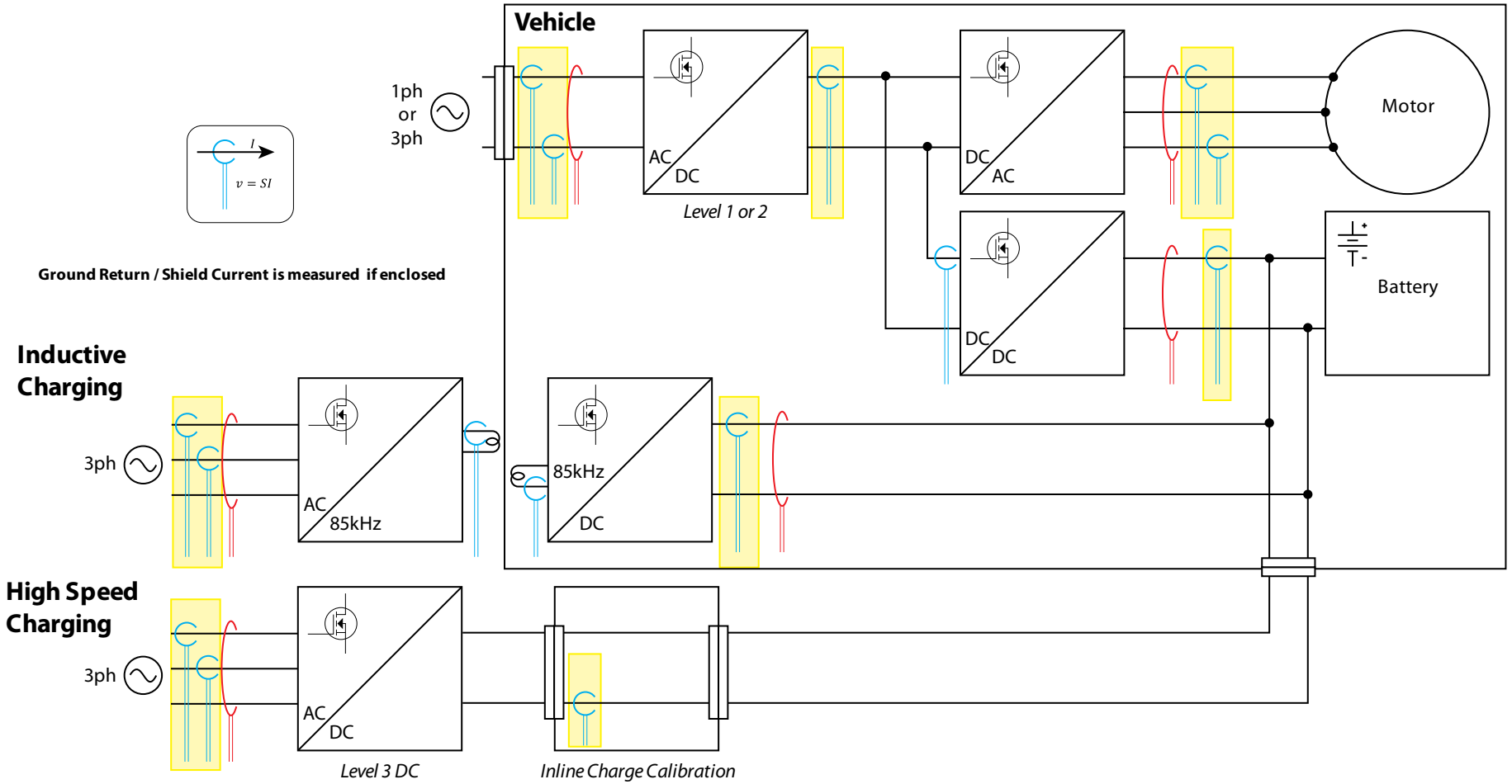
CPC – small size enables installation in difficult locations.

Current Sensitivity	8mV/A to 1mV/A
Current Range	±250A to ±2000A
Frequency Range	dc to 75kHz (-3dB)
Amplitude Error	< ±1%
Output Change, Magnetic Field	< 0.2% of range for 40mT(1)
Response Time	< 2µs
Insertion Impedance	< 1pH
Operating Temperature	-40°C to +100°C
Moisture Resistance	Sealed, NEMA 5
Aperture	27mm (1.06”)
Mass	< 30g (1 oz)
Power Supply	3.5V to 5.5V, <85mA, USB Port

(1) A current of 10kA generates a field of 40mT at a radius of 0.05m (~2”).

