Jim Fitzgerald
6-12-02

Recycler Ion Clearing Field Power Supplies

Introduction

The Ion Clearing Field (ICF) is a system that connects high voltage (HV) to the Recycler Ring (RR) Beam Position Monitors (BPM) electrodes for the purpose of collecting charged ions drifting in the beam pipe. One ICF power supply chassis is installed in each of six Main Injector service buildings, and provides HV to all the BPMS in the respective sector. A circuit in the RR BPM pre-amps isolates the HV from the BPM position measurement circuits.

The HV is distributed by (Red RG-58) with the up stream BPMs daisy chained using separate A and B electrode cables. The down stream BPMs are daisy chained in a like manner. There are approximately 35 BPMs in each of the US and DS strings. A map of all RR BPMs is shown in Fig. 5. The resulting four HV cables are routed upstairs to a relay rack and the PS chassis near the RR BPM electronic modules.

PS Chassis

Each PS chassis contains two small programmable power supplies, a four channel current measuring circuit board, an analog voltage and current monitoring circuit board and a logic board for status, local and remote control. The output of each of the small internal HV supplies drives two independent current measuring circuits. This arrangement provides four HV and four associated current reference outputs. The four HV outputs are then connected to the four HV cables leading to the BPMs. The cables can be arraigned to provide the common or opposite polarity voltage to the BPM A and B plates (1000 V Max). The cables are initially connected for opposite polarity to provide a voltage gradient across the BPM. See Fig. 1 for a simplified block diagram.

The chassis provides semi-independent control for the individual supplies. The voltage level is programmable, with both internal supplies tracking one reference input. The HV output can range from 0 to 500, with a scale factor of 50V/V. The polarities are programmable, using a common control bit for both supplies. The supplies can be set for either opposite or the same polarity. They are initially set for opposite polarities. A standard Camac CC218 is used for the power supply controller. See Fig. 2 and 3 for the Camac card I/O and Crate information. The power supplies are operated from Acnet parameter page R34, BPM sub pages 24 and 25 (Fig. 4)

The chassis can be switched to local control, from the front panel. All functions are available as noted above, except that 10 turn pots independently control the voltage of the internal supplies. PS voltages and current in each of the four channels can be monitored on the front panel LCD meter.

Included on the logic board are provisions for an over current trip, and safety system interlock s. The PS's have short circuit protection built in. The Safety Department has determined that this application is similar to the HV routing for Ion Pumps, and that it is not necessary to interlock the ICF power supplies. Status bits for indicating chassis local/remote, and individual supply on/off, and polarity. Refer to drawing 8130-ED- 356126 for a block diagram of the complete chassis.

High Voltage Power Supplies

The power supplies are the "RP" series manufactured by the "Emco High Voltage Company" The make nine models of this series with voltages ranging from 500 to 10KV all having the same physical size features and general specifications. The ICF uses the 0-500v “RP05” model. These supplies use TTL control for polarity and enable/disable (on/off), and a 0 - 10 Volt reference (always positive). They provide a voltage reference and polarity status bit outputs. Maximum current output of this model is 6 ma, with short circuit protection. A complete PS specification sheet is available in the document list below.

Current Measuring Circuit

The current measuring circuit is based on the Analog Devices (AD) AD204 isolation amplifier. Gain and low pass filter blocks have been added to a basic AD application circuit. This circuit measures the voltage drop across a large value resistor in series with the load. This resistor, buffer amplifiers, and part of the isolation amplifier, have a common ground, which floats on top of the HV PS output. The MADC analog to digital converter, which in this application is 12 bits bipolar or 2048(LSB value) determines the measurement resolution and range measured. The resolution (LSB value) and full-scale values in "engineering units" are chosen by setting the amplifier gain stages to the appropriate values. The current measuring schematic is shown on drawing 8130-EC-356129, which includes instructions for setting the amplifier gains. Referring to the schematic, the front-end gain is selected at Amp U1, and must be set for a maximum of 5 Volts at the AD 204's output. On the low voltage side of the AD 204 full-scale output range is set to 10v at Amplifier U3b. Using a 1 Mohm series resistor and gain at 10, the resolution becomes .488 nAmps, with full scale at 1.0 µAmps. The scale factor is 100 nAmps / V. Installing a 5 Mohm series resistor and with over circuit gain set at 200, the resolution becomes 4.88 pAmps with full scale at 10 nAmps. The scale factor would then be 1.0 nAmps/Volt.

