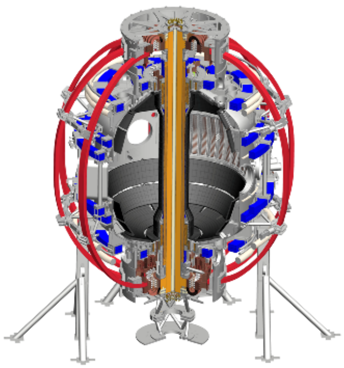
Peer Review: CHI Bus Current Measurements

S.P. Gerhardt

Earth
21st century



Outline

- What are the goals?
- Where are the measurements?
- What instruments are used?
- What is the cost? Design tasks are outstanding?

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Motivation and Goals

- Large currents (~50 kA, 2 ms) were observed to flow in the CHI bus on NSTX:
  - During CHI, this current is the supply current
  - During disruptions
- The sensors that made those measurements are gone.
  - Were large Pearson CTs, that won't fit on the present buswork.
- We want this measurement back:
  - To look at current amplitudes & sharing during CHI.
    - Three connections to the vessel instead of the single connection like NSTX.
  - To look at disruption halo currents and associated loads
- Propose to recreate the measurement with commercial clamp-on Rogowski coils.

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Three Sensors on Inner Vessel, and Three on Outer Vessel

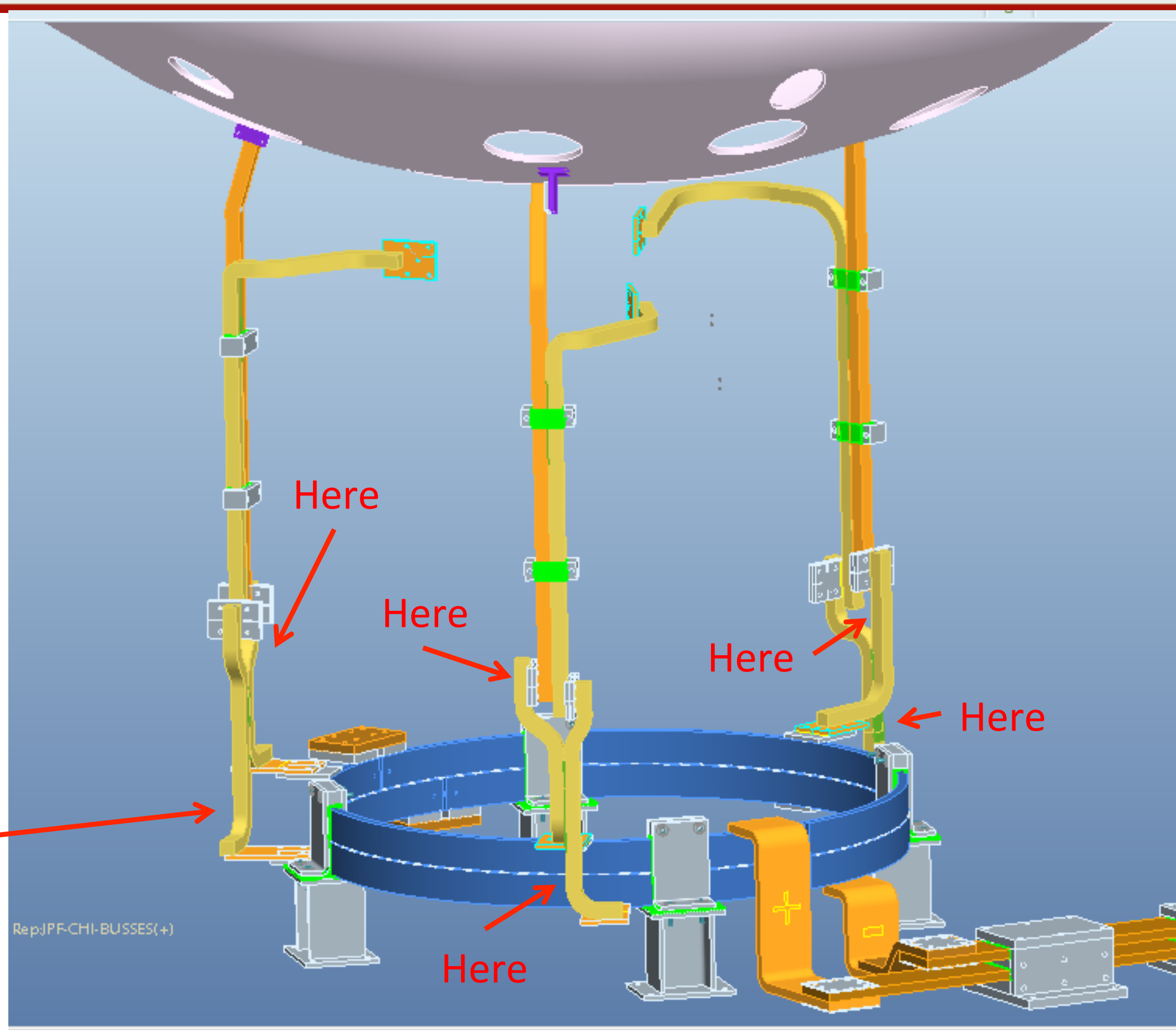


Image From Neway's Peer Review on 05/01/2013

Options Exist For Measuring the Total Current…

However, this is little better than summing the three individual rods…propose to NOT do this.