GMW Associates

Current Probe Connections in Electric Vehicle Chargers – GMW CPC DC-AC Current Probes



GMW Associates

Senis 3DACMT

Three-Component AC Magnetic Field Transducer

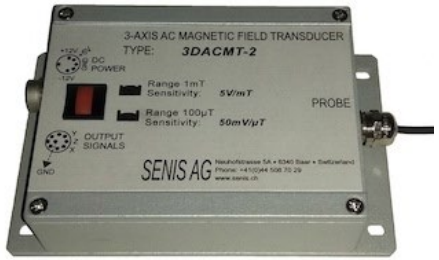
GMW Associates

Senis 3DACMT – Three-Component AC Magnetic Field Transducer

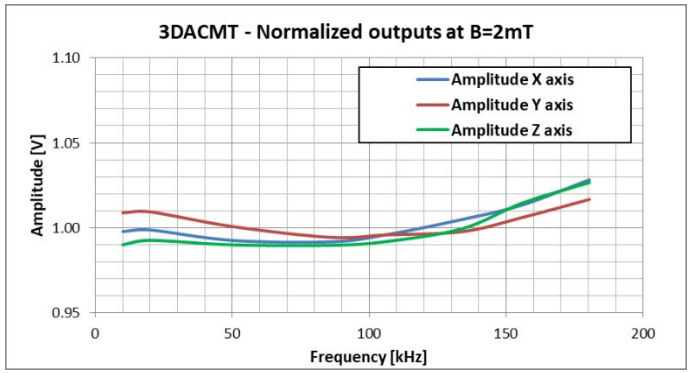
Small size enables field mapping between coils. High resolution for fringe field mapping.

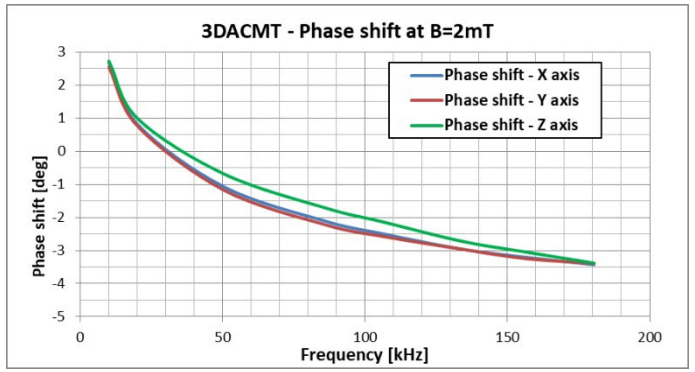
$B_x(t)$
$B_y(t)$
$B_z(t)$

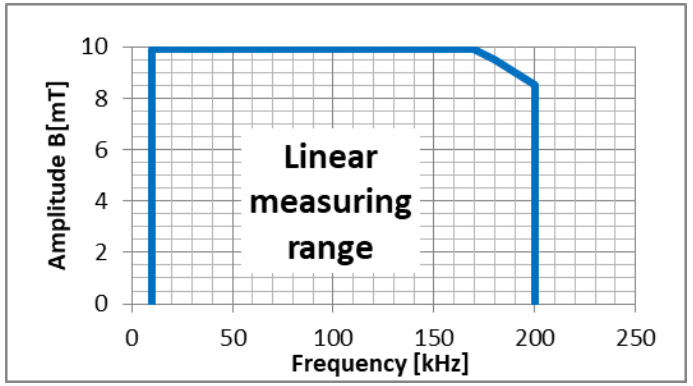
Sensitive Volume
10 x 10 x 10 mm



Field Components	$Bx(t), By(t), Bz(t)$
Output Signals	$Vx(t), Vy(t), Vz(t)$
Sensitivity, Sx, Sy, Sz	500mV/mT
Field Range	±10mT
Field Resolution	< 1.5µTrms
Signal Nonlinearity	< 1%, f < 100kHz
Frequency Range (LF) (HF)	10kHz 200kHz
Phase Shift	< 3° at 85kHz

