Current Transformers & Sensors Series

Introduction

In many applications, to know the current flowing through a given conductor is very useful. As well as the voltage transduction is easy, the comparable process for current is more complex. Because of this need, a lot of technological options have been developed to achieve this goal - measuring electric current.
It is important to the designer to understand well all these options in order to select the most suitable one.

Shunt Resistor

Shunt resistors are, maybe at priori, the simplest way to measure current. The principle is based in a serial connection of a resistance. It is preferable to have very low tolerance, to allow current flowing through resistor to measure it. Ohm's Law tells us that the voltage measured and the current are related, both magnitudes are related by the Shunt resistance value, R[1]. Variations in the current will be detected as variations of voltage in the Shunt. This voltage can be used in feedback processes or for activating security conditions. The representation of a shunt resistance coupled to the circuit is showed in figure 1.

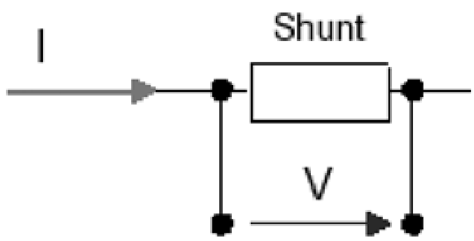

Figure 1

Shunt resistors give a very accurate current measurement, offer a cost effective solution and are easy to set up. Even so, their use to sense high currents is not recommended, because measurement current losses are proportional to quadratic value of this current.

$$Pp = I^2 \cdot R_{SHUNT}$$

On one hand, Shunt resistors are usually used to sense current in certain applications, to check the quality of an electrical net, regarding power factor and THD[1] of the application. On the other hand, they are useful in motors control systems current sensing by means of frequency variation or switched mode power supplies. The greatest inconvenient of this kind of sensor is that it is not isolated galvanically in the circuit, besides the impossibility to measure high currents because of high dissipation heating.

1- Total Harmonic Distortion, THD parameter informs about the quality of the current that flows in a line, related with the number of harmonics contained in the frequency spectra of the current. Optimal THD parameter: 1.

Rogowski Coil

Rogowski coil consists on a coil containing an air core with a toroidal shape. When current flows through a cable, a magnetic field H is created. Its direction is related to the direction of the current; as is shown in the figure 2.

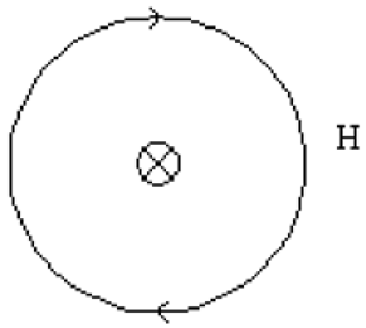

Figure 2

If current flows through a Rogowski coil (Figure 3), a certain voltage is induced in the terminals of the coil rolled up on the air core[3]. This voltage is proportional to current derivative and coil L mutual inductance.

$$V_L(t) = -L \cdot \frac{d\,i(t)}{dt} \rightarrow i(t) = -\frac{1}{L} \cdot \int V_L(t) \cdot dt$$

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Therefore, it is only necessary an integration stage on the terminals of the Rogowski coil to get the desired value of current. It's obvious that Rogowski coil can not measure DC levels of current, because voltage is induced by an AC current rather than by a DC current. With an air core, Rogowski coil is able to measure AC current with high level offset, because there are not core saturation problems.

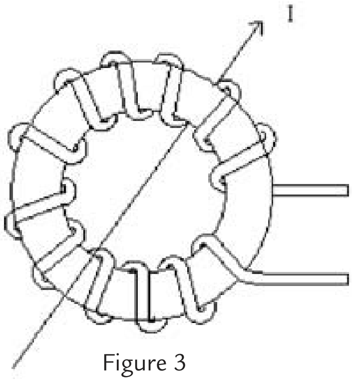

Figure 3

Typical restriction is the resonance frequency, because of the existence of parasitic capacitance. This frequency limits Rogowski coil frequency operability. In any case, a suitable reeling of the coil, makes possible that this frequency may have a high value, near MHz in many cases.

There are two kinds of Rogowski coils: rigid and flexible. The operation principle is the same, but the difference lies in the coil. One kind of coil is flexible, that is, it has the same features and has the possibility to surround any line current. Otherwise, rigid coil is more accurate and has better stability in the measurement. Both applications are showed in figures 4.a and 4.b.

Figure 4.a Figure 4 Figure 4.b

(Figure 4.a Flexible Coil, 4.b Rigid Coil.)

50/60 Hz Current Transformers

Another way to measure current is using the magnetic coupling between two coils rolled up in the same magnetic core. In this case, the secondary coil has got a high number of turns (higher the number, higher the precision). Primary coil will have one turn and will carry the current to measure, the ideal magnetic coupling tells us:

$$\frac{n_1}{n_2} = \frac{I_2}{I_1} \rightarrow I_2 = \frac{1}{n_2} \cdot I_1$$

Current transformers for net frequencies of 50/60Hz are designed with different kinds of magnetic cores. One kind are iron-steel laminations, since at this frequency range this material is able to measure currents up to 600 or 700 A ,[3]. Current transformers can measure AC current levels but they cannot admit DC current, because DC levels saturate the magnetic core.

Other kind of cores, as for example nanocrystalline and amorphous cores, makes it possible to get more measurement accuracy, although, on the other hand, they are not suitable to measure high levels of current, up to 100 A. These low frequency transformers, based in nanocrystalline and amorphous cores, can carry, in some cases, levels of DC current without saturation of the core. In figure 5, equivalent circuit of a current transformer is shown next.

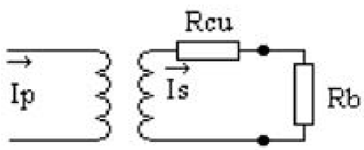

Figure 5

Figure 6a shows a picture of the high current transformers based in iron-steel laminates. Figures 6.b shows low frequency transformers, based on ferrite, amorphous or nanocrystalline cores are shown.

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With the response signal, an average along a period of time is made. This value is always zero, as long as another induced signal is not added or does not interfere in the transducer. If this happens, the mean value is different from zero.

This kind of sensors measures both AC and DC signals. The following figures (13a, 13b) give us an example of a DC signal measurement. It can be seen that the current directions are opposite respectively.

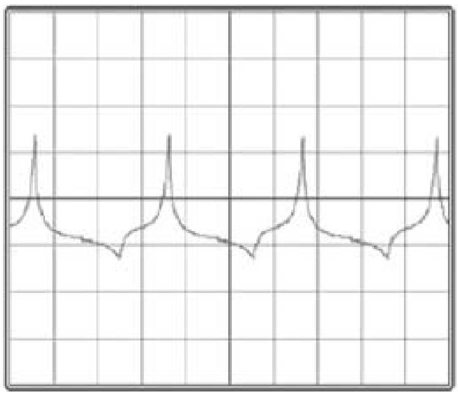

Figure 13.a

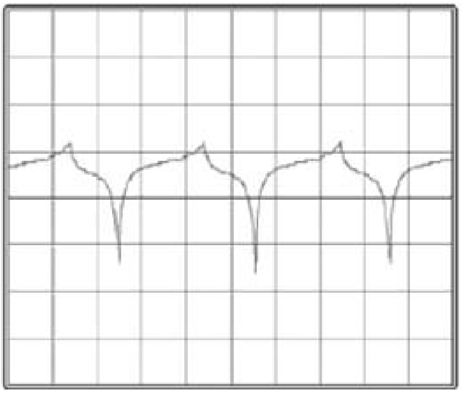

Figure 13.b

Application frequency range of this sensor depends on the electronic stage associated and the frequency response of the magnetic cores, usually toroidal cores.

Comparative Table

A comparative table of the different solutions in this article is shown. Principal features of each one are mentioned in this table.

Parameter	Current Transformers	Hall Effect Sensors	Rogowski Coil	Flux Gate	Shunt
Cost	Medium	High	Low	High	Low
Bandwidth	Low	Medium	High	Medium	Low
Isolation	High	High	High	High	Low
Dimensions	Medium	Medium	Low	Medium	Low
Linearity	Good	Medium	Very Good	Good	
High Current Measurement	Good	Good	Very Good	Very Good	Low
Saturation Problems	Yes	Yes	No	No	No
Power Dissipation	Low	Medium	Low	Medium	Low
Temperature Effects	Low	Medium	Very Low	Low	Medium

References

[1] Measurement, Instrumentation and Sensors Handbook, CRC Press, 1999.
[2] D.A. Ward, J.La.T. Exon, Engineering Science and Educational Journal, June 1993.
[3] Ras, Enrique. Transformadores de Potencia de Medida y Protección. 6ª Edición. Marcombo.
[4] Waters, C. Current Transformers Provide Accurate, Isolated Measurements. PCIM Magazine, Diciembre 2006.
[5] Hall Effect Sensing and Application, Honeywell manual.

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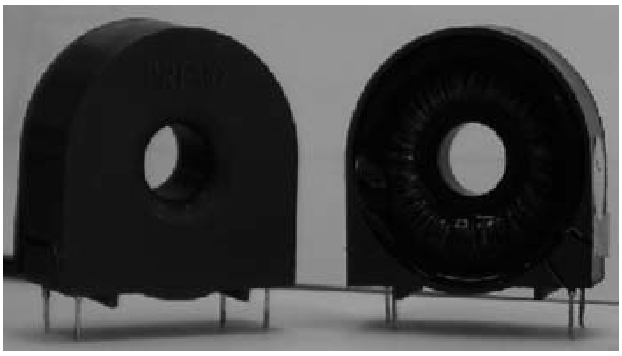


Figure 6.a

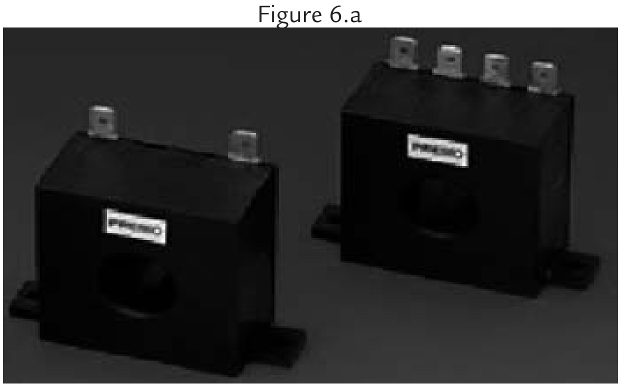


Figure 6.b

High Frequency Current Transformers

The operation principle is the same as in the previous case. To measure currents at high frequencies properly, it is necessary that magnetic cores having a high magnetic permeability at these frequencies [3,4]. Iron-steel laminates, that are useful at 50/60 Hz currents, are substituted by ferrites, amorphous or nanocrystalline materials.

These sensors have smaller size than high current industrial ones and thanks to their magnetic properties, they can operate at high frequencies. One of the applications is the sensing of the current in switching power supplies to implement current-mode loop control. They have a great advantage regarding Shunt resistors, because they are galvanically isolated between primary and secondary currents. Figure 7 shows this current transformers.

Figure 7

Hall Effect Based Sensors

Hall sensors are based in Hall effect. This effect consists on the appearance of a voltage when a current flows through a conductive plate and a magnetic field is applied. Usually this conductive plate is made of a semiconductor material. Voltage generated is perpendicular to the direction of current and the applied magnetic field [1,5], as shown in figure 8:

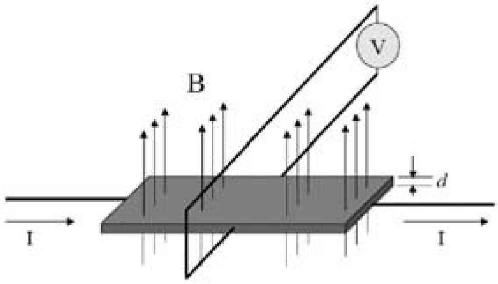


Figure 8

This is the Hall configuration. Theoretical relation between voltage generated and applied magnetic field has the form:

$$V_H \propto I \cdot B$$

Where B is the magnetic flux density and I the current that flows through the plate. Typical values of this voltage are of the order of microvolts, therefore, it is necessary to add an amplifier stage to make an adequate reading of the generated Hall voltage.
This stage adds an offset voltage in the measurement of B[5].

Sensor has different response to magnetic flux density and frequency according to the electronic stage and the Hall transducer (semiconductor plate). It can cover ranges of DC to 100 kHz and 1gauss to 30 Teslas, approximately. And according to the design, this sensor can measure currents between 1 mA and 1kA.