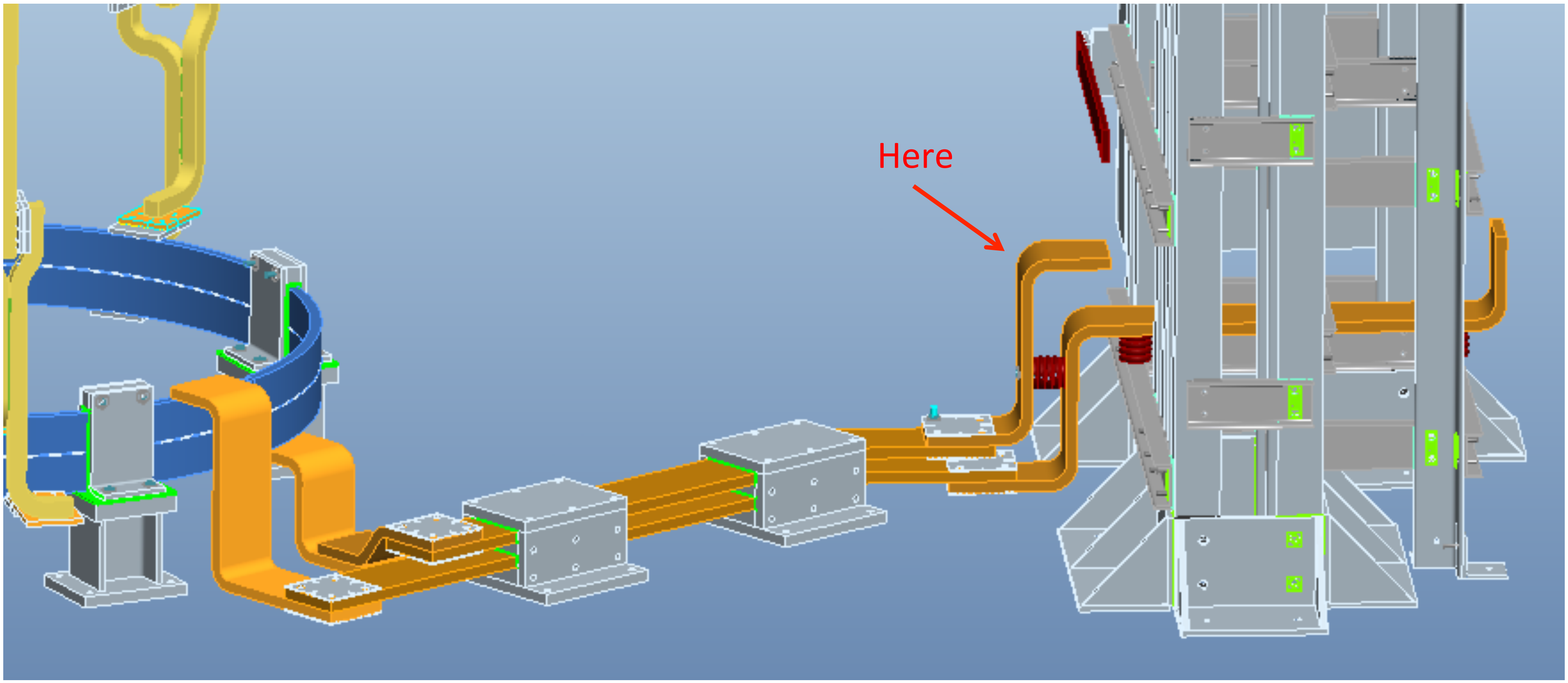
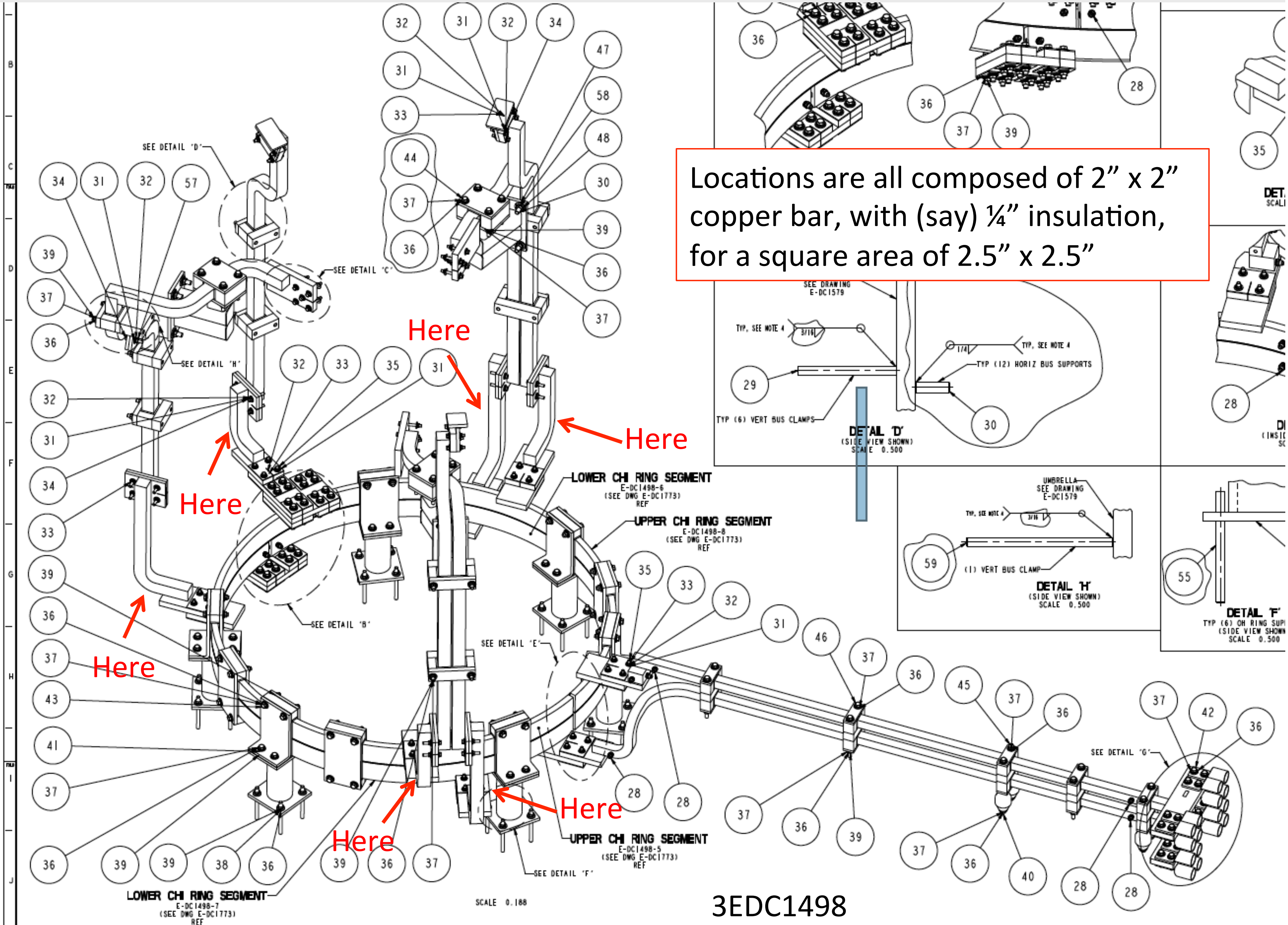