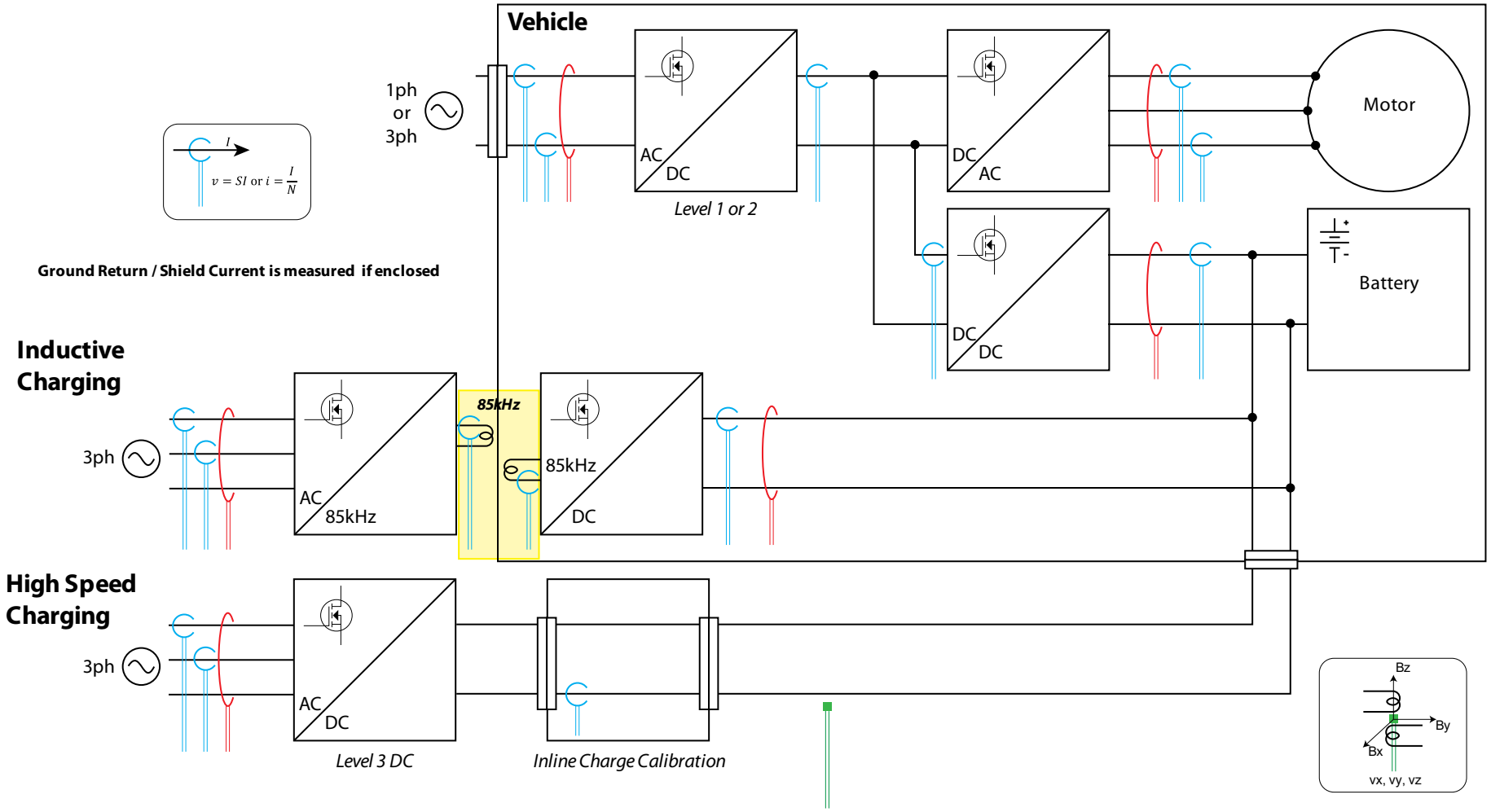






GMW Associates

Field Measurement Points in Electric Vehicle Chargers – Senis Magnetic Field Transducer