Active low pass filters (one pole) are included on Amps U1, U3b, U5b, with an additional passive filter at the input of U5b. The filters all have a cutoff at approximately 1 Hz, with combined roll-off of -40 dB at 10 Hz.

Performance and Noise

This circuit has the capability of measuring low level current, at the pico amp range. However, the actual current resolution and accuracy is limited by the quality of the load, induced cable noise, the circuit gains, and filter Bandwidth. The initial gain setting gives a resolution of .5 nAmps, a range of 1 µAmp with a scale factor 100 nA/Volt. Bench testing at this gain setting has shown the circuit to contribute errors of approximately .2 nAmps.

Fig. 6 is recent fast time plot showing leakage current present in one string of 35 BPMs and connecting cable. It also shows noise at the 2-nano-amp range, which is due to pickup on the on connecting cable. Temperature drift over several days, and thermal cycling, contribute errors of approximately .3 nAmps.

Fig. 7 is a fast time plot showing current during a Main Injector cycle. This interference produces up to 25 nAmps p-p currents during the MI ramp. Measurements by the instrumentation group have shown differences between the beam line ground and service building grounds to be as much as 50 mVolts during a MI ramp. Calculations show that this voltage will produce an unbalance and current error about equal to that shown on the plots.

Fig. 8 is fast time plot showing charging current for a string of BPMs and cable. The charging initially peaks to few µAmps and then settles down to a few nAmps, which represents the BPM string leakage current. This current leakage is dependent almost entirely to the quality of the RG-58 high voltage cable. Current leakage ranges from about 10 nAmps for the better cables to several hundred nAmps for poor cables. Several cable sections have been identified and replaced because of high leakage or shorts. The charging time constant (TC) appears to be long for the final settling current. The plot shows (1) TC to be about 3 seconds, but final settling time runs out to about (5) TC. Calculations show that one string of 35 BPMs and cable should have a TC of about .5 sec, this combined with the amplifier filters 1Hz BW should give a TC of about 1 sec. Benches testing with actual cable (2000 ft) and simulated load agrees with the calculated value. The discrepancy is presently attributed to cable, connector and capacitor dissipation (or leakage).

Summary

The Ion Clearing Field Power Supplies work well, and discounting the connecting loads, are capable of measuring the current draw well into the pAmp range. They are presently set up with gain and BW values for measuring in the nAmp range, which they are capable of doing on the better cables, despite the cable leakage and induced MI ramp noise. Measurements should done after the ramp period and take into account the offsets caused by cable leakage. Zero offset compensation and sampling circuits could be added if warranted.

The Power Supplies (alone) are capable of measuring currents in the pAmp range, with the scale factor and BW change, noted previously. A more critical adjustment of gains and circuit offsets would also be required. However the present cable is questionable. This installation uses a single ended connection and will always pick up the MI ramp due to the different ground potentials. The cable does not have uniform characteristics. Each string has different leakage current. A spare PS is available and will be available for suggestions to improve the system.