Image From Neway's Peer Review on 05/01/2013

Locations are all composed of 2” x 2” copper bar, with (say) ¼” insulation, for a square area of 2.5” x 2.5”



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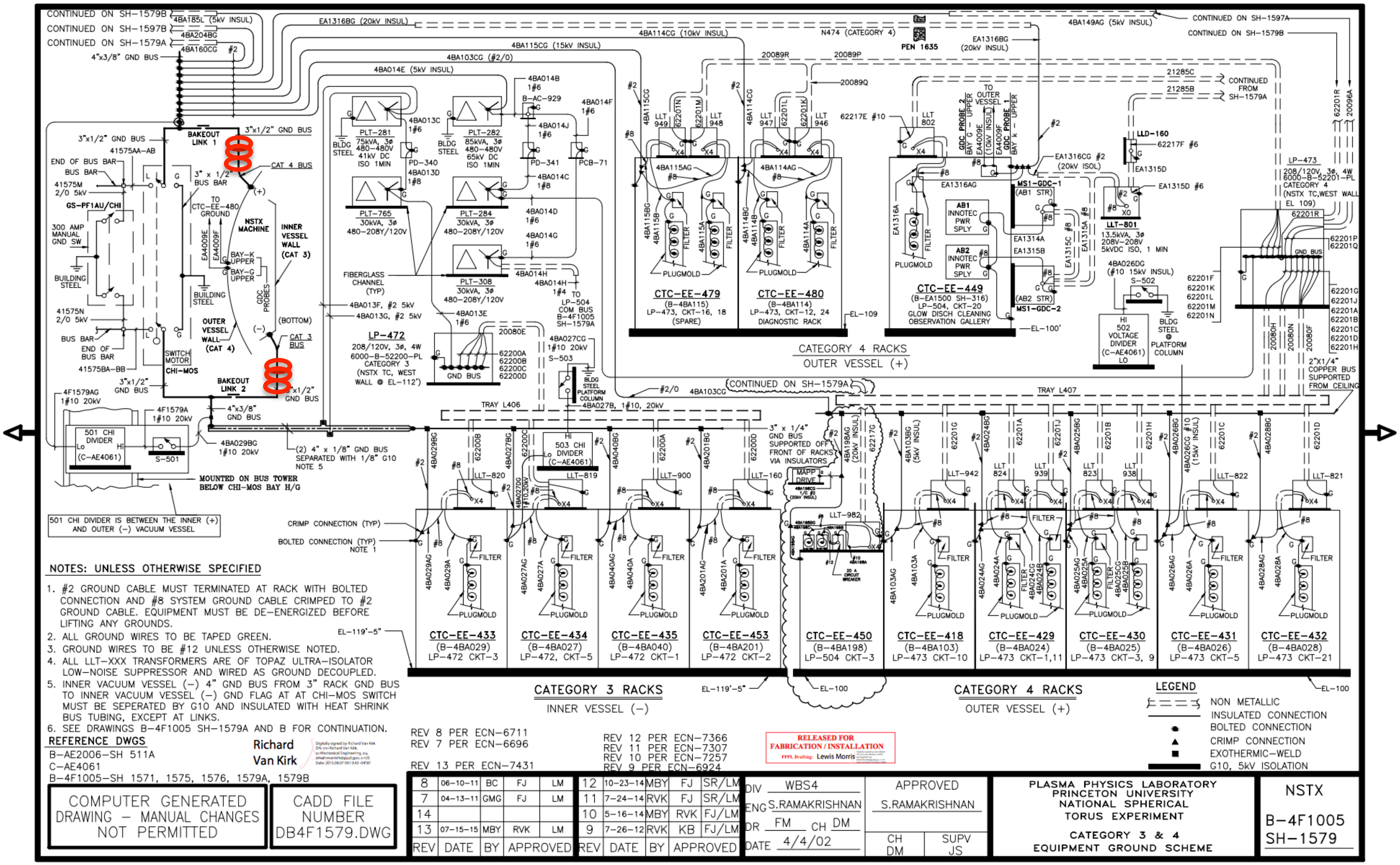
Three Sensors on Inner Vessel, and Three on Outer Vessel



Outline

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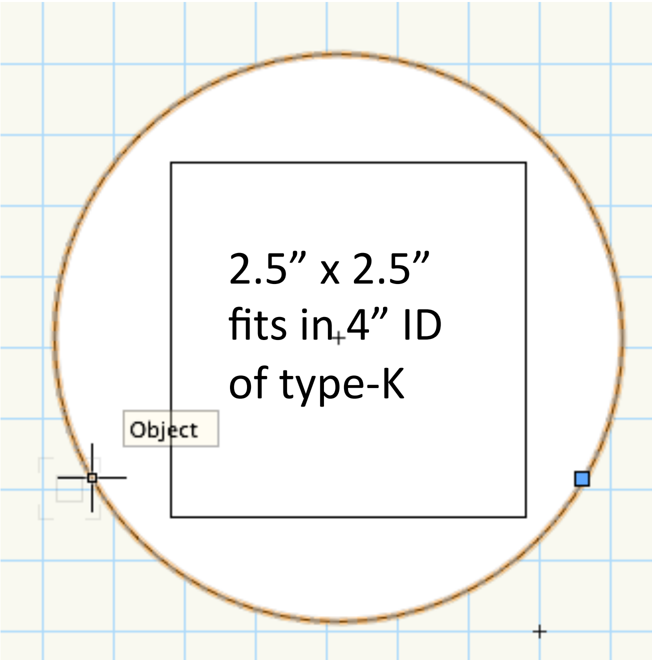
Apparent Choice is to Use a Pearson Current Transformer: Considerations

- Pearson CTs are good:
  - No integrators required.
  - Blazing fast
- Pearson CTs are bad:
  - Magnetic core means they experience some forces
    - would need to evaluate.
  - Can saturate
  - Rigid, not as easily field fit
  - Have basically a charge limit.
    - Need to support at least 30000*0.002 = 60 As
- We do not want to disturb the existing bus work.
  - Therefore need a clamp-on design

