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Fast Current Transformer User's Manual

Rev. 3.1

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SUMMARY Page

INITIAL INSPECTION

It is recommended that the shipment be inspected immediately upon delivery. If it is damaged in any way, contact Bergoz Instrumentation or your local distributor. The content of the shipment should be compared to the items listed on the invoice. Any discrepancy should be notified to Bergoz Instrumentation or its local distributor immediately. Unless promptly notified, Bergoz Instrumentation will not be responsible for such discrepancies.

WARRANTY

Bergoz Instrumentation warrants its beam current monitors to operate within specifications under normal use for a period of 12 months from the date of shipment. Spares, repairs and replacement parts are warranted for 90 days. Products not manufactured by Bergoz Instrumentation are covered solely by the warranty of the original manufacturer.   In exercising this warranty, Bergoz Instrumentation will repair, or at its option, replace any product returned to Bergoz Instrumentation or its local distributor within the warranty period, provided that the warrantor's examination discloses that the product is defective due to workmanship or materials and that the defect has not been caused by misuse, neglect, accident or abnormal conditions or operations. Damages caused by ionizing radiations are specifically excluded from the warranty. Bergoz Instrumentation and its local distributors shall not be responsible for any consequential, incidental or special damages.

ASSISTANCE

Assistance in installation, use or calibration of Bergoz Instrumentation beam current monitors is available from Bergoz Instrumentation, 01630 Saint Genis Pouilly, France. It is recommended to send a detailed description of the problem by fax or email.

SERVICE PROCEDURE

Products requiring maintenance should be returned to Bergoz Instrumentation or its local distributor. Bergoz Instrumentation will repair or replace any product under warranty at no charge. The purchaser is only responsible for transportation charges.

For products in need of repair after the warranty period, the customer must provide a purchase order before repairs can be initiated. Bergoz Instrumentation can issue fixed price quotations for most repairs. However, depending on the damage, it may be necessary to return the equipment to Bergoz Instrumentation to assess the cost of repair.

RETURN PROCEDURE

All products returned for repair should include a detailed description of the defect or failure, name and fax number of the user. Contact Bergoz Instrumentation or your local distributor to determine where to return the product. Returns must be notified by fax or email prior to shipment.

Return should be made prepaid. Bergoz Instrumentation will not accept freight-collect shipment. Shipment should be made via Federal Express or United Parcel Service. Within Europe, the transportation service offered by the Post Offices "EMS" (Chronopost, Datapost, etc.) can be used. The delivery charges or customs clearance charges arising from the use of other carriers will be charged to the customer.

SAFETY INSTRUCTIONS

The instrument designated as "Fast Current Transformer" may become RADIOACTIVE when exposed to ionizing radiations.

Standard models contains :

- Cobalt……………………………………………………Up to 0.4 Kg
- Iron………………………………………………………Up to 0.2 Kg

GENERAL DESCRIPTION

FCT is a passive device. It contains no electronics.
Its model number has the syntax: FCT–DDD–TT:1
Where DDD is the inner diameter [mm], e.g. 055 for 55 mm
TT:1 is the turns ratio, e.g. 10:1 for 10 turns

Some suffixes may be appended to the model number:
-LD for Low-droop models
-WB for Wideband models
-H for Rad-hard models

Some special models include a floating calibration winding:
-CAW/xx suffix indicates a calibration winding of xx turns

The passive FCT has a rise time faster than 1ns. Some models have risetime as low as 175 ps, corresponding to 2 GHz upper frequency cutoff (-3 dB).
The output signal is a current to be measured across a 50Ω load.

The core is a composite of CoFe amorphous alloy and nanocrystalline alloy to optimize the frequency response and minimize ringing The CoFe alloy is specifically cross-field annealed for this application.