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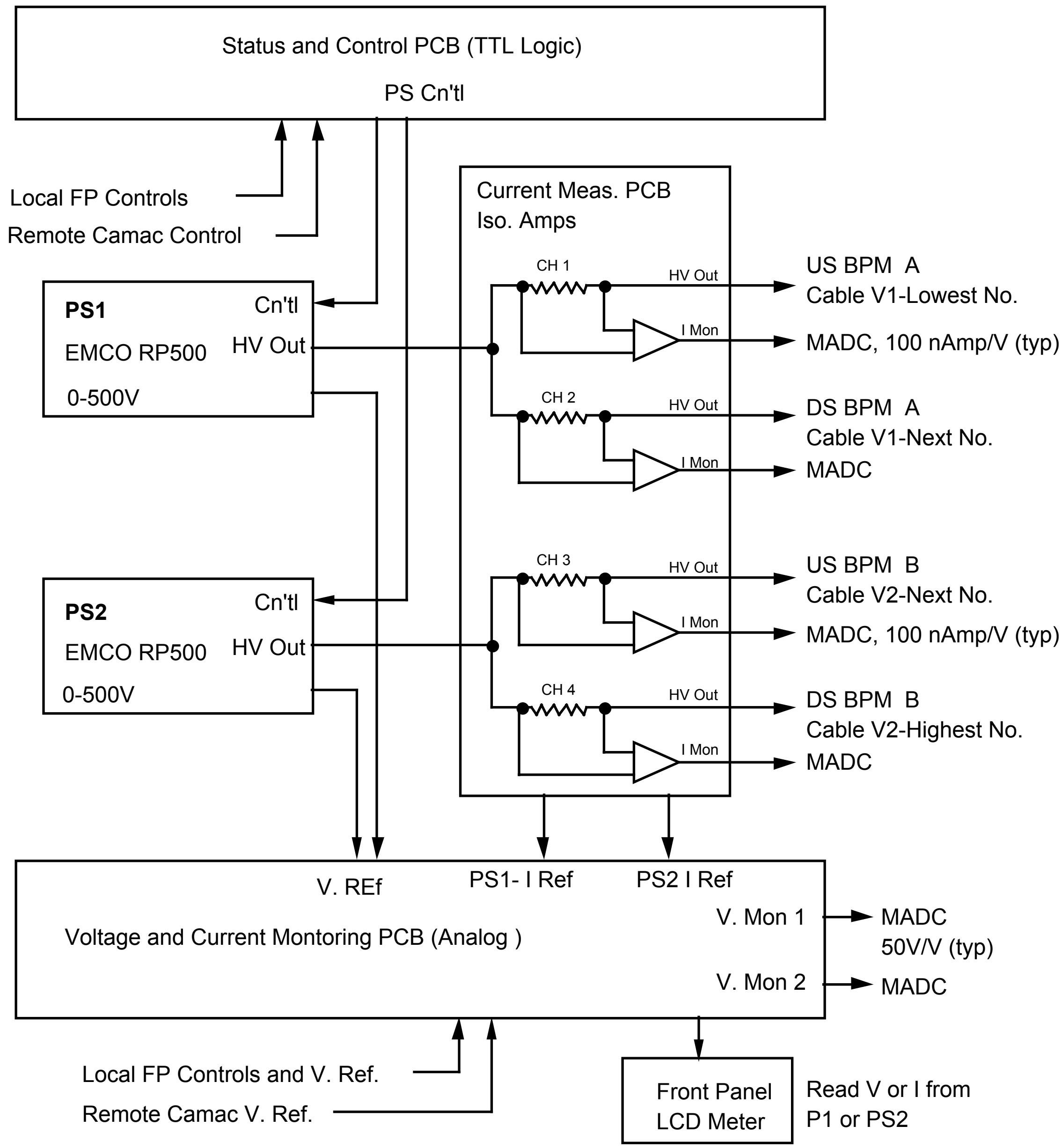

Fig. 1 Block Diagram of the Ion Clearing Field Power Supply

Drawings on file:

ICF Chassis Diagram / Schematic	8130-ED-356129
ICF Current Measurement Board Sch.	8130-EC-356126
(Previous P-Bar version)	8000-EC-266290
ICF Control Board	8130-EC-356127
ICF Analog Board	8130-EC-356128

Drawings and other items available Beams WNT/2000 server:

On WNT/2000 Beams Div. Server, log on to: "rfinst.bd on beamssv1"
At the "Y" drive go to : >public>Instrumentation>J. Fitzgerald>Ion C. F. Folder