No Really Good Choices for Pearson CTs



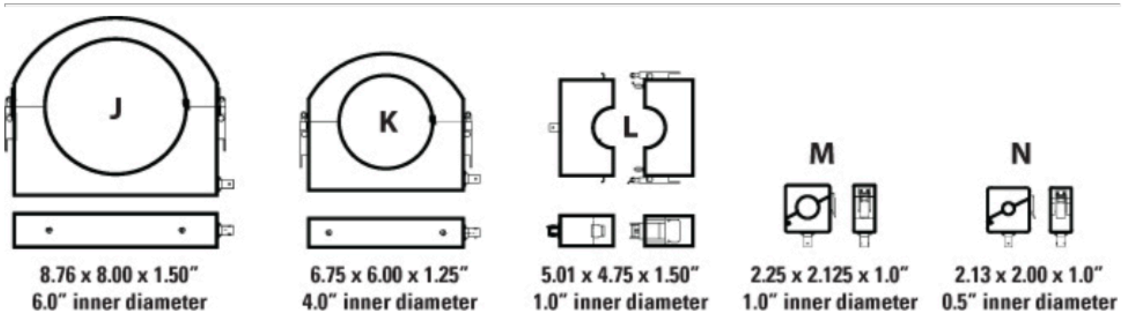
- Should use the type K
  - Maximum IT is 3.0 As.
  - So, for 1 ms, can see 3 kA.
  - Is not enough.
- And cannot be sure that it will fit in the as-built condition.
- So consider commercial clamp-on rogowskis.

Clamp On Current Monitors

Current Transformer | Current Probe | Current Transducer
Current Toroid | Current Sensor | Pulse Current Monitor
High Frequency Current Transformer

Accuracy ±1% or better, initial pulse response for all models, with a high impedance load such as 1 megOhm in parallel with 20 pF. A 50 Ohm termination will reduce the output to half. All models listed below come with a BNC connector except as noted and are to be used with a 50 Ohm coaxial cable. The current monitor case is conductive and not insulated. Adequate insulation must be provided on the conductor being monitored. To avoid electrical shock, do not mount or remove the current monitor from a live conductor.

				Time Domain Parameters				Frequency Domain Parameters				
Model #	Shape (click to expand)	Output (Volts/ Amp)	Hole Id. (inches)	Peak Curr. (Amps)	Droop (%/µsec.)	Useable Rise Time (nsec.)	IT Max. (Amp-sec.)	Max. RMS Curr. (Amps)	3dB pt. Low (Hz)	3dB pt. High (MHz)	I/f (RMS Amps /Hz)	I^2t max (Amps squared sec)
8585C	N	1.0	0.5	500	1.0	2	0.003	5	1,500	200	0.01	5
4100C	N	1.0	0.5	500	1.0	15	0.0015	5	1,500	25	0.008	150
8590C	M	1.0	1.0	500	0.7	2.5	0.002	5	1,000	150	0.01	25
7790	M	1.0	1.0	500	1.0	15	0.002	5	1,500	25	0.01	150
4688	L	1.0	2.0	500	0.4	12	0.005	15	600	30	0.03	150
7805	K	1.0	4.0	500	0.7	25	0.004	15	1,000	25	0.02	150
7760	J	1.0	6.0	500	0.5	50	0.005	20	750	7.0	0.03	350
5101	L	0.5	2.0	1,000	0.1	20	0.02	25	150	18	0.08	700
5949†	K	0.5	4.0	1,000	0.1	30	0.02	30	150	12	0.08	700
411C	N	0.1	0.5	5,000	0.015	20	0.15	50	25	20	0.7	18,000
7795	M	0.1	1.0	5,000	0.015	25	0.15	60	25	15	0.8	18,000
3525	L	0.1	2.0	5,000	0.004	25	0.5	100	6.0	15	2.5	18,000
7810	K	0.1	4.0	5,000	0.007	50	0.4	150	10	7.0	2.0	18,000
7655	J	0.1	6.0	5,000	0.007	100	0.4	175	10	4.0	2.0	35,000
5008C	N	0.01	0.5	50,000	0.005	150	1.0	150	7.5	3.0	4.2	250,000
7800	M	0.01	1.0	50,000	0.003	175	0.8	125	5.0	2.0	4.0	140,000
4160	L	0.01	2.0	50,000	0.001	200	2.5	300	1.5	2.0	15.0	1,000,000
7815	K	0.01	4.0	50,000	0.001	200	3.0	400	1.5	2.0	15.0	2,000,000
7450	J	0.01	6.0	50,000	0.001	250	3.0	400	1.5	1.5	12	2,000,000
5664	L	0.001	2.0	200,000	0.00025	250	8.0	500	0.4	1.5	50	1,000,000



- Accuracy +1%, initial pulse response for all models, with a high impedance load such as 1 megOhm in parallel with 20 pF. A 50 Ohm termination will reduce the output to half.

Metrics For Selecting Sensors

- Should have > 1kV insulation characteristics
  - This + the insulation on the bus should prove sufficient
- Should produce reasonable signal levels (~1-5 V) for reasonable integrator time constants (1-100 ms).
- Should fit nicely on the bus
  - not too snug, not too droopy.

Three Sensors Have Been Identified That Would Work

Model	Units	Dent Instruments RoCoil R16	HQ Sensing, JRF1S	JRF105
Web Link		http:// www.dentinstruments.com/ rogowski-coils-flexible-ct-current-transformers	http://www.hqsensing.com/ product.asp? prod=02-01&dept_id=02&m=2, or http://tichenassociates.com/ documents/JRFS_DataSheet.pdf	http://www.tichenassociates.com/ sensors/rogowski/jrf80/
Voltage	V	0.131	0.405	0.00125
Current	A	1000	1000	1
Frequency	Hz	60	60	60
Inductance	H	3.47488E-07	1.0743E-06	3.31573E-06
HC Pulse Amp	A	25000	25000	25000
Digiized Voltage	V	5	5	5
Required Time Constant	ms	1.74	5.37	16.58
HC Rise Time	ms	0.001	0.001	0.001
Max Sensor Voltage	V	8.69	26.86	82.89
Window Size (ID)	[m]		0.12	
Window Size (ID)	[in]	4.5	4.72	4.13
Sensor Diameter	[in]	0.5"	0.5	0.35
Lead Length	[in]	80	39.6	39.6
Insulation, Coil	V	7400	7400	3500
Insulaton, Leads	V	1000	1000	1000
Part Number		CT-R16-A4-U	JRF-1S	JRF105

Note: T.I. Chen appears to be a distributor for HQ Sensing (?)

Data Sheets for Sensor 1

Mini Loop, Split Rogowski Coil Current Sensor

The **JRF55-80-105** series of mini loop, split Rogowski Coil current sensors are designed for fast and easy installation on existing primary conductors/ BUS bars. The split design permits non-contact AC current or current pulse measurement without requiring that the primary conductor be taken offline and disconnected for the current sensor installation. This method provides for the safe, easy and portable measurement of current.