Thus, associated electronics fixes current sensor capabilities and increases its cost; Figure 9 shows a diagram of the response of the Hall sensor.

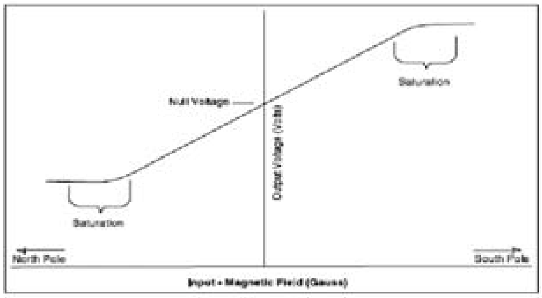


Figure 9

An example of a current sensor based in a Hall sensor would be a "closed loop Hall effect current sensor":

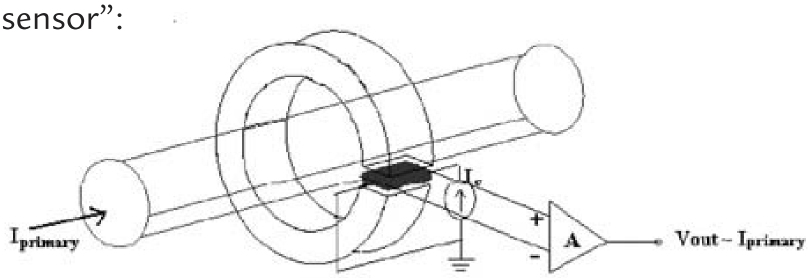


Figure 10

In this example, Hall sensor measures the magnetic flux density induced in a toroidal core by the primary current. Magnetic core, for getting more sensitivity in the transduction, should have a high magnetic permeability and low magnetic losses.

Fluxgate Sensor

A Fluxgate [1] transducer has almost the same scheme than Rogowski coil, since it consists in a coiled magnetic core, as in figure 11:

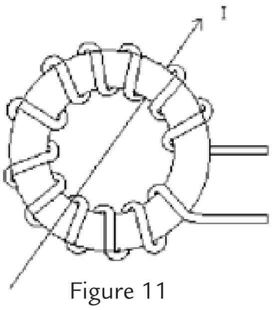


Figure 11

Usually, magnetic cores shape fluxgate sensors have a high magnetic permeability, very low coercitivity and as many number of turns in the coil as possible to improve its sensitivity. Ferrites are the standard materials for this purpose, because of the good frequency response.

Fluxgate sensor operation consists on applying a square signal to the coil (V_{SAT}), which saturates the magnetic core, obtaining the response shown in figure 12.

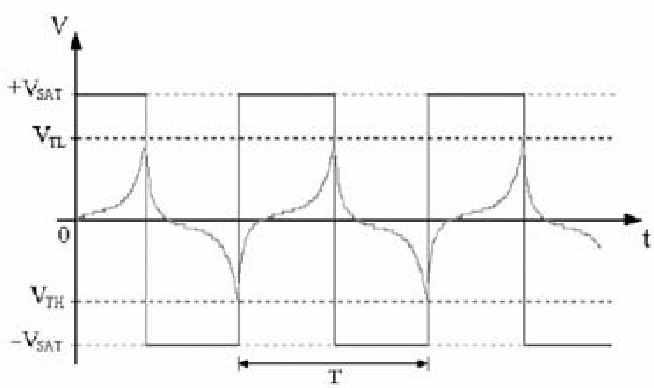


Figure 12

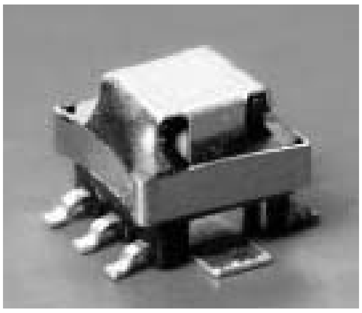
CM Series

SMD Current Transformer Up to 6A

RoHS COMPLIANT 2002/95/EC

Features

- Designed for switching power supply applications.
- Nominal primary current 6 A rms.
- Low profile: 4.9mm height.
- Pick and place mounting.
- Frequency range above 100KHz.
- Taped & Reeled.
- Operating temperature from -25° C to 105° C.



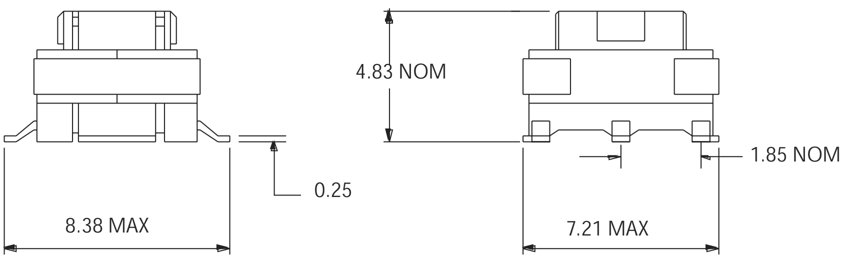
Product List

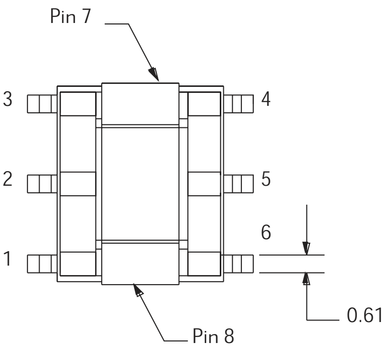
Part Number	Turns Ratio	Ls min (μH)	Sec Rcu (Ω Max)	Load Resistor R_B (Ω)
CM - 020	1 : 20	75	0.55	3.33
CM - 030	1 : 30	170	0.87	5.00
CM - 040	1 : 40	300	1.14	6.67
CM - 050	1 : 50	470	1.50	8.33
CM - 060	1 :60	675	1.75	10.00
CM - 070	1 : 70	920	4.75	11.67
CM - 100	1 : 100	1875	5.50	16.67
CM - 125	1 : 125	3000	6.50	20.83

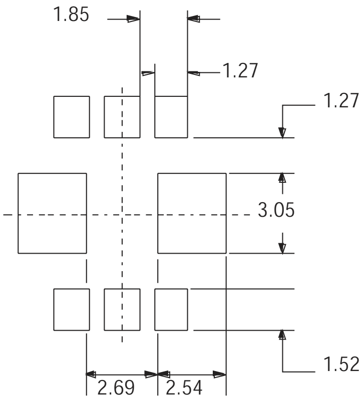
Notes:

- Inductance at 0.1 Vac, 10KHz.
- Terminating resistor for 1 V out with 6 amps AC in the primary.
- Reverse polarity parts are available for all turns ratios: (CM-020R / CM-125R).
- Hipot is 500 Vrms / 50 Hz / 2 seconds.
- Ls: Secondary inductance.

Dimensions

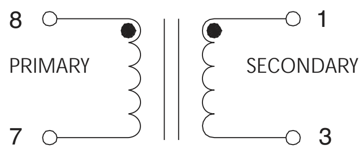






Recommended pad layout

Schematics



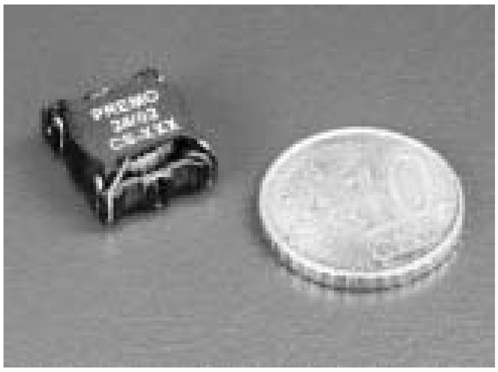
CS Series

SMD Current Transformer Up to 15A

RoHS COMPLIANT 2002/95/EC

Features

- Designed for switching power supply applications.
- Low profile and self leaded, surface mount.
- UL94-V0 Plastic material.
- Taped & Reeled according to EIA 481.
- Less than 8mm height.
- Up to 15 Arms primary current.
- Storage temperature -30° to 130° C.
- Operating temperature from -20° to 105° C.



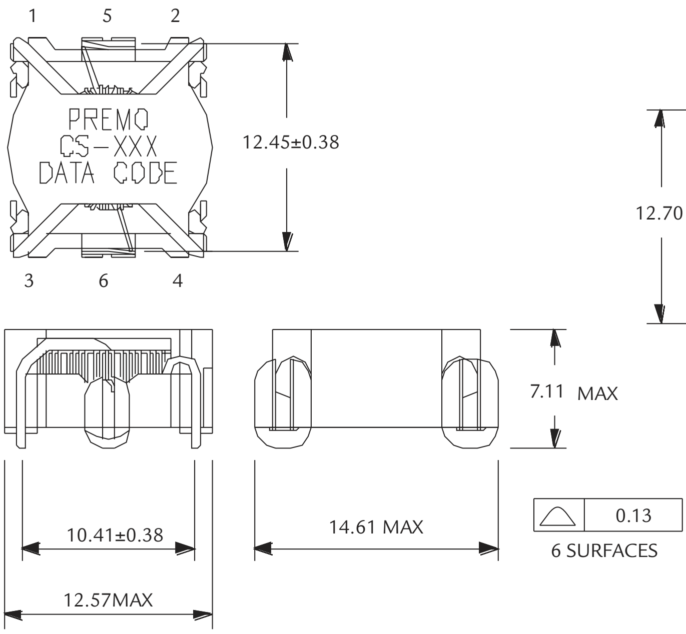
Product List

Part Number	Ip (Arms)	R_B (Ω)	Ls (mH Min)	Sec Rcu (Ω Max)	Turns (Ns)
CS - 050	15	25	4.6	0.3	50
CS - 100	15	50	18.5	0.8	100
CS - 200	15	100	74*	2.8	200

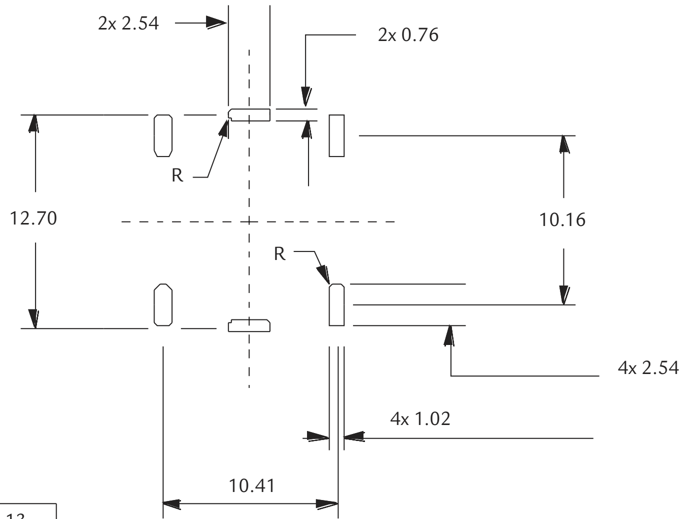
Notes:

- Inductance is mesured at 100 KHz, 20 mVrms. *10 KHz, 60 mVrms.
- Hipot is 500 Vrms, measured at 50 Hz, 2 seconds.
- I, Rt are reference values only.
- Reference values are for the one turn winding connected in parallel for unipolar operation at 200 KHz.

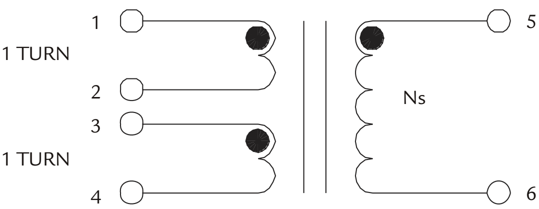
Dimensions



Footprint



Schematics



CWP/CWL Series

High Precission 50 Hz KWh-meter Current Transformer

RoHS COMPLIANT 2002/95/EC

Features

- Negligible amplitude error due to low core losses.
- Reduced phase error due to simple electronic calibration.
- Improved stability of the permeability across the entire temperature range.
- Reduced core size or number of windings.
- Frequency 50/60 Hz.
- Operating temperature from -40° C to 85° C.