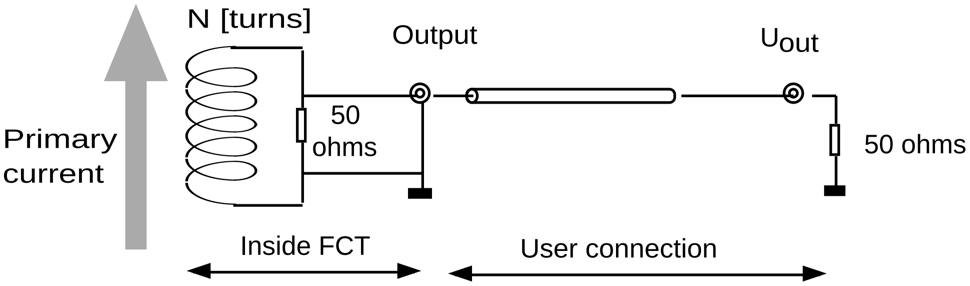
FCT main advantages

- The FCT displays the beam current with a minimum of distortion up to very high frequency. It is therefore, primarily, an instruments to be used with an oscilloscope.
- Very low ringing when it is properly installed (See: "Installation on the vacuum chamber" in this manual).

FCT limitations

- The FCT, like all passive transformers, differentiates the signal. When the pulses to be observed are longer than a few microseconds, the droop of the FCT becomes excessive.
- The FCT has eddy current loss up to a few percents. Eddy current losses are frequency dependent, increase towards the higher frequencies. Yet, the FCT is still the best instrument to visualise a short, fast pulse on an oscilloscope when non-contact measurement is a necessity: particle beams, high voltage, etc.

OPERATING PRINCIPLE



SPECIFICATIONS

Fastest wideband (-WB) models

Technology: Predominantly amorphous

Turns ratio	100:1	50:1	20:1	10:1	05:1	Units
Sensitivity (nominal)	0.25	0.5	1.25	2.5	5.0	V/A
Rise time (typ.)	600	300	200	300	500	ps
Droop	<1	<3	<6	<10	<20	%/µs
Upper cutoff frequency -3dB (typ.)	580	1170	1750	1170	700	MHz
Lower cutoff frequency -3dB	<1.6	<4.8	<9.5	<16	<32	kHz
Position sensitivity (on axis)	<0.2	<0.2	<0.2	<0.2	<0.2	%/mm
L/R time constant (min.)	100	35	17	10	5	µs
Max. charge/pulse (pulses <1ns)	2	1	0.4	0.2	0.1	µC
Max. peak current (pulses >1ns)	2000	1000	400	200	100	A
Max. rms current (*ƒ* > 10 kHz)	28	14	5.6	2.8	1.4	A

Low droop (-LD) models

Technology: Predominantly nanocrystalline

Turns ratio	100:1	50:1	20:1	10:1	05:1	Units
Sensitivity (nominal)	0.25	0.5	1.25	2.5	5.0	V/A
Rise time (typ.)	1000	540	400	500	780	ps
Droop	<0.05	<0.2	<1	<3	<8	%/µs
Upper cutoff frequency -3dB (typ.)	350	650	850	700	450	MHz
Lower cutoff frequency -3dB	<0.08	<0.32	<1.6	<5	<13	kHz
Position sensitivity (on axis)	<0.2	<0.2	<0.2	<0.2	<0.2	%/mm
L/R time constant (mim.)	2000	500	100	30	12	µs
Max. charge/pulse (pulses <1ns)	3.8	1.8	0.7	0.4	0.1	µC
Max. peak current (pulses >1ns)	2000	1000	400	200	100	A
Max. rms current (*ƒ* > 10 kHz)	50	25	10	5	2.5	A

ELECTRICAL CONNECTIONS

Coaxial connectors on the FCT toroid sensor and external box

FCT model	*Ordering code*	*Output connector type*
Standard	No suffix	SMA 50Ω female
BNC	-B suffix	BNC 50Ω female
Lemo	-L suffix	Lemo 00 50Ω female
N-type	-N suffix	N 50Ω female

On above models, the body of the connector is connected to the shield.