A current sensor that is based upon the Rogowski Coil principle offers significant advantages over the standard magnetic core current transformer products. Specifically, since the sensor does not incorporate a magnetic core, magnetic core saturation (the point where incremental increases in magnetic flux are not reflected in proportional increases in secondary signal outputs) is avoided.

Features:

- Minimal sensitivity to primary conductor position within the sensor loop.
- Split core design for ease of installation on "live" primary conductors.
- Non-magnetic core eliminates core saturation and core stored energy concerns.

Specifications:

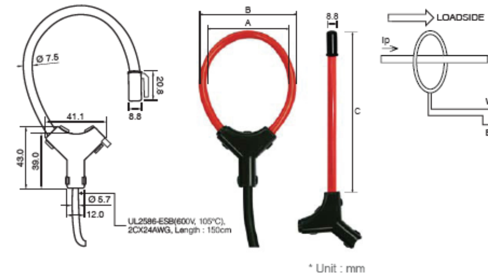
- Rated Input: < 1A to 3kA.
- Frequency: 25 Hz to 5 kHz.
- Output Sensitivity Tolerance:
  - ± 5% maximum (uncalibrated).
  - ± 0.5% of reading @ +25°C (calibrated through the voltage integrator).
- Primary Conductor Position Sensitivity: ±1% maximum.
- Influence of External Field: ± 2.0% maximum.
- Working Voltage: 1000V_{RMS} or 1000 VDC.
- Dielectric Surge Withstand: 3.5kV_{RMS} for 1 minute (coil closed).
- Operating Temperature: -20°C to +60º C.
- Construction:
  - Coil - Thermoplastic rubber (available in red, blue or black).
  - Coupling - Thermoplastic rubber (Black), Polypropylene, flame retardant rating UL 94 V-0 (Black).
- Lead Wire: Shielded cable, 24 AWG, UL 2586, 600V, 1.0m/ 3.3FT.
- UL Certified (File #E344623)
- RoHS Compliant.

Performance:

- Output:
  - JFR55: 0.100mV/ A @ 50Hz, 0.120mV/ A @ 60Hz
  - JFR80: 0.104mV/ A @ 50Hz, 0.125mV/ A @ 60Hz
  - JFR105: 0.068mV/ A @ 50Hz, 0.082mV/ A @ 60Hz
- Accuracy: < ± 1% error.
- Phase Shift: < 1° @ 50/60Hz (Typical: < 0.5°).

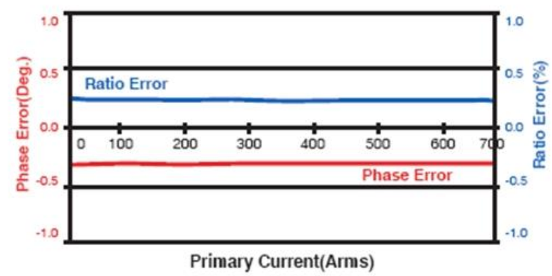
- Linearity: ± 0.2% of reading from 10% to 100% of range.

Outline Dimensions (mm):



	A	B	C
JRF-55	55.0	68.5	197.0
JRF-80	80.0	93.5	300.0
JRF-105	105.0	118.5	378.0

Typical Performance:



Accuracy Relative to Primary Conductor Position:

Conductor Position	Typical Error(%)
Adjacent to the inside coil edge	< 1%
Adjacent to the clip together mechanism	< 2%
Central in the Rogowski loop	0.2%

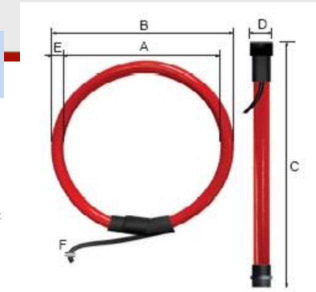
Note that as the outside diameter of the primary conductor approaches the inside diameter of the current sensor, the current sensor accuracy will approach the calibrated value.

Technical Support: For a no obligation technical evaluation of specific performance requirements, please provide the specific requirements to ApplicationEngineering@tichenassociates.com H or the address below.

Note: T.I. Chen appears to be a distributor for HQ Sensing (?)

Data Sheets for Sensor 2

Shielded, Flexible, Split Rogowski Coil Current Sensor



The **JRF-xS** series of shielded, flexible, split Rogowski Coil current sensors are designed for fast and easy installation on existing primary conductors/ BUS bars. The split design permits the non-contact AC current or current pulse measurement without requiring that the primary conductor be taken offline and disconnected for the current sensor installation. This method provides for the safe, easy and portable measurement of current.

A current sensor that is based upon the Rogowski Coil principle offers significant advantages over the standard magnetic core current transformer products. Specifically, since the sensor does not incorporate a magnetic core, magnetic core saturation (the point where incremental increases in magnetic flux are not reflected in proportional increases in secondary signal outputs) is avoided.

Features:

- Very wide range of AC current and/ or current pulse inputs.

Specifications:

- Rated Input: < 1kA to 100kA
- Frequency: 10 Hz to 20 kHz.
- Output Sensitivity Tolerance:
  - ± 5% maximum (uncalibrated).
  - ± 0.5% of reading @ +25°C (calibrated through the voltage integrator).
- Primary Conductor Position Sensitivity: ± 2% maximum.
- Influence of External Field: ± 1.5% maximum.
- Working Voltage: 1000V_{RMS} or 1000 VDC.
- Dielectric Surge Withstand: 7.4kV_{RMS} for 1 minute (coil closed).
- Operating Temperature: -20°C to +85° C.
- Lead Wire: Shielded cable, 24 AWG (White/ Black), UL 2586, 600V, 1.0m (3.3 FT).
- Construction:
  - Coil - Thermoplastic rubber.
  - Coupling - Thermoplastic rubber (Black), Polypropylene, flame retardant rating UL 94 V-0 (Black).
- UL Certified (File #E344623)
- RoHS Compliant

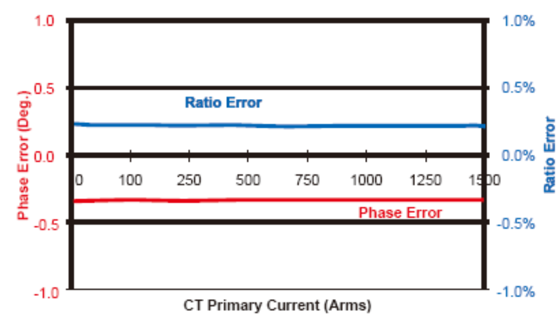
Performance:

- Output:
  - JRF-1S: 0.338mV/ A @ 50Hz, 0.404mV/ A @ 60Hz
  - JRF-2S: 0.344mV/ A @ 50Hz, 0.412mV/ A @ 60Hz
  - JRF-3S: 0.346mV/ A @ 50Hz, 0.415mV/ A @ 60Hz
- Accuracy: < 1% error.
- Phase Shift: < 1° @ 50/60Hz (Typical: < 0.5°).
- Linearity: ± 0.2% of reading of reading from 10% to 100% of range.