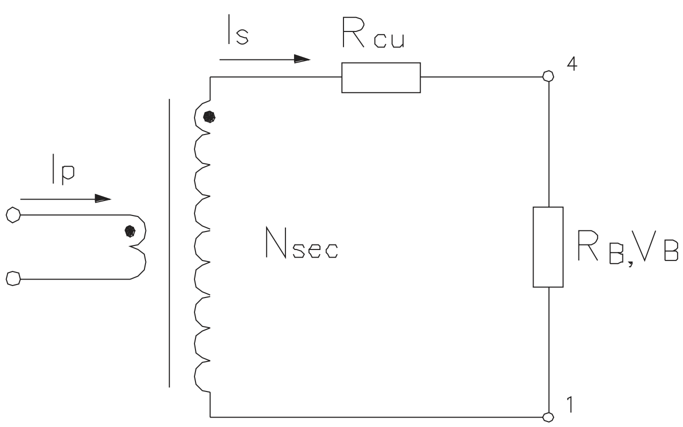
Product List

Part number for pins	Part number for lead wire	I_P (A_{RMS})	I_{PMax} (A_{RMS})	I_{DCMax} (A_{DC})	Phase error tan Φ (°)	Burden R_B (Ω)	Burden voltage V_B (V_{RMS})	Centre hole Ø (mm)
CWP-0061 B1	CWL-0061 C1	0.10 - 6	6	-	< 0.4	125.0	0.3	7
CWP-0062 B1 (*)	CWL-0062 C1 (*)	0.10 - 6	6	-	< 0.55	100.0	0.3	7
-	CWL-0201 A1	0.25 - 20	79	-	< 0.2	37.5	0.3	5
-	CWL-0202 A1	0.25 - 20	135	36	< 3.4	37.5	0.3	5
-	CWL-0601 A2	0.50 - 60	83	-	< 0.2	12.5	0.3	7
CWP-0600 B2	CWL-0602 A2	0.50 - 60	270	80	< 3.7	12.5	0.3	8.5/7
-	CWL-1001 A3	1 - 100	176	-	< 0.1	7.5	0.3	10
CWP-1000 B3	CWL-1002 A3	1 - 100	345	113	< 4.1	7.5	0.3	11.5/9.5

Notes:

Nsec = 2500 *Nsec = 2000
I_P primary-current range.
I_{pmax} max.permissible AC-primary current without saturation.
I_{DCmax} max. DC-current value without saturation for class 1-counter (IEC 1036).
tan Φ max. phase error concerning of I_P.
R_B burden resistance for 0.3V signal voltage at I_{pmax}.
V_B burden voltage RB during max I_P.
Linearity better than 0.1%.
Amplitude error better than 1%.
Values in product list are referenced to 50 Hz measurements.
Dielectric strenght 2500 Vac/50 Hz/1 min.

Test Circuit



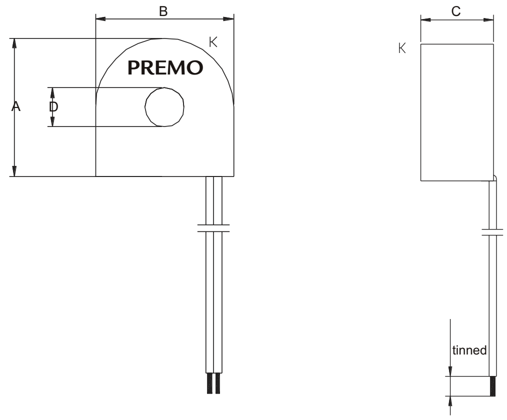
CWP/CWL Series

High Precission 50 Hz KWh-meter Current Transformer

RoHS COMPLIANT 2002/95/EC

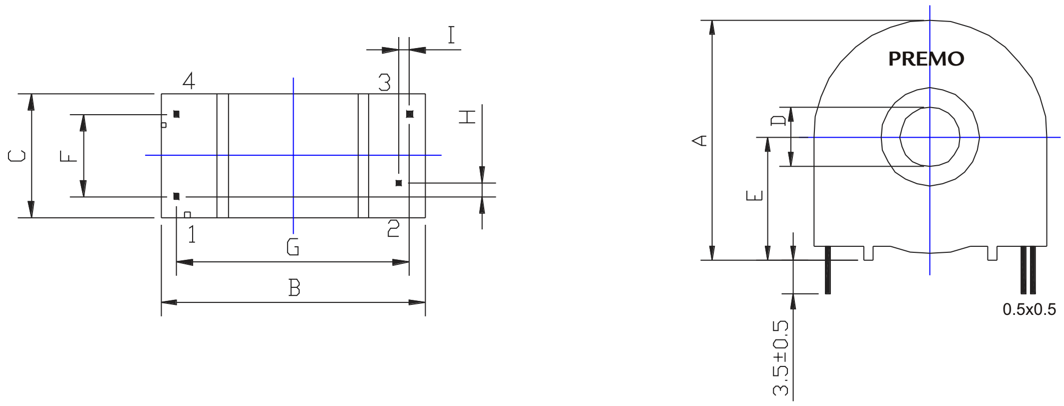
Dimensions for A housing

Type	A	B	C	D
A1	≤ 30.0	≤ 28.5	≤ 14.5	≥ 5.0
A2	≤ 31.5	≤ 31.5	≤ 17.0	≥ 8.0
A3	≤ 35.0	≤ 35.0	≤ 18.5	≥ 9.5



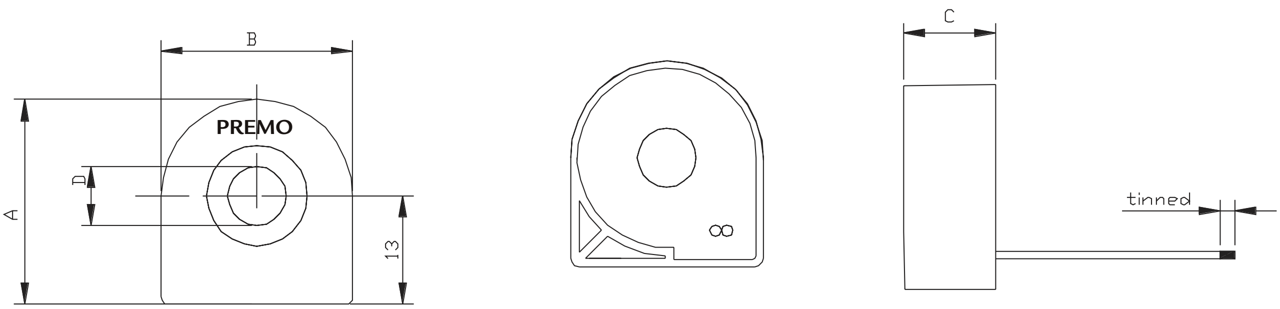
Dimensions for B housing

Type	A	B	C	D	E	F	G	H	I
B1	≤ 25.5	≤ 24.5	11.5	≥ 6.3	13.0	7.62	21.59	1.27	0.00
B2	≤ 31.5	≤ 31.0	14.0	≥ 8.5	16.0	10.00	25.5	2.54	2.54
B3	≤ 33.5	≤ 34	14.0	≥ 11.5	17.3	10.16	27.94	2.54	2.54



Dimensions for C housing

Type	A	B	C	D
C1	24.5	23	11	7



Tolerances ± 0.1 unless otherwise noted.
Dimensions in mm.

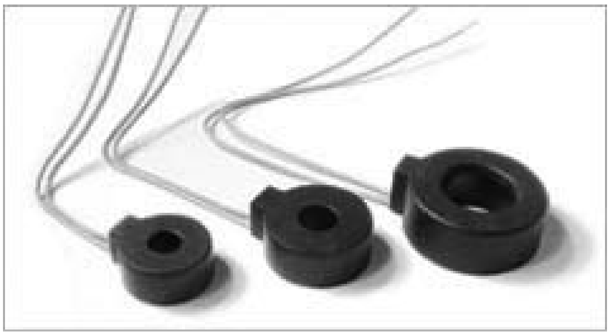
TCRC Series

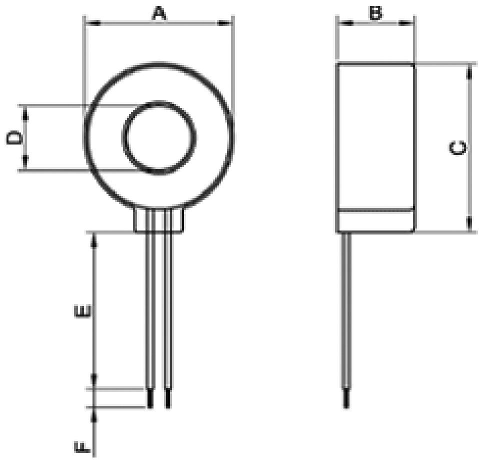
Wire Lead current transformers

RoHS COMPLIANT 2002/95/EC

Wire Lead current transformers.

- Compact size.
- Light weight.
- High sensitivity.
- Non-contact, isolated measurement.
- Five different case sizes.
- Frecuency: 50 to 400 Hz.
- Ideal for electric shock prevention earth leakage breakers and short circuit relays.





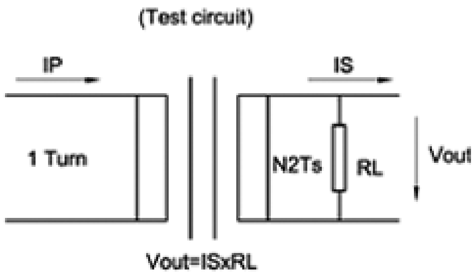


Table of dimensions

Code	A	B	C	D	E	F
TCRC 50-1	18,7	7	21,2	6,7	65	5,0
TCRC 50-2	22	8	25	7,6	65	5,0
TCRC 50-3	24	12	27	10,2	65	5,0
TCRC 50-4	30	11	33	15,0	65	5,0
TCRC 50-5	48	19,3	51,5	19,0	65	5,0
Tolerance (mm)	max.	max.	max.	min.	±2	±1

Table of characteristics

Code	Rated Current (Arms)	Output Voltage (mV) min.	Overload Charct. (%) max.	Temp.Charct. (%) max.	Measurments Conditions
TCRC 50-1	30	8	10	±10	I_0=11,25 mA R_L=1,0k
TCRC 50-2	30	8	10	±10	I_0=11,25 mA R_L=1,0k
TCRC 50-3	60	8	10	±10	I_0=22,50 mA R_L=0,3k
TCRC 50-4	125	8	10	±10	I_0=22,50 mA R_L=0,3k
TCRC 50-5	200	8	10	±10	I_0=22,50 mA R_L=0,3k

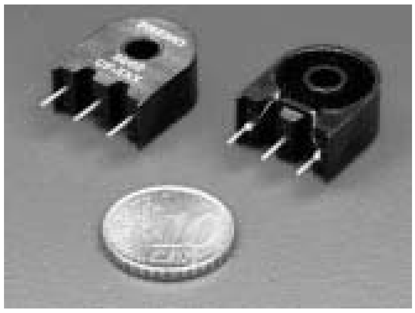
CF Series

PTH SMPS Current Transformer Up to 15A

RoHS COMPLIANT 2002/95/EC

Features

- Speciallly designed for current-mode feedback in PWM switched mode power supplies and converters.
- Fully encapsulated in Polyurethane according to UL94-V0.
- Frequency range from 5 - 200 KHz.
- Isolation Primary to Secondary 2750 Vac.
- Extended isolation to full fill EN60950 standard available on request.
- Maximum primary current 15 A rms.
- Operating temperature from -20° C to 85° C.