PDF Files

ICF PS Block Diagram	8130-ED-356129.pdf
ICF PS Control Board	8130-EC-356127.pdf
ICF PS Analog Board	8130-EC-356128.pdf
List of Recycler BPMs	Recycler BPM Loc.pdf
Camac Crate info. and CC218 I/O	ICF PS CC218 I/O.pdf
HV Power Supply Data Sheet	HV PS data sheet.pdf
ICF PS Parts List	ICF PS parts list.pdf
ICF PS Chassis Front Panel	PS Front Panel.pdf
ICF PS Chassis Rear Panel	PS Rear Panel.pdf

P-Cad Files (printed circuit board artwork)

Printed Circuit Board Art Work. Requires P-Cad Software to view.

ICF Analog PCB	(8 P-Cad documents)
ICF Control PCB	(3 P-Cad documents)

	MI/RR Ion Clearing Field HV Power Supply				
	Acnet Parameter Page, and Camac Control Card Info.				
Par. P.					
Name I:	**MADC**	**Function**	**V. Level**	**Cable ID**	**Burndy Pin**
CF60UV	1	ICF Volts PS1 (A)	0 to +10, 50V/V		RG-58
CF60C1	2	ICF nAmps US BPMs A	0 to +10, 100nA/V		RG-58
CF60C2	3	ICF nAmps US BPMs B	0 to +10, 100nA/V		RG-58
CF60DV	3	ICF Volts PS2 (B)	0 to +10, 50V/V		RG-58
CF60C3	4	ICF nAmps DS BPMs A	0 to +10, 100nA/V		RG-58
CF60C4	5	ICF nAmps DS BPMs B	0 to +10, 100nA/V		RG-58
	Camac CC218, 12 bit, Unipolar Control, 5V Status Interface				
	CC218	**PS Function**	**V. Level**	**Viking Con.**	**Wire ID**
CF60PS	**Control D/A**	D/A Output	0 to +10 V	10R	RG- 58
		D/A Return		2L	RG-58 Gnd
	Status Bits	**Inputs**	**C. Sink, Active L**		
	0	US PS On	L=On	14R	A BK
	1	US PS Pol	L=Pos	13L	B BRN
	2	US PS OC Trip (NA)	L=No OC	13R	C RED
	3	US PS L/R	L=On	12L	D ORG
	4	DS PS ON	L=Pos	12R	E YEL
	5	DS PS Pol	L=Remote	10L	F GRN
	6	DS PS OC Trip	L= No OC	11R	G BLU
	7	DS L/R	L=Remote	11L	H VIO
	8	Safety S. OK (NA)	L=Safety OK	15L	J GRAY
	9	Spare			K WH
		Gnd		1R, 1L	L W/BK
	Control Relays				
	K2 NO	On	On=On/Reset	9R	M W/BRN
	K3 NO	Off	On=Off	5R	N W/RED
	K3 NC	Spare		7R	P W/ORG
	K4 NO	Polarity Pos	On=Pos	6L	R W/YEL
	K5 NO	Polarity Neg		3L	S W/GRN
	K5 NC	Spare	On=Neg	4L	T W/BLU
	K1	Spare		9L	U W/VIO
		Common V+		8R, 5L, 8L	V W/GRAY
Repeat same pattern for each MI service building.					
CF10xx	CF20xx	CF30xx	CF40xx	CF50xx	CF60xx

Fig. 2 Acnet parameter page names and Camac card connections.