Twisted pair	-TW suffix	No connector

On the twisted pair model, the winding is isolated from the shield.

OUTPUT SIGNAL POLARITY

The Fast Current Transformer is bipolar.
Arrows are printed on the outer surface of the toroid.
Charges (positive) crossing the aperture in the direction of the arrow give positive outputs.
E.g. an electron beam passing in the direction of the arrow yields a negative output.

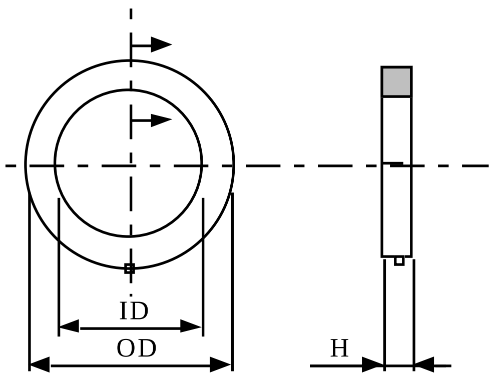
COAXIAL CABLE SELECTION

The FCT output is a wideband signal up to and beyond 2 GHz. If the integrity of the signal must be preserved, the cable must feature a bandwidth commensurate to the signal frequency spectrum.

Some examples:

Cable length	Adequate cable technology	Manufacturer, type
5 meters	RG 58	
50 meters	Low-loss RF cable	Suhner S 12272-04
Above 50 m.	Foam-dielectric cable	Cellflex
	Air-dielectric cable	Flexwell, Heliax

MECHANICAL DIMENSIONS



FCT Order codes * (XX:1 = turns ratio)	ID (min)	OD (max)	H (max)
FCT-016-XX:1	16	42	
FCT-028-XX:1	28	64	
FCT-055-XX:1	55	91	
FCT-082-XX:1	82	118	
FCT-122-XX:1	122	156	
FCT-178-XX:1	178	226	
FCT-XXX-05:1			35
FCT-XXX-10:1 to 100:1			22

INSTALLATION (GENERAL)

The metal shield of the FCT toroid sensor must be isolated from the local ground, because its grounding creates a ground loop with the oscilloscope ground, or the power supply ground in the case of an active FCT.

From the standpoint of external noise pickup, it is advantageous to install the external box as close as possible from the FCT sensor.

External noise picked up by the FCT cables can often be attenuated by common-mode chokes.
This applies to the coaxial cables and to the power supply twisted pair.
A common-mode choke consists in passing the cable up to 6-7 times thru a ferrite core. The ferrite must be selected for its high core loss at the noise frequency to be attenuated.

INSTALLATION ON A VACUUM CHAMBER

The installation of a Fast Current Transformer (FCT) on the outside of a vacuum chamber requires some precautions.

a) The electrical conductivity of the vacuum chamber must be interrupted in the vicinity of the FCT, otherwise the wall current will flow thru the FCT aperture and cancel the beam current.

b) The wall current must be diverted around the FCT thru a low impedance path.

c) A fully-enclosing shield must be installed over the ICT and vacuum chamber electrical break to avoid RF interference emission.

d) The enclosing shield forms a cavity. Cavity ringing at any of the beam harmonics must be avoided.

e) The FCT must be protected from being heated beyond 80°C during vacuum chamber bake-out.

f) The higher harmonics of the beam should be prevented from escaping the vacuum chamber, because (1) they are not "seen" by the FCT therefore unnecessary, (2) they heat the FCT and any other conductive material inside the cavity, (3) they cause quarter-wave mode ringing in the cavity.