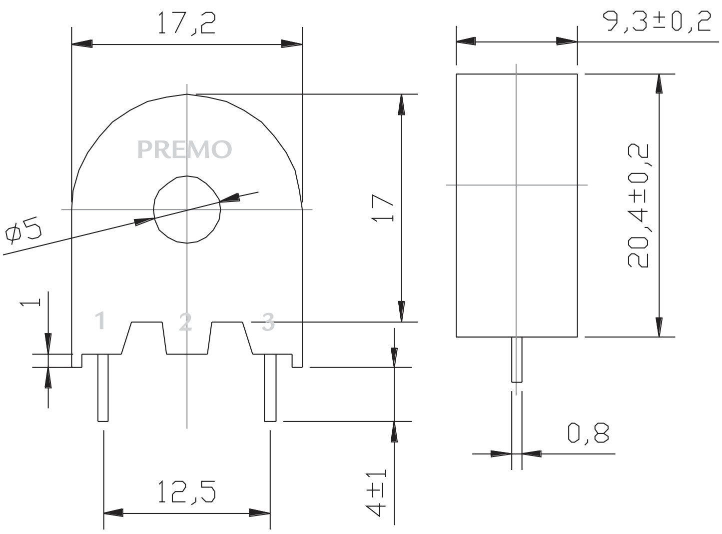


Product List

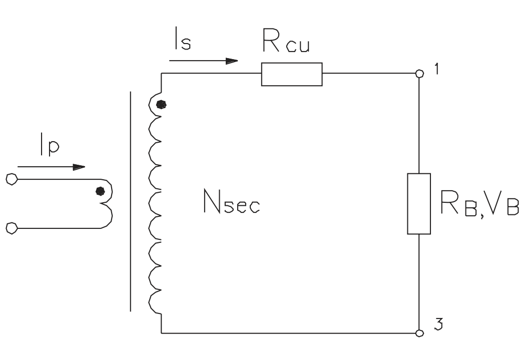
Part Number	Prim/Sec Ratio	Ip (A_{RMS} Max)	Sec L (mH Min)	Sec Rcu (Ω Max)	V x τ (Max)
CF 050	1/50	15	5.0	0.65	175 VμS
CF 100	1/100	15	22.0	1.30	350 VμS
CF 200	1/200	15	94.5	4.50	700 VμS

Notes:
L: Inductance: (1-3) tested at 10 KHz & 10 mV
V x τ: V = RB x Is τ = 1/2F
I_P (A): Primary current
R_B (Ω): Recommended Terminating Resistance
Is (A): Secondary current
F (Hz): Frequency

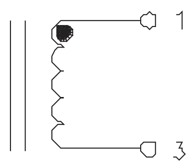
Dimensions



Test Circuit



Schematics



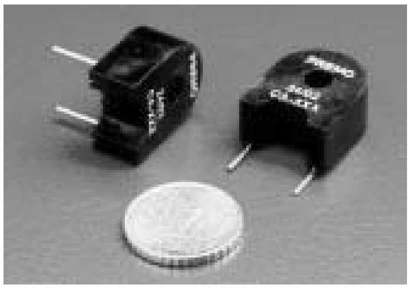
CA Series

PTH SMPS Current Transformer Up to 15A

RoHS COMPLIANT 2002/95/EC

Features

- Designed for switching power supply applications
- Transformer meets IEC950 insulation requirements
- Frequency range from 20 KHz to 200 KHz
- Material according to UL94-VO
- Operating temperature from -20° C to 85°C



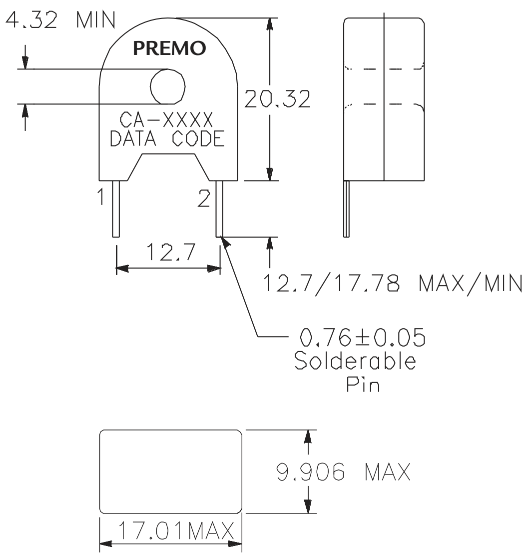
Product List

Part Number	Turns Ns	Secondary Inductance MH (Min)	Secondary Inductance Test Voltatge (15.75 KHz)	R_S (Ω Max)	R_B (Ω Nom)	Primary Unipolar Amp μ Sec. Rating (Max)	Primary Bipolar Amp μ Sec. Rating (Max)
CA-050X	50	7.7	0.5	0.55	50	150	300
CA-100X	100	30.9	1.0	1.2	100	300	600
CA-200X	200	123.6	2.0	3.5	200	600	1200

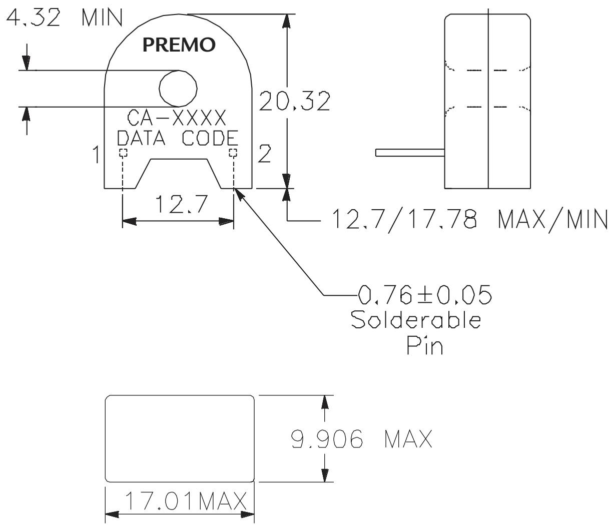
Notes:

- Maximum ratings specified with rated secondary terminating resistance and 1 turn primary.
- Amp-microsecond (AμSec.) rating of primary equals volt microsecond (VμSec.) rating of secondary when secondary is terminated in rated resistance. (Amp-microseconds is equals to the product of a square pulse of current in amps, times the current pulse width in microseconds).
- When terminated with rated terminating resistance, the inductor scale factor is Vout = 1 volt per amp. For center tapped units terminating resistance for each half of winding is listed value divided by two.
- 1 turn primary peak sense current is 20 amps for all parts listed above.

Dimensions

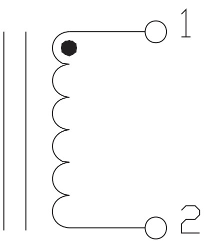


Type V



Type H

Schematics



CV/CH Series

SMPS High Isolation (2500V min) Current Transformers

RoHS COMPLIANT 2002/95/EC

Features

- Designed for switching power supply application.
- Wide range of housings.
- Cases made of UL94-V0 material.
- Insulation 2.5 KVac.
- Typical Frequency range 10 KHz ~ 200 KHz.
- Storage temperature from - 20° C to 100° C.
- Operating temperature from - 20° to 85° C.

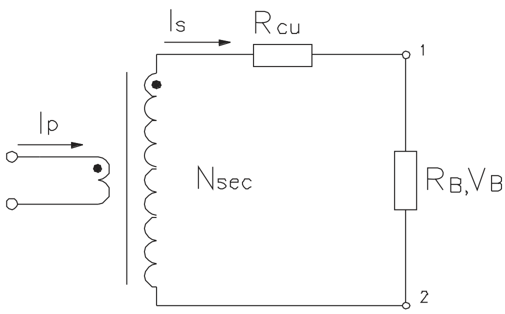
Product List

Part Number	Prim/Sec Ratio	Ipn (A_{RMS})	Sec Ls (mH Min)	Sec Rcu (Ω Max)	V x τ (VμS Max)
CV1 - 050	1/50	15	7.5	0.30	175
CV1 - 100	1/100	15	30	0.70	350
CV1 - 200	1/200	15	120	4	700
CV2 - 050	1/50	25	8	0.30	300
CV2 - 100	1/100	25	35	0.80	600
CV2 - 200	1/200	25	140	3.80	1200
CV3 - 050	1/50	40	8	0.20	500
CV3 - 100	1/100	40	33	0.50	1000
CV3 - 200	1/200	40	135	3	2000
CV4 - 050	1/50	55	12	0.20	700
CV4 - 100	1/100	55	45	0.60	1400
CV4 - 200	1/200	55	180	2	2800
CH2 - 050	1/50	25	8	0.30	300
CH2 - 100	1/100	25	35	0.80	600
CH2 - 200	1/200	25	120	4.2	1200
CH3 - 050	1/50	40	8	0.20	500
CH3 - 100	1/100	40	33	0.50	1000
CH3 - 200	1/200	40	135	3	2000
CH4 - 050	1/50	55	12	0.20	700
CH4 - 100	1/100	55	45	0.60	1400
CH4 - 200	1/200	55	180	2	2800

Notes:

L_S: Secondary inductance 10KHz / 10 mV.
V_B x τ: V = R_B x Is   τ = 1/2F
I_P (A): Primary current.
I_S (A): Secondary current.
R_B (Ω): Load resitance.
F (Hz): Switching frequency.
Rcu (Ω): Secondary winding DCR.

Test Circuit



CV/CH Series

SMPS High Isolation (2500V min) Current Transformers

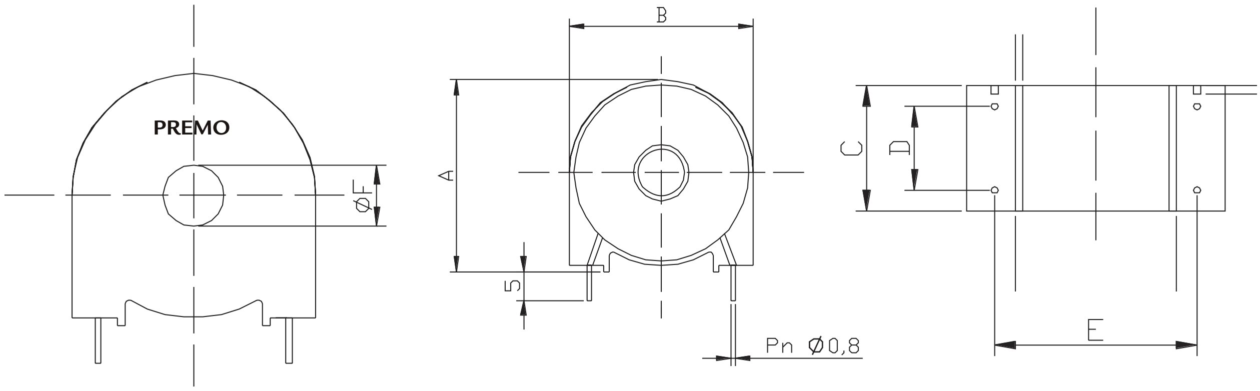
RoHS COMPLIANT 2002/95/EC

Product List CV Serie

Type	A	B	C	D	E	F
CV1	20	18	10.5	5	15	5
CV2	25.5	23	12.5	7.5	17.5	5
CV3	29.5	27	15	10	22.5	6
CV4	33.5	32	15	10	25	8

Dimensions in mm.
Tolerances ± 0.1 unless otherwise noted.

Dimensions



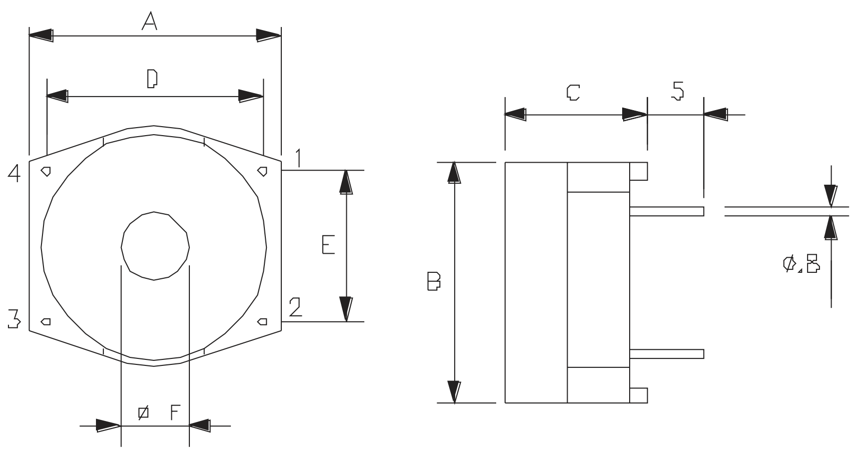
Bottom view

Product List CH Serie

Type	A	B	C	D	E	F
CH2	23	22	15	20	12.5	5
CH3	28	28	17.5	25	15	6
CH4	33	32	17.5	30	20	8

Dimensions in mm.
Tolerances ± 0.1 unless otherwise noted.

Dimensions



Bottom view

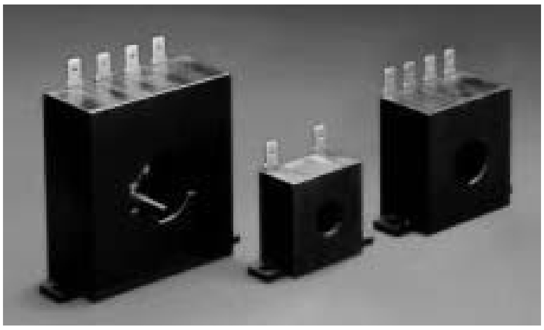
TC Series

50/60 Hz Industrial Current Transformer up to 600A

RoHS COMPLIANT 2002/95/EC

Features

- For 50/60 Hz current, from 25 to 600 A nominal primary current.
- High number of secondary turns for a precise measurements of primary current.
- Low value for secondary currents, directly suitable for electronic circuit measurements.
- Cases made of UL94-VO material.
- Insulation prim/sec 4K Vac.
- Operating temperature from -40° to 70° C.