	MI/RR Ion Clearing Field HV Power Supply				Jim Fitzgerald
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Location	BPM Sys. Loc.	ICF PS Loc.	CC218 Loc.	MADC Loc.	MADC CH
MI 10	MI 10116	MI10115	$13/slot 22	$13/slot 23/#19	40-45
MI20	MI 20116	MI20115	$23/slot 22	$23/slot 23/#30	40-45
MI30	MI 30116	Mi30115	$33/slot 22	$32/slot 23/#49	50-55 *
MI40	MI40116	MI40115	$43/slot19	$43/slot 23/#54	40-45
MI50	MI 50116	MI50115	$53/slot 22	$53/slot 23/#58	40-45
MI60 (N.)	MI 60211	MI60211	$73/slot 19	$73/slot 23/#38	40-45

Fig. 3 Acnet Camac Crate assignments for the power supply controllers and MADC channels.

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R34  CLEARING ELEC                   SET      D/A    A/D   Com-U ◆COPIES◆
-<FTP>+ *SA◆ X-A/D   X=TIME      Y=B:APGAWM,B:CIGWM ,B:VXBIAS,B BIAS
COMMAND ---- Eng-U   I= .058     I= 0        , 0      , 0       , 0
-<24>+  r_12 AUTO    F= .078     F= 10       , 10     , 10      , 10
torroid flux... rad_mon dcct... BPM_NOD ipm.... peanuts testdev
-R:CF10PS         Ion Clearing Field HV PS      500        500     VLTS ...-
 R:CF10UV         ICF Volts US BPMs                      * 496.1   VLTS
 R:CF10C1         ICF nAmps US BPMs A                    * 7.469   nAmp
 R:CF10C2         ICF nAmps US BPMS B                    * 3.719   nAmp
 R:CF10DV         ICF Volts DS BPMs                      *-498.8   VLTS
 R:CF10C3         ICF nAMPs DS BPMs A                    *-4.781   nAmp
 R:CF10C4         ICF nAmps  DS BPMs B                   *-9.781   nAmp
-R:CF20PS         Ion Clearing Field HV PS      500        500     VLTS ...-
 R:CF20UV         ICF Volts US BPMs                      * 486.6   VLTS
 R:CF20C1         ICF nAmps US BPMS A                    * 2.594   nAmp
 R:CF20C2         ICF nAmps US BPMS B                    * 2.719   nAmp
 R:CF20DV         ICF Volts DS BPMs                      *-486.8   VLTS
 R:CF20C3         ICF nAMPs DS BPMs A                    *-2.781   nAmp
 R:CF20C4         ICF nAmps  DS BPMs B                   *-9.156   nAmp
-R:CF30PS         Ion Clearing Field HV PS      500        500     VLTS ...-
 R:CF30UV         ICF Volts US BPMs                      * 493.3   VLTS
 R:CF30C1         ICF nAmps US BPMs A                    * 1.5     nAmp
 R:CF30C2         ICF nAmps US BPMS B                    * 8       nAmp
 R:CF30DV         ICF Volts DS BPMs                      *-507     VLTS
 R:CF30C3         ICF nAMPs DS BPMs A                    *-6       nAmp
 R:CF30C4         ICF nAmps  DS BPMs B                   *-4       nAmp
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Fig. 4 Acnet Parameter Page, for ICF power supplies at MI10, MI20 and MI30.