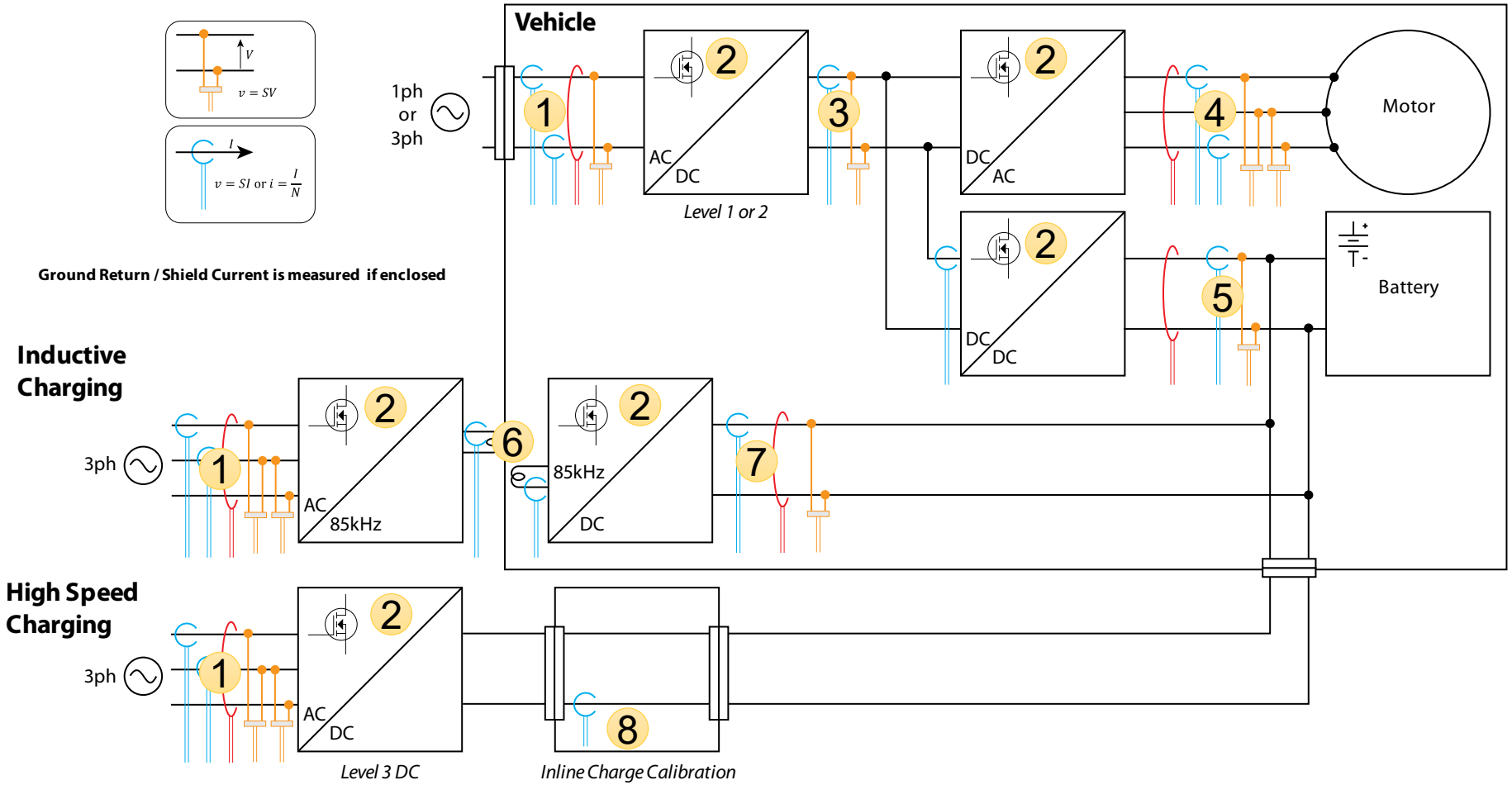
GMW Associates

Measurement Points

Selection Guide

GMW Associates

Field Measurement Points in Electric Vehicle Chargers – Selection Guide



	1	2	3	4	5	6	7	8
PEM CWT	■			■				
PEM CWT Mini50HF	■	■		■				
PEM CMC				■				
PEM 85kHz						■		
Danisense CT	■		■	■	■		■	■
Bergoz IPCT	■			■				
GMW CPC & CPCO	■		■	■	■		■	■
Senis 85kHz						■		

GMW Associates

Thank You!

www.gmw.com

Brian Richter
President
brian@gmw.com
(650) 200-4734

Ben Hartzell
Senior Vice President, Marketing
ben@gmw.com
(650) 200-4736

Sandro Renteria
Calibration Lab Manager
sandro@gmw.com
(650) 200-4740

Ian Walker
Senior Applications Engineer
ian@gmw.com
(650) 240-1134

GMW Associates