Product List

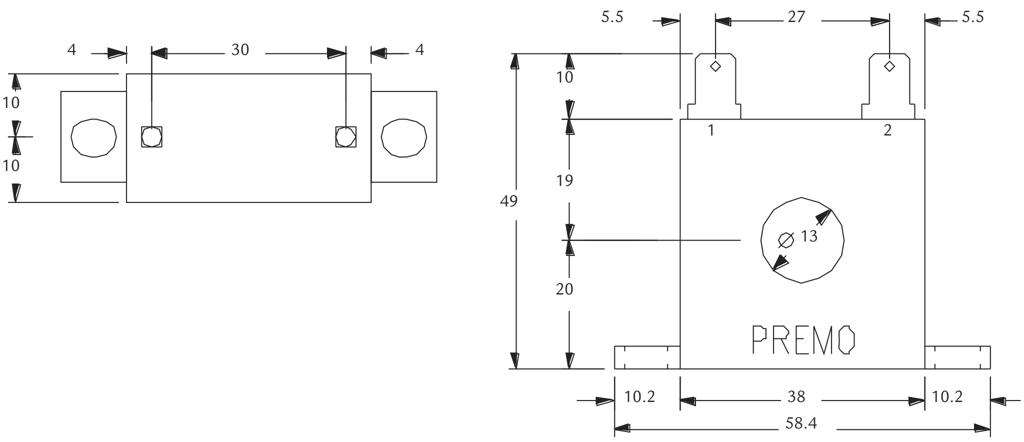
Part Number	Ip/Is (A)	Ns	VB (Vac)	RB (Ω)	Accuracy	Case	Outputs	Diagram
TC-1012505	25 / 0.05	500	2	40	2%	A	1 - 2	1
TC-1015005	50 / 0.05	1000	4	80	1%	A	1 - 2	1
TC-2011002	100 / 0.2	500	4	20	1%	B	1 - 4	2
TC-2011001	100 / 0.1	1000	4	20	0.5%	B	1 - 4	2
TC-3014004	400 / 0.4	1000	8	20	0.5%	C	1 - 4	2
TC-3014002	400 / 0.2	2000	4	20	0.25%	C	1 - 4	2
TC-3016006	600 / 0.6	1000	6	10	0.25%	C	1 - 4	2
TC-3016002	600 / 0.2	3000	4	20	0.5%	C	1 - 4	2
	25 / 0.2	125	4	20	2.5%	B	1 - 2	3
TC-2031002	50 / 0.2	250	4	20	1.5%	B	1 - 3	3
	100 / 0.2	500	4	20	1%	B	1 - 4	3
	200 / 0.2	1000	4	20	0.5%	C	1 - 2	3
TC-3034002	300 / 0.2	1500	4	20	0.35%	C	1 - 3	3
	400 / 0.2	2000	4	20	0.25%	C	1 - 4	3
	200 / 0.4	500	8	20	1%	C	1 - 2	3
TC-3036004	400 / 0.4	1000	8	20	0.5%	C	1 - 3	3
	600 / 0.4	1500	8	20	0.25%	C	1 - 4	3

Notes:

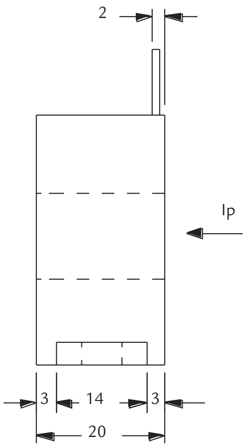
I_P: Primary alternating current (rms) I_S: Secondary alternating current (rms) N_S: Secondary turns.
VB: Voltage in RB (rms) RB: Secondary load resistance.

Dimensions

CASE A



CASE B

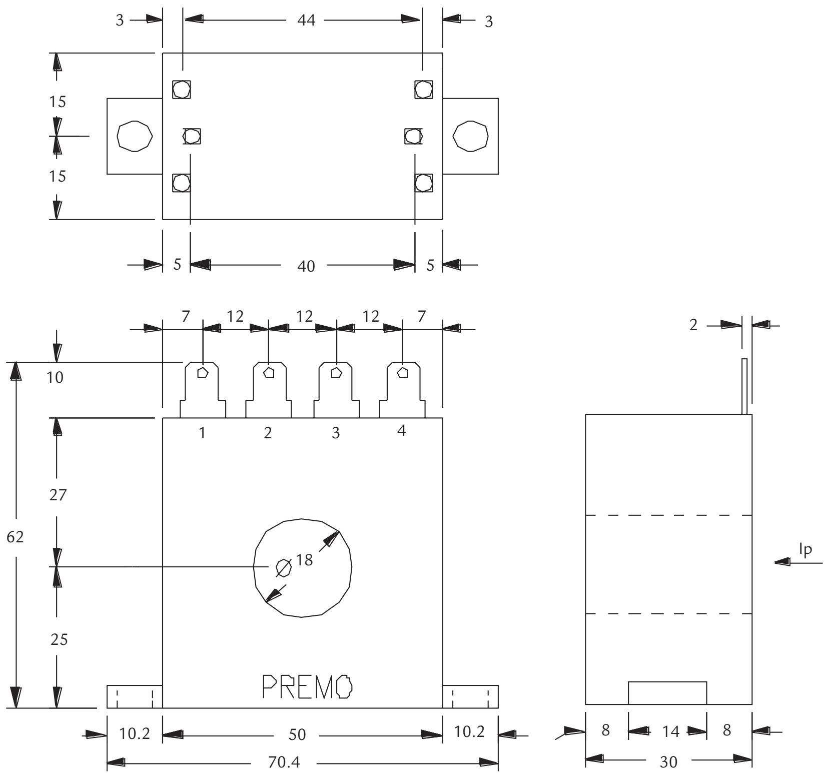


TC Series

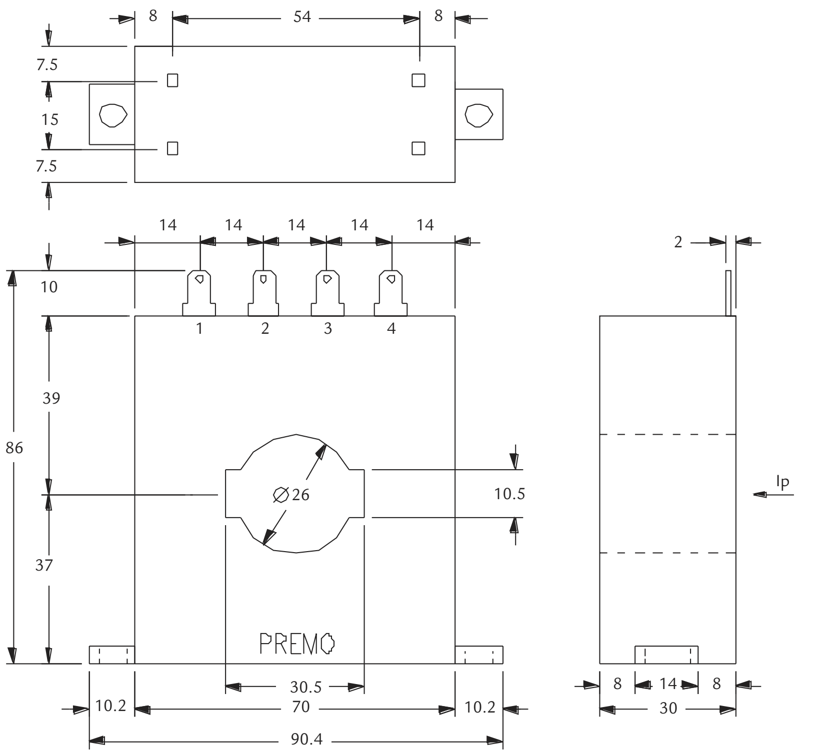
50/60 Hz Industrial Current Transformer up to 600A

Dimensions

CASE B



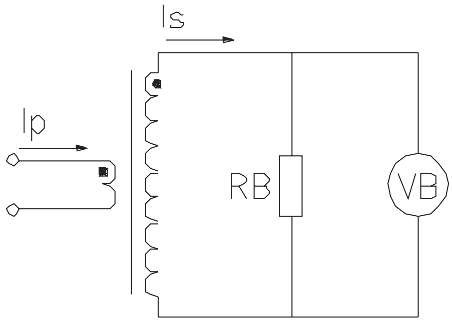
CASE C



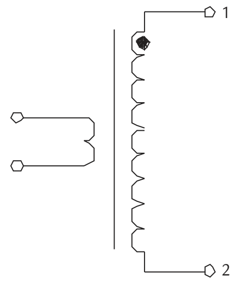
FIXATION:

Holes for self-tapping screws 2.9 x 9 or M4 screws and nuts.
Dimensions in mm.
Pin dimensions: 6.35 x 0.80 mm.

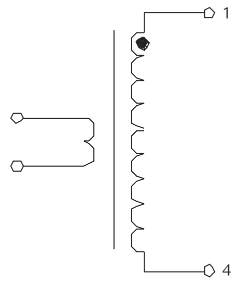
Test Circuit



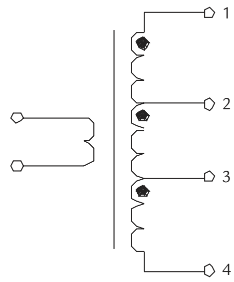
Electric Diagram



1



2



3

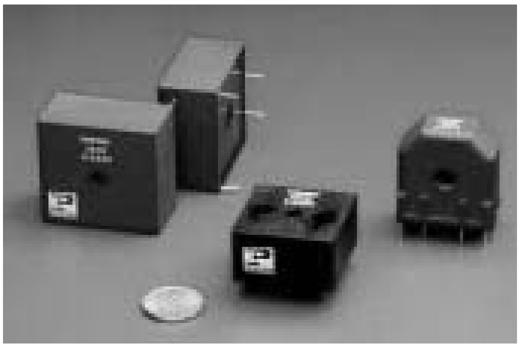
Custom Made Current Transformers

RoHS COMPLIANT 2002/95/EC

Features

- Wide range of housings for custom design application.
- UL94-V0 plastic material and potting resin.
- 50/400 Hz or 1/20 KHz frequency ranges for currents.

This range includes a large variety of housings that allow designers to choose the most suitable size and dimensions according their needs. At the same time, PREMO offers the possibility to design the complete transformer if we know electrical parameters.
Selecting appropiate magnetic core, frequency of measured current can be inside 50/400 Hz and 1/20 KHz ranges, as most usuals.



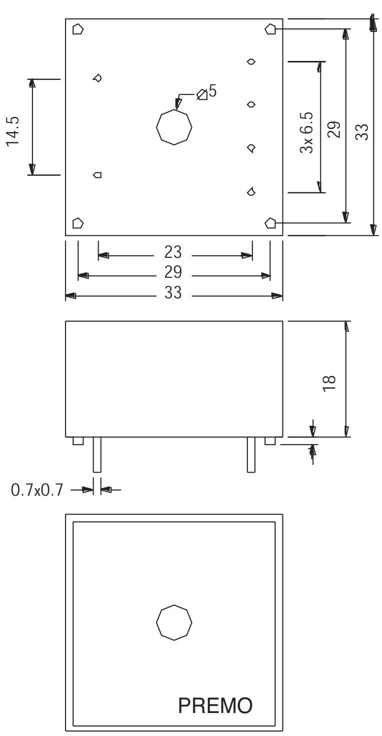
Connection pins are of free election.
If not specified, housing have a hole for primary conductor, but if needed, this primary can be integrated into housing with direct output to PBC.
Despite all this range, if you do not find a suitable box, please, contact PREMO for a

Product List

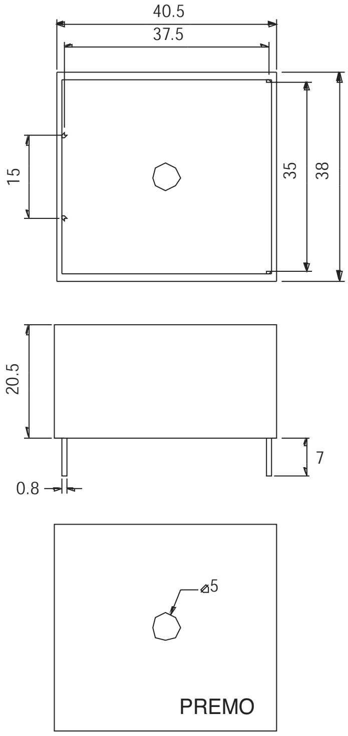
Type	A	B	C	D	E	F
1	20	17.8	12.8	15	10	5
2	25	23	15.5	20	12.5	5
3	30	27	18	22.5	15	5
4	35	32	20.5	27.5	17.5	7.5
5	35	32	23	27.5	20	7.5
6	37.5	32	25.5	27.5	22.5	7.5
7	40	37	25.5	30	22.5	7.5
8	47.5	43	28	40	25	7.5

Dimensions

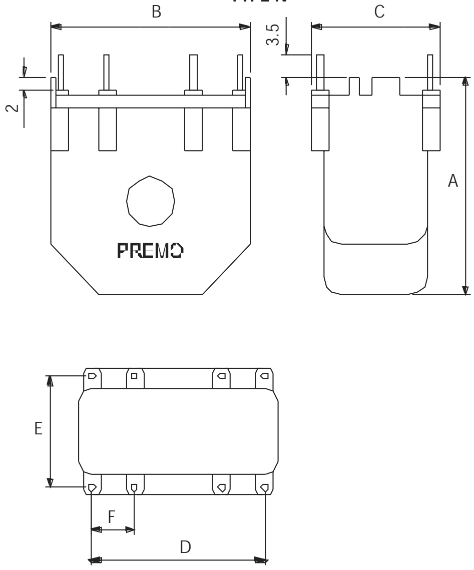
TYPE Z



TYPE G



TYPE N



Dimensions in mm.