Outline Dimensions:

Model	A	B	C	D	E
JRF-1S	12.0cm (4.7")	14.5cm (5.7")	41.5cm (16.3")	2.2cm (0.9")	1.2cm (0.5")
JRF-2S	19.0cm (7.5")	20.5cm (8.1")	61.0cm (24.0")		
JRF-3S	30.5cm (12.0")	33.5cm (13.2")	102.5cm (40.4")		

Typical Performance:



Options:

- The body of the Rogowski Coil current sensor is available in; red, blue or black.
- The JRF333 models incorporate the JRF Rogowski Coil current sensor with a voltage integrator.

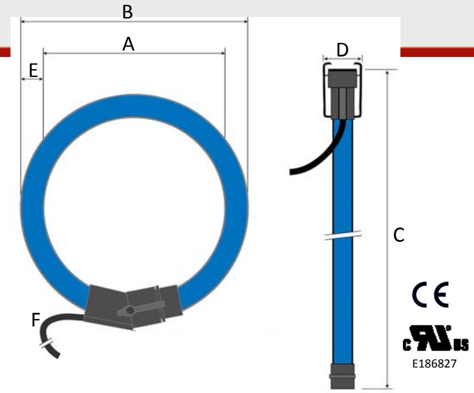
Technical Support: For a no obligation technical evaluation of specific performance requirements, please provide the specific requirements to ApplicationEngineering@tichenassociates.com or the address below.

RōCoil™
Flexible CTs

DENT INSTRUMENTS

Data Sheets for Sensor 3

The DENT RōCoil™Current Transformers have been designed for accurate non-intrusive measurement of AC current, pulsed DC or distorted waveforms where conventional rigid core CTs are unsuitable. This type of sensor may be used to measure AC current over a wide dynamic range and from 20 Hz to 5 kHz. Note: Some applications may require use of integrator/amplifier. See also RōCoil mV™.



KEY SPECIFICATIONS

Four Lengths	40 cm (16”), 60 cm (24”), 90 cm (35”), 120 cm (47”)
Window Size	11.5 cm (4.5”), 17.9 cm (7.0”), 27.5 cm (10.8”), 37 cm (14.6”)
Output Signal (*di/dt*)	131 mVAC/1000A @ 60 Hz 109.2 mV/1000A @ 50 Hz
Current Range	5 - 5000A AC*
Accuracy (typical)	< 0.6%**

ELECTRICAL

All accuracies specified at 20°C (±2°C) with RōCoil™ centered on conductor.

Output Signal	131 mV/1000A @ 60 Hz 109.2 mV/1000A @ 50 Hz
Wire Colors	White = (+) positive Brown = (-) negative Bare wire = shield
Phasing	Arrow Points Towards Load
Phase Shift	< 0.2° at 50/60 Hz
Frequency Range	20 Hz to 5 kHz*
Useful Current Range	5 - 5000A AC*
Linearity	± 0.2%
Temperature Sensitivity	0.07% per °C

MECHANICAL

Coil Materials	Blue thermoplastic rubber, flame retardant UL 94 V-0 rated
Coupling Materials	PA6 UL 94 V-0 rated
Shielding	100% transducer, 100% output lead
Working Temp	-20 °C to +70 °C (-4° to +158 °F)

SAFETY

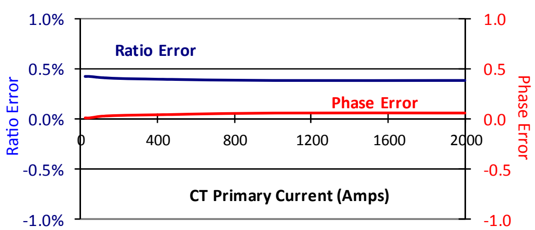
Working Voltage		1000 Vrms maximum
Dielectric Strength		7400 VAC around coil 1000 VAC rated leads
Certifications	CE cULus E186827	Conforms to UL STD 61010-1 Certified to CAN/CSA STD C22.2 No. 61010

**Depending on meter compatibility. RōCoil CTs UL Rated to 100KA AC. ELITEpro SP/XC (v .212 or newer firmware) and PowerScout™ 3 and 24 (v. 3.16 or newer firmware) rated for 5-5000A. Meters with earlier firmware versions rated from 50-5000A AC. PowerScout™ 18 rated for 50-3500A.*

***Installed using best practices with conductor centered in the CT window and ensure any external conductors are a minimum distance of > 2X the diameter of the RōCoil. Accuracy below 20A rated at 1.5% +/- 0.5A when used with DENT ELITEpro/PowerScout meters. RōCoil have been 100% verified to meet the C57.13-2008 Class 1.2 Standard.*

DIMENSIONS

	DIMENSIONS	R16 40 cm (16”)	R24 60 cm (24”)	R36 90 cm (35”)	R47 120 cm (47”)
A	Window Size	11.5 cm (4.5”)	17.9 cm (7.0”)	27.5 cm (10.8”)	37 cm (14.6”)
B	Transformer Coil O.D.	13.9 cm (5.5”)	20.3 cm (8.0”)	29.9 cm (11.8”)	39.4 cm (15.5”)
C	Transformer Length	40 cm (15.8”)	60 cm (23.6”)	90 cm (35.4”)	120 cm (47.2”)
D	Locking Connector O.D.	2.0 cm (0.8”)			
E	Transformer Coil Diameter	1.2 cm (0.5”)			
F	Wire Lead Total Length	2 m (80”)			



CT testing performed with 16”RoCoil. Conductor used filled 90% of RoCoil window.