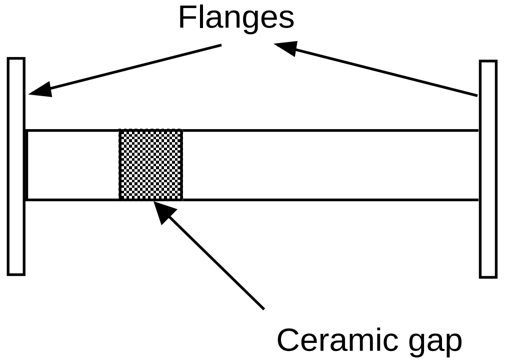
Note: The FCT does not need to be protected from external magnetic fields. When it is exposed to external magnetic fields it may saturate; this causes the droop to increase up to a factor of 2. It has no effect on the FCT linearity.

Break in the vacuum chamber electrical conductivity

If the vacuum chamber does not require bake-out and the vacuum requirements are moderate, a polymer gasket in-between two flanges is adequate to assure the desired galvanic isolation.

If the vacuum chamber needs bake-out, the most commonly use solution is to braze a section of ceramic on the vacuum chamber tube. This is called a "ceramic gap".

The ceramic gap may be installed on centre or off-centre of a short pipe section:



INSTALLATION ON THE VACUUM CHAMBER (Cont'd)

Vacuum chamber impedance

The ceramic gap causes a disruption of the impedance seen by the beam. On leptons accelerators, this is particularly detrimental to emittance. The most usual corrective measure consists of metallizing the inside of the ceramic gap. Metallization has been used successfully used on many electrons / positrons accelerators. Depending on the type of current transformer being installed (AC or DC), the resistance of the desirable metallization varies:

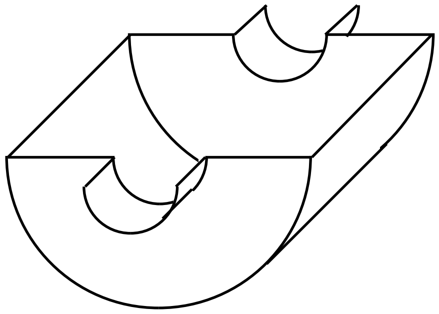
FCT current sensors tolerate a metallization with ca. 1Ω without problem, provided the wall current bypass is of very low impedance.

If a DC current transformer PCT or MPCT-S is installed over the same ceramic gap, these instruments are adversely affected by an ohmic value R < 100Ω because it shorts the PCT or MPCT modulator windings. The commonly used solution is to etch a narrow groove in the metal deposit to prevent DC conductivity of the gap metallization.

Wall current bypass and RF shield

The two functions of wall current by-pass and RF shield can be performed by a solid copper or aluminum shield attached to the vacuum chamber on either side of the electrical break.

A cylindrical enclosure which splits into two half shells is the easiest solution:



The shells can be firmly attached to the vacuum chamber with water hose clamps.

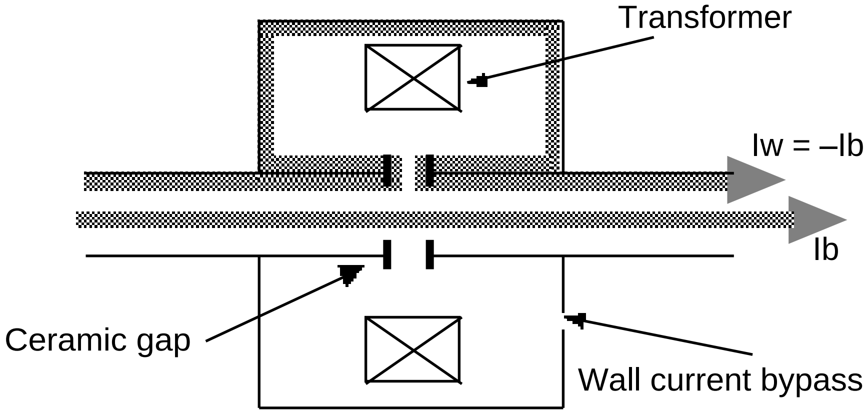
Thermal protection of the FCT

The FCT must not be heated beyond 80°C. If the vacuum chamber requires bake-out, a thermal shield must be installed between the vacuum chamber (or the heating sleeves) and the FCT.
The thermal shield can be a simple copper cylinder cooled by water circulating in a copper tube brazed onto the cylinder.
The water circuit must not pass thru the FCT aperture. It must enter and go out on the same side of the FCT, otherwise it makes a shorting loop around the FCT toroid.