Recycler Ring BPM Locations										
MI-10	slot 1	slot 2	slot 3	slot 4	slot 5	slot 6	slot 7	slot 8	slot 9	slot 10
chan 1	HP628	VP628	HP632	VP632	HP636	VP636	HP640	VP640	HP102	VP102
chan 2	HP629	VP629	HP633	VP633	HP637	VP637	HP641	VP641	HP103	VP103
chan 3	HP630	VP630	HP634	VP634	HP638	VP638	HP100	VP100	HP104	VP104
chan 4	HP631	VP631	HP635	VP635	HP639	VP639	HP101	VP101	HP105	VP105
	slot 11	slot 12	slot 13	slot 14	slot 15	slot 16	slot 17	slot 18	slot 19	slot 20
chan 1	HP106	VP106	HP110	VP110	HP114	VP114	HP118	VP118		
chan 2	HP107	VP107	HP111	VP111	HP115	VP115	HP119	VP119		
chan 3	HP108	VP108	HP112	VP112	HP116	VP116	HP120	VP120		
chan 4	HP109	VP109	HP113	VP113	HP117	VP117	HP121	VP121		
MI-20	slot 1	slot 2	slot 3	slot 4	slot 5	slot 6	slot 7	slot 8	slot 9	slot 10
chan 1	HP122	VP122	HP126	VP126	HP130	VP130	HP204	VP204	HP208	VP208
chan 2	HP123	VP123	HP127	VP127	HP201	VP201	HP205	VP205	HP209	VP209
chan 3	HP124	VP124	HP128	VP128	HP202	VP202	HP206	VP206	HP210	VP210
chan 4	HP125	VP125	HP129	VP129	HP203	VP203	HP207	VP207	HP211	VP211
	slot 11	slot 12	slot 13	slot 14	slot 15	slot 16	slot 17	slot 18	slot 19	slot 20
chan 1	HP212	VP212	HP216	VP217	HP220	VP221	HP703	VP704	HP708	
chan 2	HP213	VP213	HP217	VP218	HP221	VP701	HP704	VP705		
chan 3	HP214	VP215	HP218	VP219	HP701	VP702	HP705	VP707		
chan 4	HP215	VP216	HP219	VP220	HP702	VP703	HP706			
MI-30	slot 1	slot 2	slot 3	slot 4	slot 5	slot 6	slot 7	slot 8	slot 9	slot 10
chan 1	HP222	VP222	HP226	VP226	HP230	VP230	HP302A	VP302A	HP307A	VP307A
chan 2	HP223	VP223	HP227	VP227	HP231	VP231	HP302B	VP302B	HP308A	VP308A
chan 3	HP224	VP224	HP228	VP228	HP232	VP232	HP307C	VP307C	HP309	VP309
chan 4	HP225	VP225	HP229	VP229	HP301A	VP301A	HP307B	VP307B	HP310	VP310
	slot 11	slot 12	slot 13	slot 14	slot 15	slot 16	slot 17	slot 18	slot 19	slot 20
chan 1	HP311	VP311	HP315	VP315	HP319	VP319	HP323	VP323	HP804	VP806
chan 2	HP312	VP312	HP316	VP316	HP320	VP320	HP324	VP324	HP805	VP807
chan 3	HP313	VP313	HP317	VP317	HP321	VP321	HP325	VP804	HP807	
chan 4	HP314	VP314	HP318	VP318	HP322	VP322	HP803	VP805		
MI-40	slot 1	slot 2	slot 3	slot 4	slot 5	slot 6	slot 7	slot 8	slot 9	slot 10
chan 1	HP326	VP325	HP330	VP329	HP334	VP333	HP338	VP337	HP400	VP341
chan 2	HP327	VP326	HP331	VP330	HP335	VP334	HP339	VP338	HP401	VP400
chan 3	HP328	VP327	HP332	VP331	HP336	VP335	HP340	VP339	HP402	VP401
chan 4	HP329	VP328	HP333	VP332	HP337	VP336	HP341	VP340	HP403	VP402
	slot 11	slot 12	slot 13	slot 14	slot 15	slot 16	slot 17	slot 18	slot 19	slot 20
chan 1	HP404	VP403	HP408	VP407	HP412	VP411	HP003	VP002		VP802
chan 2	HP405	VP404	HP409	VP408	HP413	VP412	HP004	VP003		VP803
chan 3	HP406	VP405	HP410	VP409	HP001	VP413	HP801	VP004		
chan 4	HP407	VP406	HP411	VP410	HP002	VP001	HP802	VP801		
MI-50	slot 1	slot 2	slot 3	slot 4	slot 5	slot 6	slot 7	slot 8	slot 9	slot 10
chan 1	HP414	VP414	HP418	VP418	HP422	VP422	HP426	VP426	HP430	VP430
chan 2	HP415	VP415	HP419	VP419	HP423	VP423	HP427	VP427	HP501	VP501
chan 3	HPR16	VP416	HP420	VP420	HP424	VP424	HP428	VP428	HP502	VP502
chan 4	HP417	VP417	HP421	VP421	HP425	VP425	HP429	VP429	HP503	VP503
	slot 11	slot 12	slot 13	slot 14	slot 15	slot 16	slot 17	slot 18	slot 19	slot 20
chan 1	HP504	VP504	HP508	VP508	HP512	VP512	HP516	VP516	HP520	VP520
chan 2	HP505	VP505	HP509	VP509	HP513	VP513	HP517	VP517	HP521	VP521
chan 3	HP506	VP506	HP510	VP510	HP514	VP514	HP518	VP518		
chan 4	HP507	VP507	HP511	VP511	HP515	VP515	HP519	VP519		
MI-60	slot 1	slot 2	slot 3	slot 4	slot 5	slot 6	slot 7	slot 8	slot 9	slot 10
chan 1	HP522	VP522	HP526	VP526	HP530	VP530	HP602	VP602	HP606	VP606
chan 2	HP523	VP523	HP527	VP527	HP531	VP531	HP603	VP603	HP607	VP607
chan 3	HP524	VP524	HP528	VP528	HP532	VP532	HP604	VP604	HP608	VP608
chan 4	HP525	VP525	HP529	VP529	HP601	VP601	HP605	VP605	HP609	VP609
	slot 11	slot 12	slot 13	slot 14	slot 15	slot 16	slot 17	slot 18	slot 19	slot 20
chan 1	HP610	VP610	HP614	VP614	HP618	VP618	HP622	VP622	HP626	VP626
chan 2	HP611	VP611	HP615	VP615	HP619	VP619	HP623	VP623	HP627	VP627
chan 3	HP612	VP612	HP616	VP616	HP620	VP620	HP624	VP624		
chan 4	HP613	VP613	HP617	VP617	HP621	VP621	HP625	VP625		VI626