High Sensibility Rogowski coils

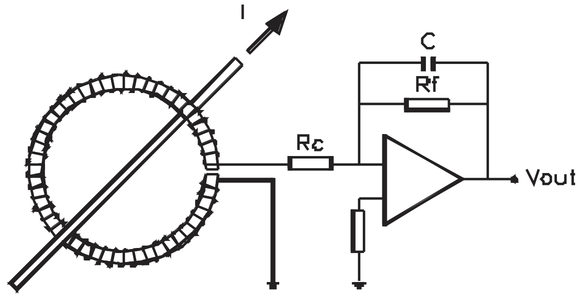
RoHS COMPLIANT 2002/95/EC

Introduction

Rogowski coils are used for detection and measurement of electric currents. The operating principle is that if an air-cored coil is placed around the conductor in a closed path, the magnetic field produced by the current induces an output voltage E in the coil that is proportional to the rate of change of the cross section area A which encircles the current I, given by the expression:

$$E = -M \frac{dI}{dt}$$

where M is the mutual inductance between the Rogowski coil and the conductor. If the coil is connected to an integrator, the output reproduces the current waveform.



Working principles

A Rogowski coil works by sensing the magnetic field in the space around the conductor that carries the current. The relationship is given by the Ampere's Law. According to it, the line integral of the magnetic field around a closed loop is equal to the net current encircled by it, no matter what path the loop takes.

$$\oint H \cos(\alpha)\, dl = I$$

The mathematical expression that shows this effect   where dl is a small element of length along the loop, H is the magnetic field in dl and a is the angle between the direction of the field and the direction of the element.

Having an helical coil with n turns per meter and cross-sectional area A which encircles the conductor, the flux linking the coil is given by:

$$\Phi = \mu_0 n A \int H\cos(a)\, dl = \mu_0 n A I$$

The output voltage from the coil is given by the relation:

$$E = -\frac{d\Phi}{dt} = -\mu_0 n A \frac{dI}{dt} = -M \frac{dI}{dt}$$

where M is the mutual inductance between a coil and the conductor and is independent of the frequency.

Construction

Basically, there are two kinds of current transformers using a Rogowski coil.

1.-Flexible Rogowski coil:

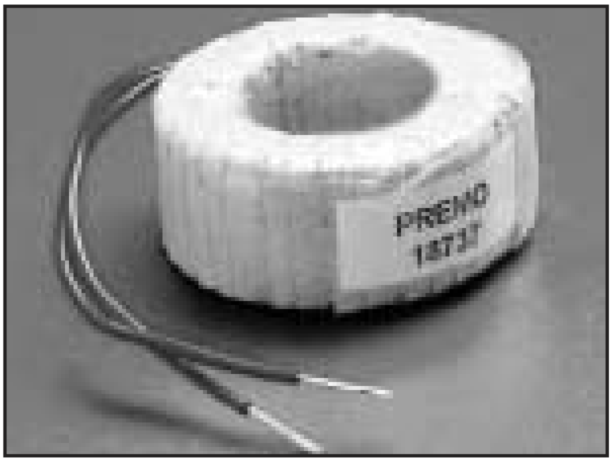
The winding is placed over a long and flexible former. The coil is fitted by wrapping it round the conductor to be measured and bringing the ends together. It is important that the ends must be aligned correctly. If it is necessary, it can be wrapped several times round the conductor to increase the output voltage, proportional to the number of wraps.

Unless this is less sensitive and less accurate than the rigid form, it is better for high-frequency measurements.

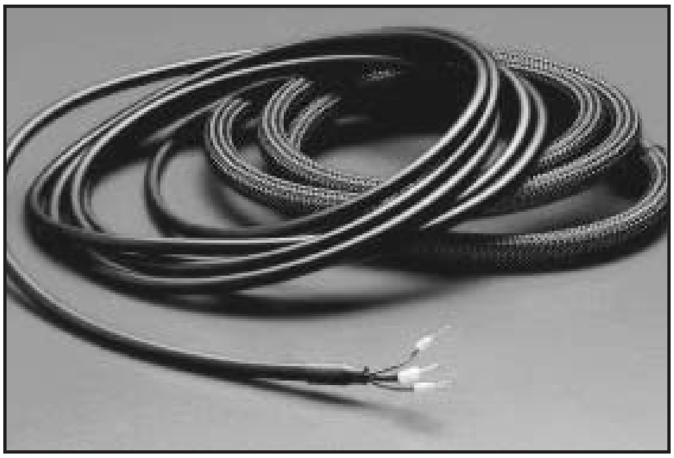
It is very useful with large size or awkward shaped conductors or in places with limited access or where a lightweight transducer is needed which can be suspended on the conductor. It is appropiate to mesure currents without disconnecting the conductor. Its form is very compact and versatile.

High Sensibility Rogowski coils

RoHS COMPLIANT 2002/95/EC



Rigid Rogowski coil.



Flexible Rogowski coil.

2.-Rigid Rogowski coil:
The rigid coils are wound on a solid former, normally in a toroidal shape, and tend to be bulkier than flexible ones.
Its stability is better than flexible coil one. The output voltage is very stable and the accuracy is very good. Rigid coil measures a range of frequencies lower than the flexible one. It is more advisable for low-current and low frequency measurements. In this case, the conductor must be disconnected before the measurement.
It can be used for high precision measurements or for permanent installation.

Features and applications

If the coil is connected to an integrator, the output reproduces the current of the conductor. The sensibility is given by:

$$\frac{V_{out}}{I} = \frac{M}{\tau}$$

where V_{out} is the output voltage of the integrator, τ =RC is its time constant and I is the current of the conductor. Changing τ, operation range can be modified and it is possible to operate from milliamperes to megamperes.
It is important to take into account linearity and bandwidth of integrator, and design it according to the kind of current to be measured. For high frequencies is more appropriate to use a passive integrator composed only of R and C.
Rogowski coil used as current sensor has numerous advantages:
- The air coil has no histeresis, it does not saturate and it is linear. What is more, the mutual inductance is independent of the current.
- Good response to current transients, so they are appropriate for current pulses or for protection systems.
- High bandwidth. The high-frequency limit is determined by the self-resonance of the coil and depends on the coil design. Even if they are not good for DC measurements, with an accurate design it is possible to measure frequencies lower than Hz.
- The same coil can measure a wide range of currents (from milliamperes to million amperes).

High Sensibility Rogowski coils

RoHS COMPLIANT 2002/95/EC

- Easy calibration. Because of its linearity, Rogowski coils may be calibrated at any current level.
- It is light-weight, compact and easy to install and to transport. Furthermore, it is easy to use.
- Output variation with the temperature is very low.
- Low consumption.

The next table shows the differences between the conventional current transformers, Hall effect sensor and current transformers based on Rogowski coils.

Features	Conventional current transformer	Hall effect sensor	Rogowski coil
Cost	Medium	High	Low
Bandwith	Low	Medium	High
Isolation	High	High	High
Weight	Medium	Medium	Low
Linearity	Good	Medium	Very good
High current measuring capability	Good	Good	Very good
Transient response	Medium	Medium	Very good
DC response	Bad	Good	Bad
Low frequency response	Medium	Good	Good
Power consumption	Low	Medium	Low
DC/high current saturation problem	Yes	Yes	No
Output variation with temperature	Low	Medium	Very low
DC offset problems	No	Yes	No
Saturation and hysteresis problems	Yes	Yes	No
Easy of installation	Medium	Medium	Good

ROGOWSKI COILS

Premo manufactures two kind of coils, flexible and rigid.

Flexible coils (FRC)

The winding is placed over a plastic flexible material.
Length depends on the needs of the customer and external diameter can be normally between 8 and
11mm. The output is connected to a standard lead with 2m long. External insulation can be composed of one or several insulation layers, thermal shrinkable protection, electrostatic screen,... which affects the flexibility of the coil. Electrostatic screen can be added to improve insulation of external influences.
As an open coil, it is no necessary to disconnect the conductor that carries the current to be measured and the user has only to unit the ends after the coil is placed around the conductor.

To increase the sensibility, it can be wrapped several times round the conductor.
Electrical features are (typical values):
- Mutual inductance M between 30 and 300nH.
- Maximum frequency: between 100KHz and 1MHz depending on M.
- Minimum frequency: between 1 and 10Hz, depending on the integrator.
- Current range: from 1A to 1MA.
- Accuracy: 1%.

Rigid coils (SRC)

The winding is placed over a plastic shaped toroidal material. The output is connected to a standard lead with 2m long. External insulation can be composed of one or several insulation layers. Other alternatives are varnishing or encapsulated and potted. Electrostatic screen can be added to improve insulation of external influences. The disadvantage of these coils is that the conductor to be measured must be disconnected and placed through the hole of the core.

High Sensibility Rogowski coils

RoHS COMPLIANT 2002/95/EC

Electrical features are (typical values):
- Mutual inductance M between 3 and 5uH.
- Maximum frequency: between 10KHz and 30KHz depending on M.
- Minimum frequency: can reach 0.1Hz, depending on the integrator
- Current range: from 100mA to more than 100A.
- Accuracy: 0.1%

Applications

Both types can be used directly, then the coil output is a voltage proportional to the $\frac{dI}{dt}$ of the measured current:

$$V_{out} = -M \frac{dI}{dt} \text{ with } M = \mu_0 nA$$

If the user wants to measure exactly the current of the conductor, it is necessary to add an integrator to the coil output.
This assembly (coil+integrator) will come defined by its sensibility that relates output voltage of the integrator and measured current, being:

$$S = \frac{V_{out}}{I} \quad \frac{M}{\tau}$$

where $\tau = R_C C$ is the time constant of the integrator. This sensibility depends on the maximum and the minimum measured current, and the integrator can offer different sensibilities to be selected..

Typical values are:

$V_{out} = 3V_{rms}$

$I_{max} = 30A$	S = 100 mV/A
$I_{max} = 300A$	S = 10 mV/A
$I_{max} = 3000A$	S = 1 mV/A

PRT Series

Standard Flexible Rogowski Transducers

RoHS COMPLIANT 2002/95/EC

Features

-Measurable current from 300mAmps to 300.000Amps.
-Bandwidth from 0.1Hz to 10MHz.
-Minimal DC offset, in order to mV.
-Voltage isolation up to 3kVac.
-Coil temperature range: from –20C° to 100°C.
-Flexible coils are thin and flexible, with standard or custom lengths.
-Output with BNC connector.
-Cable length 2.5 meters.