RōCoil™ PART NUMBERS

40 cm (16”) RōCoil™	CT-R16-A4-U
60 cm (24”) RōCoil™	CT-R24-A4-U
90 cm (35”) RōCoil™	CT-R36-A4-U
120 cm (47”) RōCoil™	CT-R47-A4-U

CONTACT US

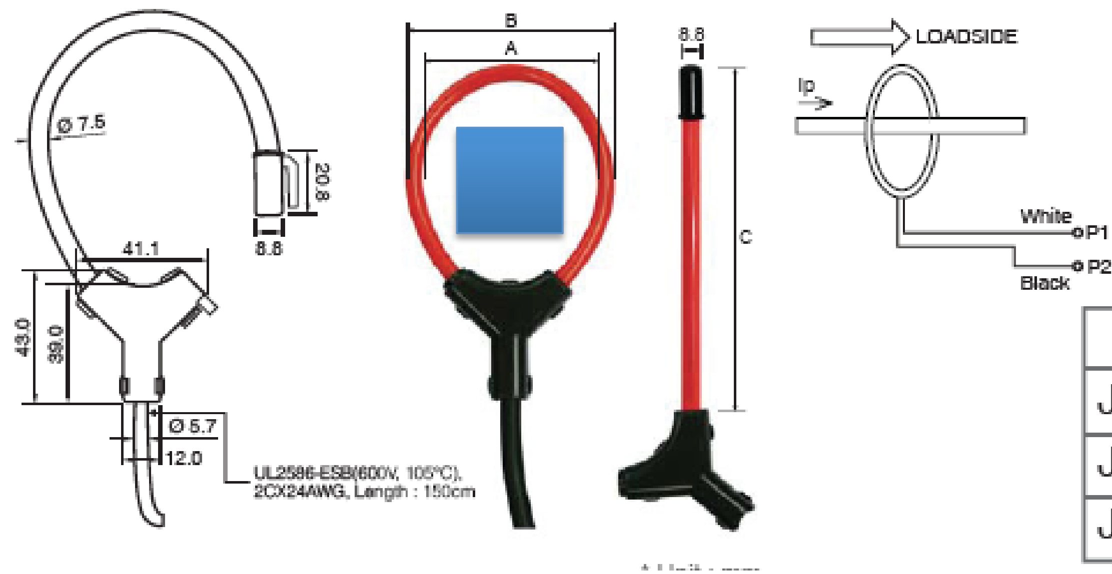
DENT Instruments, Inc.
Energy & Power Measurement Solutions
An ISO 9001:2008 Certified Company

925 SW EMKAY DRIVE
BEND, OREGON 97702 USA
541.388.4774 | 800.388.0770
WWW.DENTINSTRUMENTS.COM

Optimal Choice Appears to Be the JRF-105

- Higher sensitivity allows a longer time constant…
  - and therefor less noise.
  - 25 kA HC pulse gives 5 volts with a 17 ms time constant
- Appears that it will fit on the bus work neatly.

Outline Dimensions (mm):



55 mm =2.16”
80 mm = 3.14”
105 mm = 4.13”

	A	B	C
JRF-55	55.0	68.5	197.0
JRF-80	80.0	93.5	300.0
JRF-105	105.0	118.5	378.0

But the Dent sensor would be OK as well

Cabling Should Be Straight-Forward

- Everything at Category 4 potential.
- Must splice a shielded twisted pair onto the leads from the sensor.
- Run the six cables to rack 430, using Cat. 4 trays.
- Will use "new-dual" integrators in 3 (of 7) empty slots in integrator crate 430-IC6/IC7
- Digitize in channels 12-17 of OPS_H908_01, in rack 430

Vessel Connection	Bay (need to triple check these)	Name	Cross-Connects, Rack 430, column C
Outer	C	ROG-CHI-C-Outer	169-170
Outer	J	ROG-CHI-J-Outer	172-173
Outer	L	ROG-CHI-L-Outer	175-176
Inner	C	ROG-CHI-C-Inner	178-179
Inner	J	ROG-CHI-J-Inner	181-182
Inner	L	ROG-CHI-L-Inner	184-185

CWD itself can be modeled from any of the 9D1095 sheets

Outline

- What are the goals?
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- What is the cost? Design tasks are outstanding?

Cost Estimates

- M&S
  - Rogowski Sensors: I have requested a quote on 10/15/2015.
  - Electrician Parts: $1k
  - Small Cabling and Connectors: $250
- PPPL Labor
  - 3 weeks drafting
    - Includes CWD, cable routing, IP writing
  - 2 weeks * 2 people electrical technician for installation of cables/conduits.
  - 3 days technician for any small fixtures to secure rogowskis on bus (if necessary).
  - 1 day technician for small cabling.

To Do…

- Work planning form.
- Drafting work requests.
- Determine the exact cable routes
  - any conduits required to get the cables into the tray system.
  - Will use drafting for that
- WAF?
- Order sensors.
- IP (will probably be part of the drafting request)

The End

The Bottom on the Machine (I)