Keeping high harmonics of the beam out of the cavity

The transformer, the gap capacitance and the wall current bypass form together a cavity.
It is important to prevent unnecessary harmonics from entering the cavity:

The beam current flows thru the vacuum chamber.
The wall current follows the conductive vacuum chamber walls.

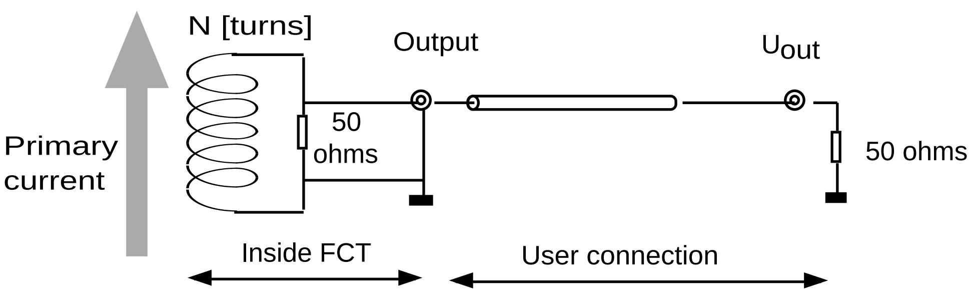


The transformer “sees” the wall current Iw. The higher frequencies of the wall current frequency spectrum will pass thru the capacitance of the ceramic gap, while the lower frequencies will enter the cavity and induce a flux in the transformer core.

Note that the full charge of the wall current pulse passes thru the cavity, irrespective of the value of the gap capacitance.

The value C of the gap capacitance determines the higher cutoff frequency of the wall current entering in the cavity. The -3dB point is obtained when the impedance of the cavity Z_{cavity} is equal to the impedance of the gap Z_{gap}.

The impedance of the wall current bypass itself can be ignored because it is much lower than the transformer’s reflected impedance, therefore:



$Z_{cavity} = R / N^2$, where:

R is the load impedance of the transformer = 25Ω (50Ω termination || 50Ω internal load)
N is the transformer’s turns ratio
Example, an FCT with 20:1 turns ratio (i.e. FCT-XXX-20:1), $Z_{cavity} = 0.0625\ \Omega$

Keeping high harmonics of the beam out of the cavity (Cont'd)

The gap impedance is determined by its capacitance:

$$Z_{gap} = 1 / \omega C, \text{ and } \omega = 2\pi f$$

For $Z_{cavity} = Z_{gap}$: $C = N^2 / 2\pi f R$

Example: FCT with 20:1 turns ratio, f_{-3dB} = 1GHz, R = 25Ω : C = 2.54 nF

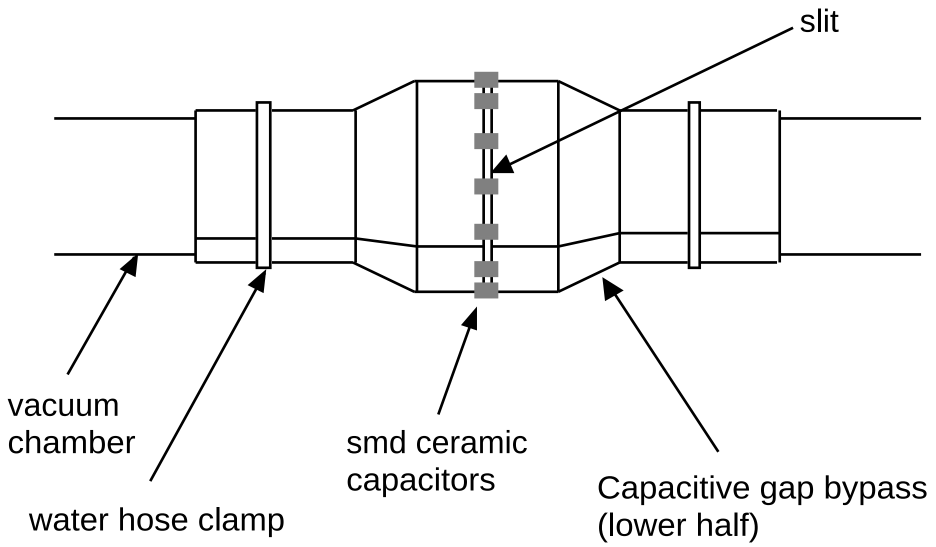
Different accelerator laboratories use different techniques to obtain the required gap capacitance. A simple method consists in building a capacitor over the ceramic gap with layers of copper foil separated by layers of 100µm-thick kapton foil. To obtain the desired capacitance value, the overlapping area is obtained by:

$$S = C\, d / \varepsilon_r\, \varepsilon_o$$

Where:
C is the capacitance [F]
S is the area [m^2]
d is the dielectric thickness [m]
ε_r is the relative dielectric constant, 3.5 for Kapton polyimid
ε_o is the dielectric constant 8.86 x 10^{-12}

Example, for C = 2.54 nF and d = 100µm and ε_r = 3.5, S = 82 cm^2.

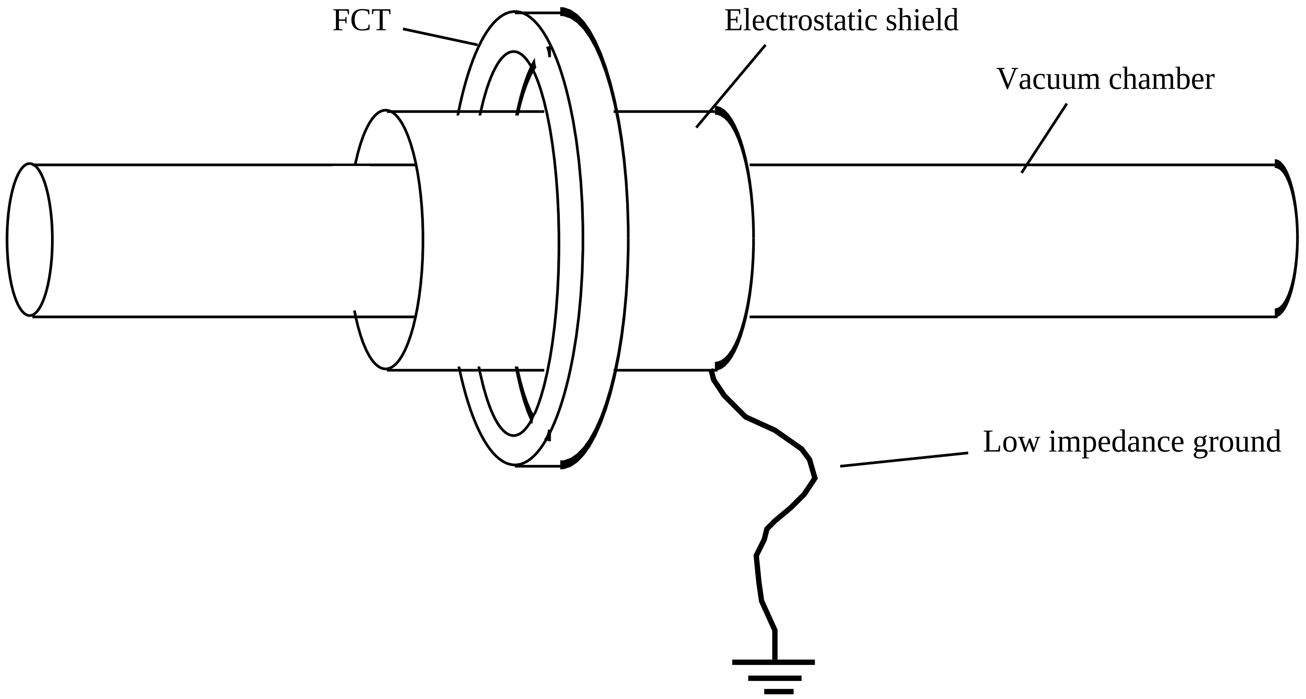
Other laboratories install a capacitive gap bypass with surface-mount capacitors distributed over the slit. The capacitive bypass is made in two halves for ease of mount:



Electrostatic shield

Electrostatic (capacitive) coupling between the FCT body and the vacuum chamber must be avoided. This is especially true for high-sensitivity FCTs like FCT-XXX-05:1.

An electrostatic shield may be installed:



The shield must be grounded on one side only (!)

Depending on the cables layout, grounding on one side will *increase* the noise pick-up, while grounding on the other side will *decrease* it. There is no easy way to predict on which side the electrostatic shield should be grounded: Different grounding conditions must be tried until the noise pickup is at its minimum. The quality of the grounding –thus the efficiency of the shield– is determined by the impedance of the grounding scheme. In practice, its inductance is the parameter to minimize.

Note: the noise picked up by capacitive coupling with the vacuum chamber is wideband noise. It is best observed with a wideband oscilloscope, while the accelerator is running.

The electrostatic shield can be made in any conductive metal, provided the grounding cable connects properly the the shield. It may have the dual purpose of thermal shield and electrostatic shield. In this case, one should take care that the cooling water pipes do not bring noise to the shield.

To hold the shield and the FCT sensor in place, while providing good isolation, the space between vacuum chamber, shield and FCT sensor can be filled with polyurethane foam. If the vacuum chamber requires high temperature bake-out, fiber glass wool will be preferred.

Note: The ICT accuracy is not affected by its radial, angular or axial position in respect of the beam axis.

Ferrite cores, tubes and beads installed on the coaxial cable contribute significantly to eliminate the noise picked up by the ICT body via capacitive coupling. Avoid the split cores when possible.

FCT RADIATION RESISTANCE

FCTs contain materials which may be damaged by ionizing radiations. They are listed hereafter:

Organic and radiation-sensitive materials used in the "Standard" sensor:

The "Standard" sensor is supplied when the "Rad-Hard" option is not ordered.

Component	*Material*	*Radiation resistance*[1]
Wiring insulation	Polyvinylchloride PVC	2 x 10^5 Gy
	Fiber glass	> 10^8 Gy
	with rubber adhesive	> 10^6 Gy
Stress absorbent	Silicon rubber tape SIR	5 x 10^5 Gy
	Silicon rubber SIR	2 x 10^5 Gy
Connector isolation	PTFE "Teflon"	< 10^3 Gy

Organic and radiation-sensitive materials used in the "Rad-Hard" sensor:

The "Rad-Hard" sensor is supplied when the "Rad-Hard" option is ordered. The ordering code and model number are then terminated by -H.

Component	*Material*	*Radiation resistance*
Wiring isolation	Polyether-ether-ketone PEEK	6 x 10^7 Gy
	Fiber glass	> 10^8 Gy
	with rubber adhesive	> 10^6 Gy
Stress absorbent	Polyurethane foam PU	5 x 10^6 Gy
	Polyurethane rubber PUR	5 x 10^6 Gy
Connector isolation	Polyethylene PEX, or	10^6 Gy
	Polyimid "Kapton"	6 x 10^7 Gy

The above radiation resistance values are indicative only. They do not imply any guarantee of whatever nature from the manufacturer.
The manufacturer specifically declines any responsibility for any damage, direct or consequential, caused by ionizing radiations.

[1] Compilation of Radiation Damage Test Data, H.Schönbacher et al., CERN 79-04, 79-08, 82-10 and 89-12.