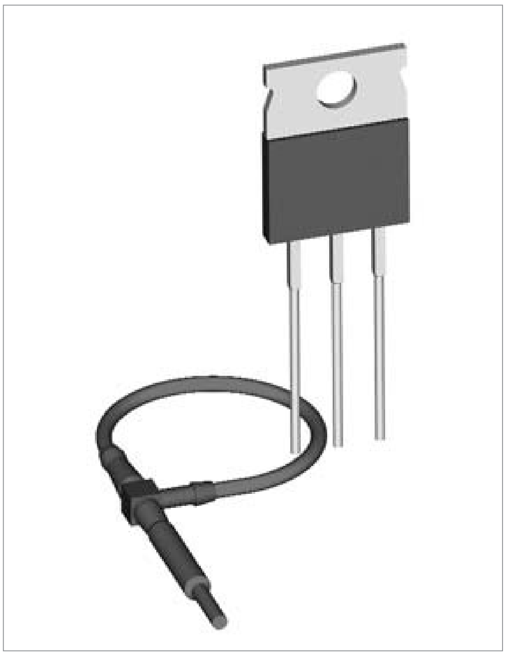
Applications

-Monitoring high frequency sinusoidal currents.
-Monitoring current waveforms for semiconductor switches.
-Measuring pulses of current.
-Measuring AC currents superimposed on large DC currents.

Premo Rogowski Transducers ordering code

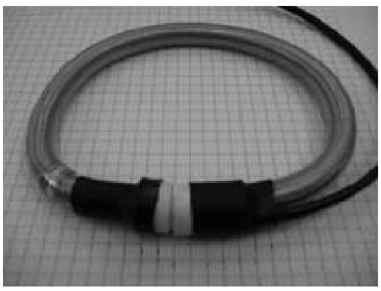
PRT - □□□ - □ - □

Coil lenght (*8-1-2-3-7*)
Coil size (*L-M-S*)
Transducer sensitivity (mV/A)



Ultra mini flexible Rogowski coil

Mini flexible Rogowski Coil



Large flexible Rogowski Coil

PRT Series
Standard Flexible Rogowski Transducers

RoHS COMPLIANT 2002/95/EC

Electrical Specifications

Size	Sensitivity (mV/A)	Peak current (kA)	COIL LENGHT 80mm	100mm	200mm	300mm	700mm
LARGE (L)	200	0,03				X	X
	100	0,06				X	X
	50	0,12				X	X
	20	0,3				X	X
	10	0,6				X	X
	5	1,2				X	X
	2	3				X	X
	1	6				X	X
	0,5	12				X	X
	0,2	30				X	X
	0,1	60				X	X
	0,05	120				X	X
	0,02	300				X	X
MINI (M)	200	0,03		X	X		
	100	0,06		X	X		
	50	0,12		X	X		
	20	0,3		X	X		
	10	0,6		X	X		
	5	1,2		X	X		
	2	3		X	X		
	1	6		X	X		
	0,5	12		X	X		
	0,2	30		X	X		
	0,1	60		X	X		
	0,05	120		X	X		
	0,02	300		X	X		
ULTRAMINI (S)	200	0,03	X				
	100	0,06	X				
	50	0,12	X				
	20	0,3	X				

DCT-700A

DC Current Transducer

Introducction

The necessity to measure currents in the industry has been, together with sensing voltage, the most important tools for proceedings controls. However, current sensing is more complicated than voltage sensing, specially with DC currents. There are many solutions for current measurement, such as conventional current transformers, shunt resistors, hall effect sensors or rogowsky coils, which have been used for many years, but all of them have the same problem: a bad response operaing at high currents and high frequencies. On the other hand, not all of them share measuraments of AC and DC currents simultaneously. Another problem is the high temperature variation of some sensors, for example the hall effect sensors. The new Premo DCT-700A current transducer is based on the Flux-Gate technology. Under that principle, the new Premo current transducer DCT-700A is capable to measure AC currents, DC currents, and AC currents with DC offset currents, in a high bandwidth and with currents up to 700A DC. Table below shows the main characteristics of the nowadays technologies for current sensing.

Parameter	Conventional Current Transformers	Hall Effect Sensors	Rogowsky Coils	Shunt Resistors	DCT Flux Gate
DC, AC or both	AC	AC , DC	AC	AC,DC	AC,DC
Bandwidth	Low	Medium	Very High	Low	High
Insulation	High	High	High	Low	High
Dimensions	Small	Small	Medium	Very Small	Medium
Linearity	Good	Medium	Good	Good	Very Good
High Currents Measurements	Medium	Medium	Good	Bad	Very Good
Saturation Problem	Yes	Yes	No	No	No
Power Consume	Low	Low	Low	High	Medium
Drift Temperature	Low	High	Very Low	Very Low	Low

Main Characteristics

-Any type of industrial Current Measurements: AC, DC, Pulse...,
-Capacity to measure currents up to 700 A DC.
-Good response to High Frequencies such as hundreds of kHz.
-Galvanic insulation between primary current and test current.
-Leds indicators of normal or incorrect measurement condition.
-Standard connector D-Sub 9 (male).

Flux-Gate Working Principle

The flux-Gate principle uses a saturable inductor for sensing the field produced by an external current. The performance can be compared to a Hall-Effect Sensor. In the Hall effect sensor, the sensing element is a thin semiconductor sheet that generates a voltage when a magnetic field is applied across it. This voltage depends on the external field and the external exciting current. In the same way, the saturable inductor inductance value (L) depends on the magnetic core permeability . The core permeability changes both with an external field and with an exciting current through the inductor. Both sensing systems are showed in figure 1.

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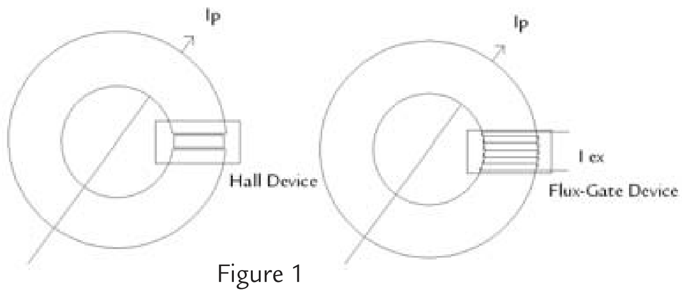

Figure 1

The L value depends on the current Iex and the external current Ip . Both currents induce magnetic fields that change the permeability of the saturable inductor core. The current across the inductor is the response to a concrete voltage applied and a function of Iex and Ip, due changes the total flux around the core increasing or decreasing permeability. In the figures showed below, the waveforms of Ie currents are showed. Figure 2 shows the case for zero external current. At this stage the core permebility and the inductance value are high.

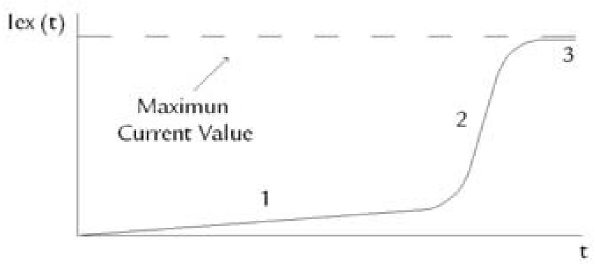

Figure 2. I_E without External Current

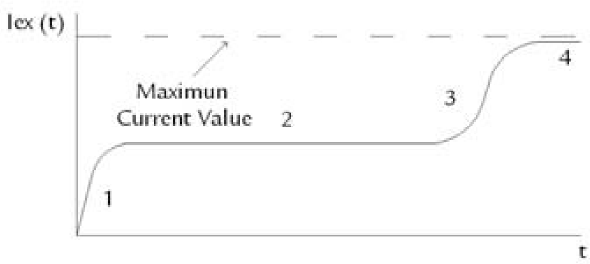

Figure 3. I_E without External Current

Figure 2 represents the response to a voltage step. When the inductance is discharched and the core is not saturated, the current increases with a low slope produced by the high L value. This period corresponds to the track 1. For a concrete current value, the core saturates and the L value deacreases rapidly. Therfore the signal slope is higher and the current rises very fast. This effect is shown in track 2. Finnally, current is limited by the winding resistance and the applied voltage value.

In figure 3, which is also a response to a voltage step, the external current is high, and accordingly, the core permaebility is smaller than nominal value, so the core is saturated and the L value deacreses, so current rises rapidly. This period corresponds to the track 1. When current Iex generates a magnetic field equal and opposite to the external field produced by Ip , the core permeability increases and current slope is again very low (track 2). In the same way than at figure 2, for a concrete current value, the core saturates, therefore the L value deacreses and the current slope current grows. Finnally, as in figure 2, current is limited by the winding resistance and the applied voltage value.

According to explained above, we can use the inductance changes to detect the external field generated by primary current, and therefore the current flowing through the conductor. This is the main principle to measure current with a Flux-Gate device, the sensor is a saturable inductor excited by a square wave. It is usual to use a low frequency square wave to saturate the core like we have explained in the figures 2 and 3. The typical frecuency values are around 200 to 600 Hz.

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DCT Operating Principle

As we have explained before, the operating principle is based in a saturable inductor. The figure 4 shows the current wave form when a low frequency voltage square wave is applied to a saturable inductor, without any external current, the value of the direct current (DC) is zero. This condition is called Zero Flux Condition.

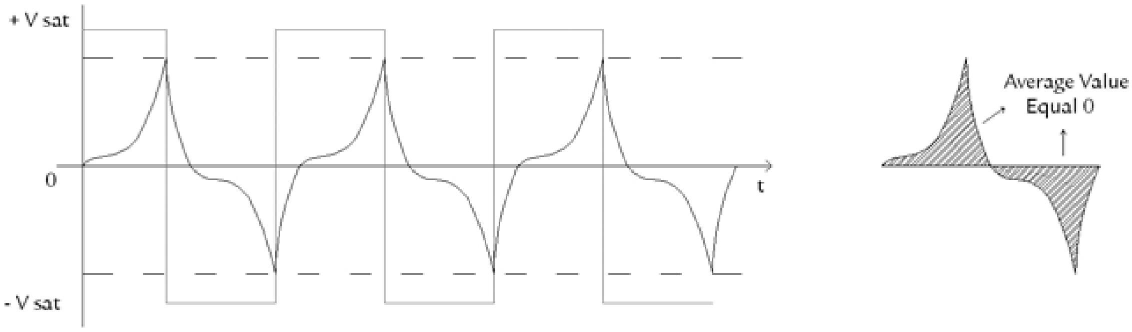

Figure 4. Current by a saturable inductance without external field applied

As shown in above figure, the flux average value, which is the area confined between current wave form and the X axis, is equal to zero. When a current passes through the primary cable, a magnetic field appears in the system, therefore the current changes to average value not equal to zero (See figure 5). The diference between both wafe forms showed corresponds to the current direction applied. If we generate then, a magnetic field to cancel this effect, we will obtain again the Zero Flux condition. Knowing the current applied to cancel this effect and return the system to the Zero Flux Condition, we calculate with high precision the current passing through the primary conductor. In order to have high accuracy, to identical saturable inductors are used to detect the primary current.

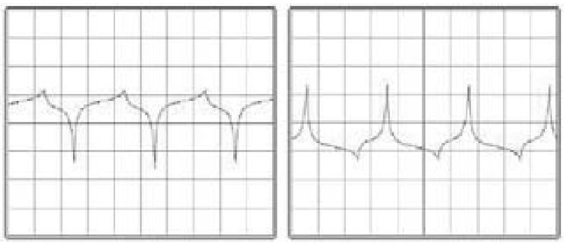

Figure 5.1 Figure 5.2

Figure 5. Effect in Current when external field is applied

The PREMO DCT current transducer operates, therefore, based on this principle. A common winding, called compensation winding, is placed around both cores. The objective of the compensation winding is to cancel the external field. The system is completed with an electronic circuit to impose always the Zero Flux Condition monitoring the compensation current.

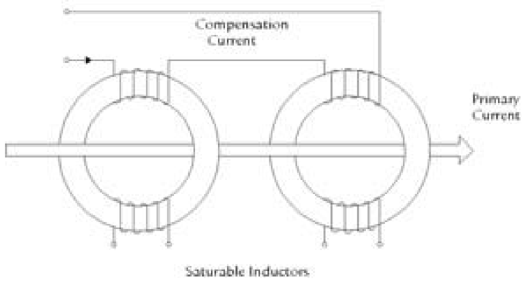

Figure 6. Two saturable inductor and compensation winding

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Block Diagram

Following we represent the operation block diagram of the PREMO DCT-700A current transducer, according to the explained operating principle:

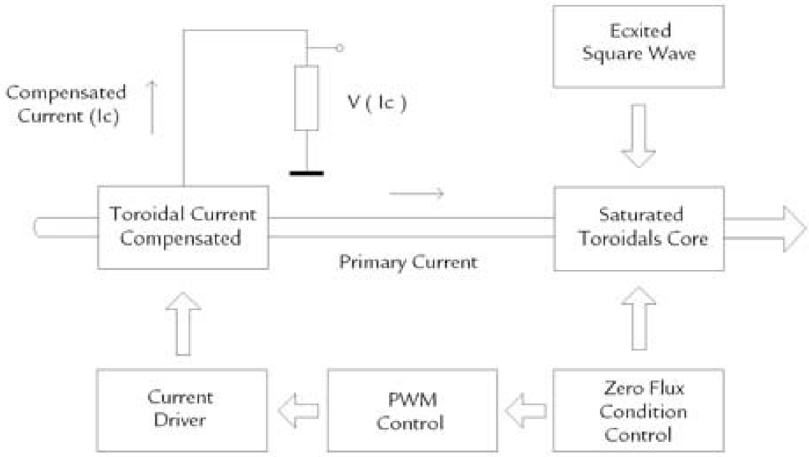

Figure 7. Block Diagram

One of the main advantages of the proposed circuit, is the use of the PWM technique for the Zero flux condition control. A feedback is established between the current wave forms in the saturable cores in order to force the average value of them always to zero. This effect is obtained by the compensated current control. The amplifier that works with PWM control are known like class D amplifier.