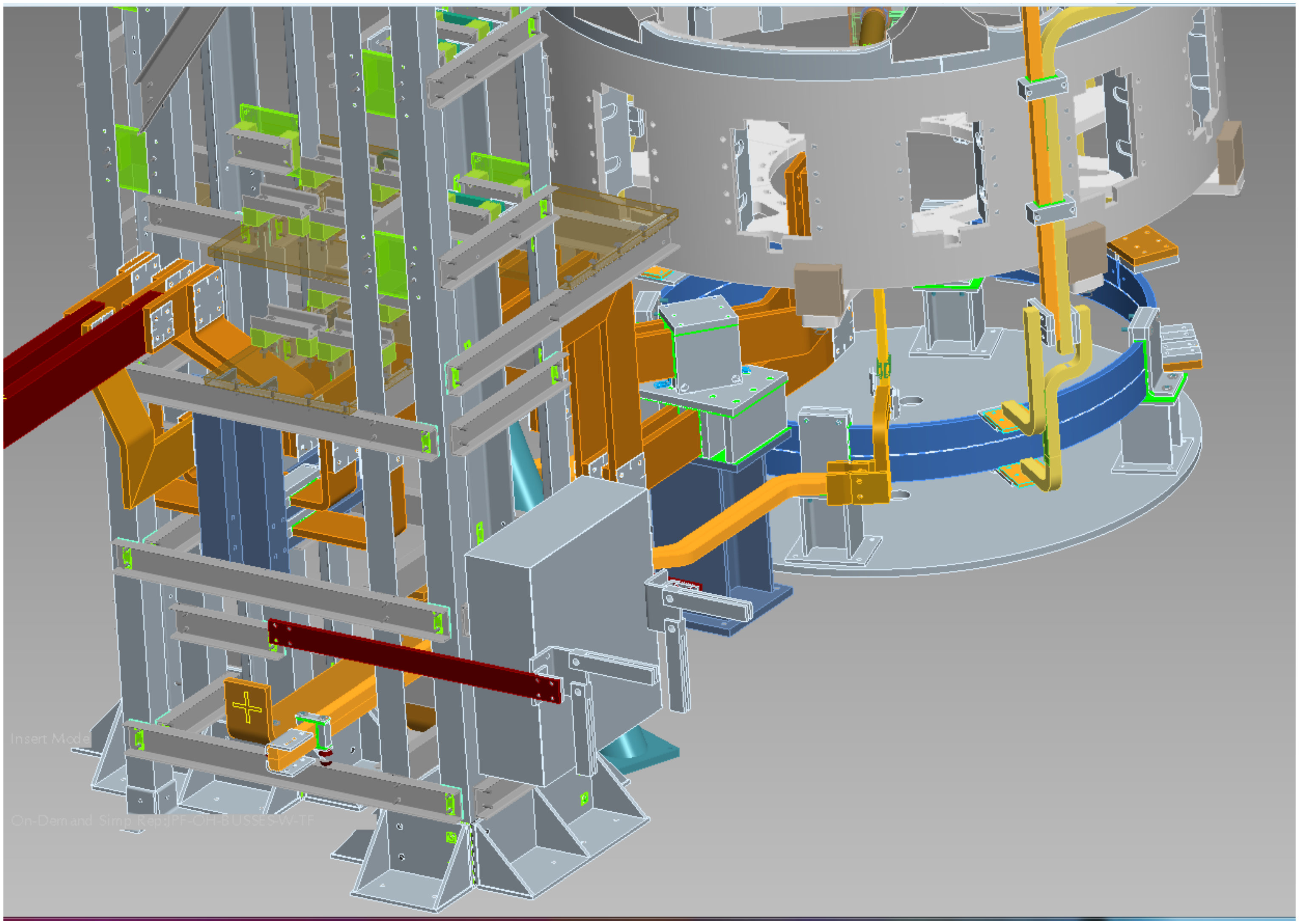
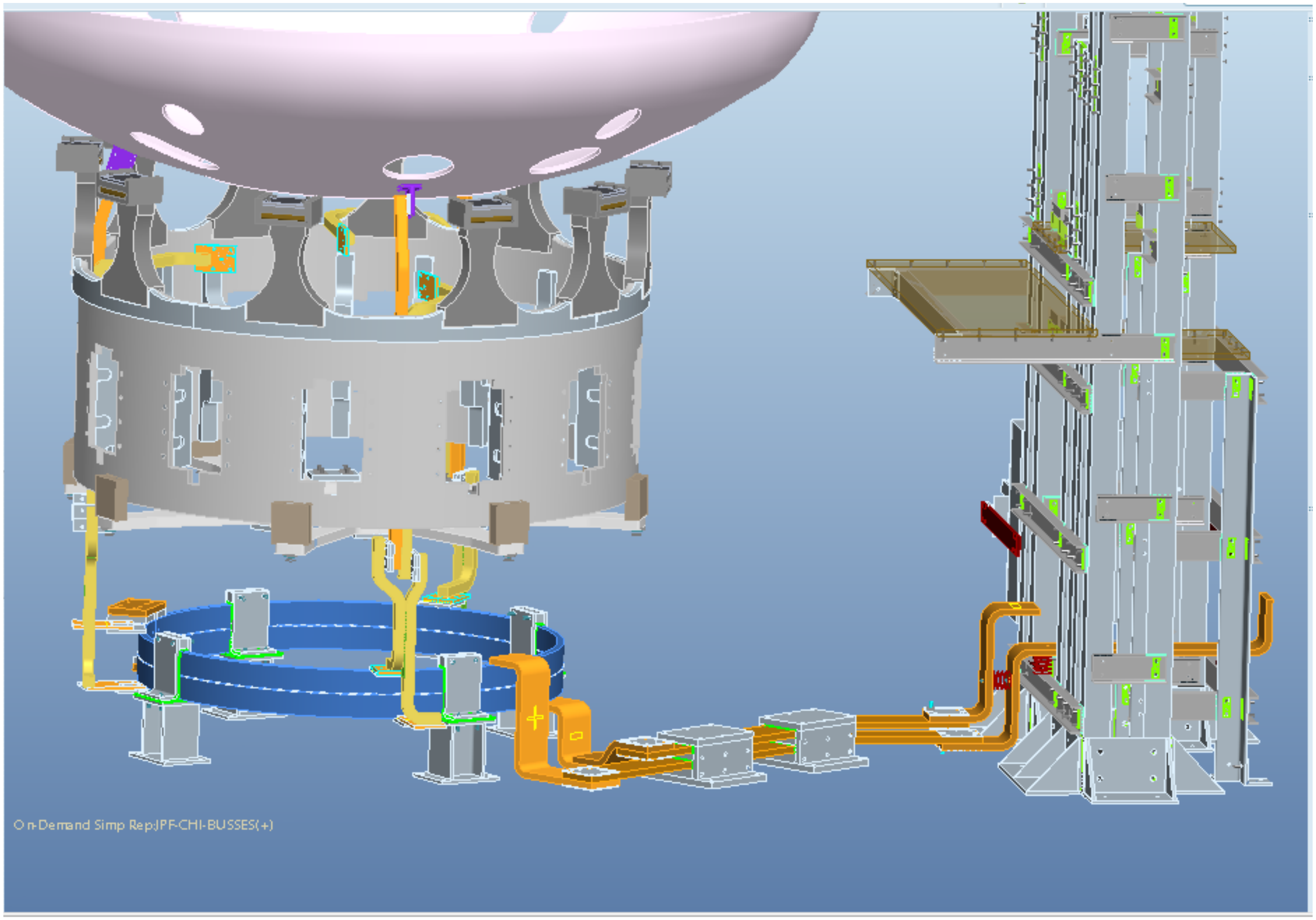


Image From Neway's Peer Review on 05/01/2013

The Bottom on the Machine (II)



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