Fig. 5 A List of the Recycler BPMs connected to the Ion Clearing Field HV power supplies.

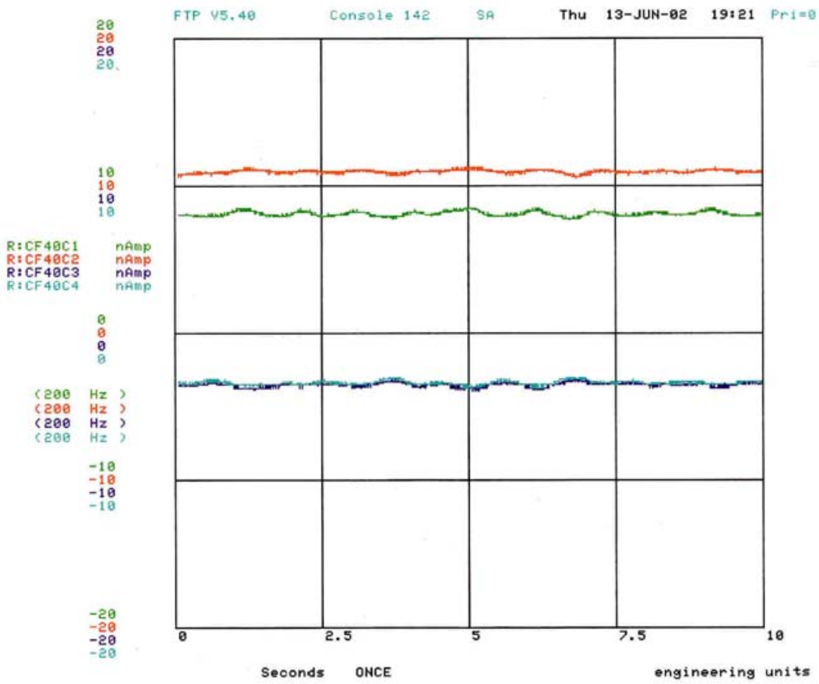

Fig. 6 Fast time plot of current measurement showing the offset and noise pickup for ICF power supply at MI40. The PS voltage was set at 300V.