PWM Control and Class D Amplifiers

The operation of Class-D amplifier is based on analog principles. The standard classes of analog amplifiers are A, B, AB, and C. The class of an amplifier is identified on the basis of transistor's operating point, also known as quiescent point of the transistor. Transistor operating point denotes a specific value of collector current "Ic" for a given "Ib" base current. Hence, the position of operating point on the load line depends on transistor biasing. The idea to migrate toward higher power amplifier classes like AB and C is to improve the amplifier efficiency in terms of power skinny from the DC power supply. This improved efficiency reduces the heat sink requirements for amplifiers and for all the device. But the efficiencies achieved with class C are still around 70 percent. This is where class-D technology plays a very important role for obtaining higher efficiency . In class-D amplifiers, the transistors used in the output stage (power stage) operate as switches. The transistors operate either in the cut-off region or in the saturation region so that the current through the transistors is very low (ideally zero when cut-off) or the voltage across the transistors is very low (ideally zero when transistors are in saturation). This reduces the amount of power drawn from the power supply and hence increases the power efficiency of the amplifier; it also helps to design amplifiers with smaller heatsinks. In order to make work the transistor as a switch we must use a PWM technique control, that produces a square wave to control the transistor. Under a PWM control, the transistor will work always in saturated or cut region.

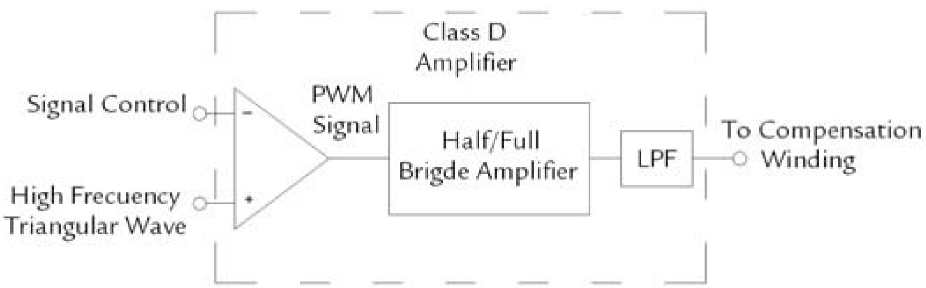

Figure 8. Complete Class D amplifier

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CE

Main Advantages

- High Accuracy over high bandwidth.
- Very low output noise and offset drift.
- Negligible insertion losses.
- High immunity to interference.
- Overload Capability.
- Medical Equipment.

Applications

- Precise and high stability inverters.
- Energy measurements.
- High Precision Power Supplies.
- Feed back element in high performance gradient amplifiers for MRI.
- Medical Equipment.

Electrical Parameters

Primary Nominal DC Current	700 A	I_P
Primary Current Range	0 to 700 A DC	
Overload Condition	± 3000 A (100ms)	I_{OV}
Burden Resistor Range (I_P = 700A)	0 to 1 Ohm Max	R_B
Secondary Nominal Current	700 mA	I_S
Conversion Ratio	1:1000	N
Supply Voltage	10 to 30 V DC	V_{cc}
Current Consumption	100mA +I_S	I_{cc}

Accuracy

Linear Error (Nominal Value)	< 5 ppm	ε_L
Offset Current	5uA Max	I_{OS}
Time Response (10% to 90% Ip)	<1us	T_R
di/dt	> 100A/us	
Frequency Bandwidth (Ip = 10A DC)	DC to 100KHz (-3dB)	F_C

General Data

Ambient Operating Temperature	0 to +50°C	T_A
Storage Temperature	-20 to +85 °C	T_S
Weight	800 g	
Primary Diameter Hole	30 mm	
Basic Insulation (Between Primary and Measurement Current)	3500 V AC 50Hz 1’	V_I

According To

- UNE EN 50178
- UNE EN 50155

DCT-700A

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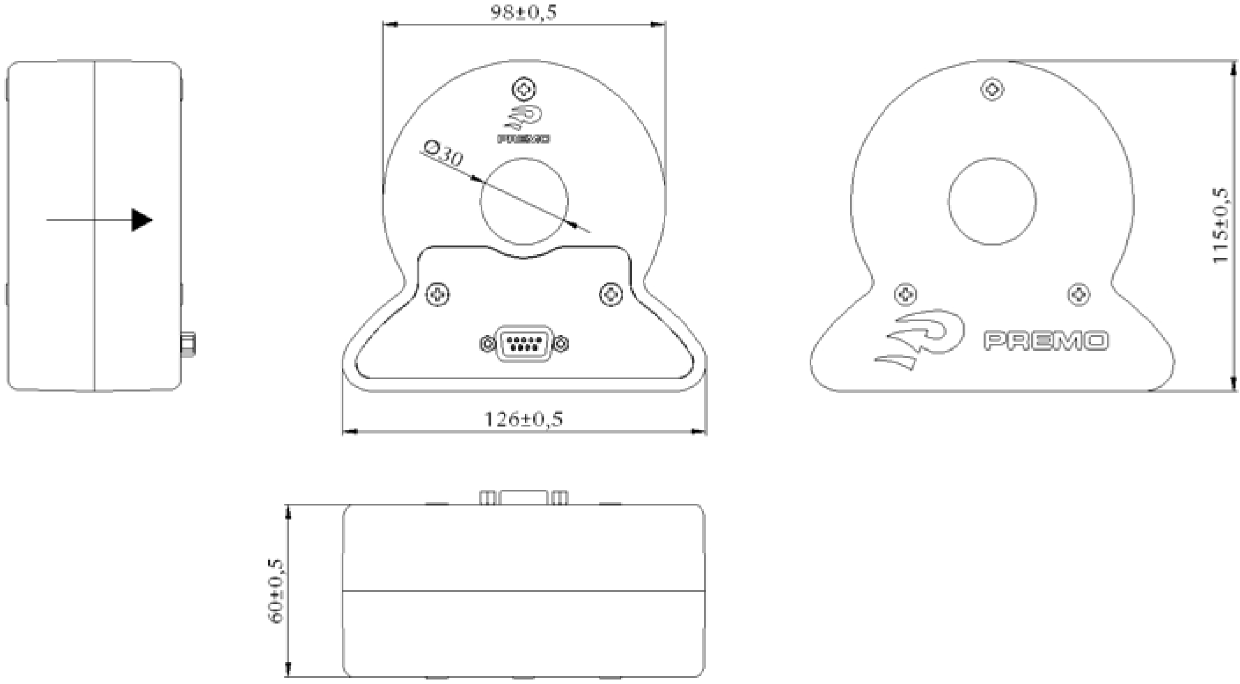
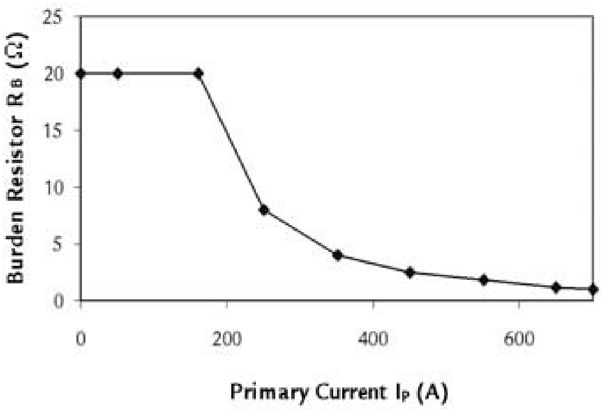
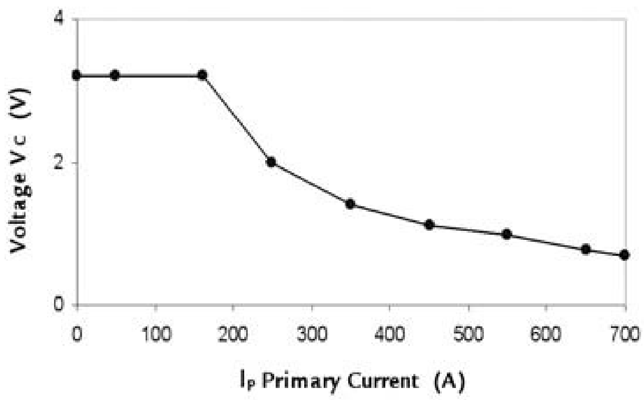
Physical Dimensions



Burden resistor and voltage range

The burden resistor (Rb in the picture) must be changed in function to the primary current. The maximum values of R burden and maximum voltage generate are showed below.





These values are recommended for a resistor that can dissipate 0,5W.

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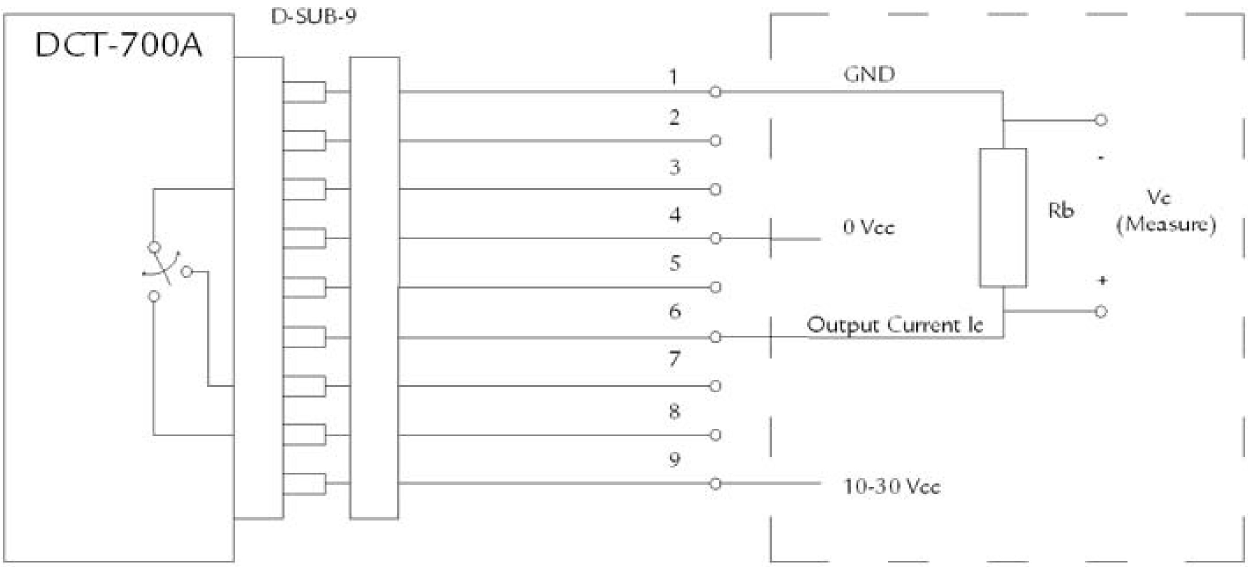
DCT-700A Installation

In the following picture we show how to connect the secondary side of current transducer.



External Connections

Between the pins 3 and 8 the DCT have a normally closed switch while the measurement is correct. In the same manner, DCT provides a normally open switch while the measurement is correct between pins 3 and 7.

D-SUB standard connector

The D-sub connection correspond to the next table.

9-POLE D-SUB

Pin 1: Connected to GND internally
Pin 2: (For Factory use only)
Pin 3: Input to normally closed/open Switch
Pin 4 : 0V
Pin 5: Earth connexion
Pin 6: Output Current
Pin 7: Output to normally open switch (1A DC MAX)
Pin 8: Output to normally closed switch (1A DC MAX)
Pin 9: Vcc