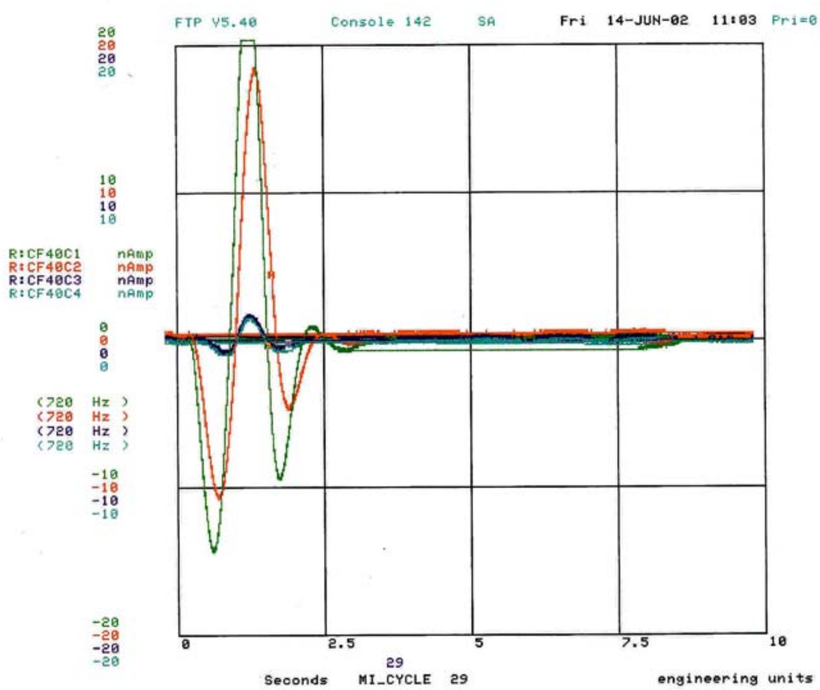

Fig. 7 Fast time plot of current measurement showing interference from MI ramp.

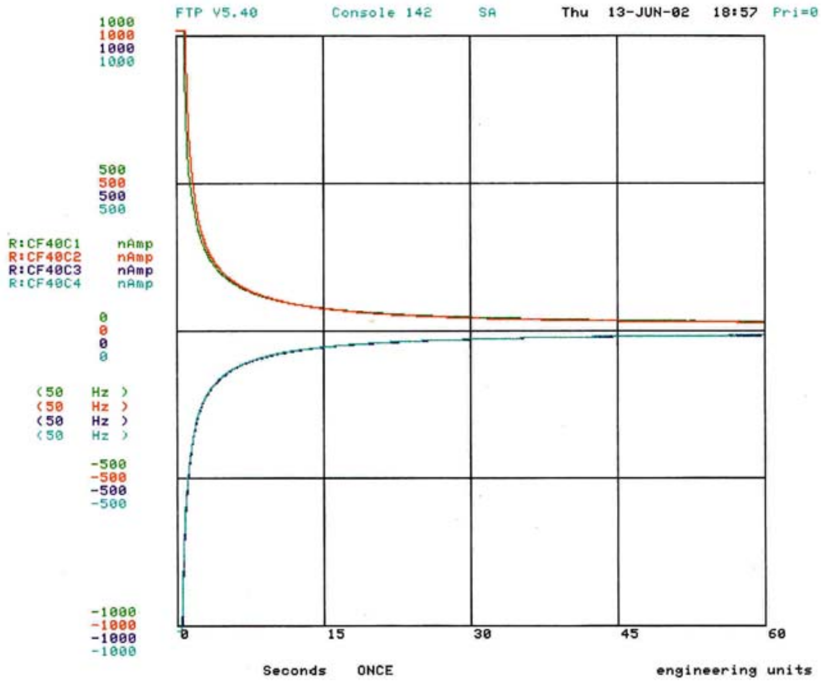

Fig. 8 Fast time plot showing current levels and time required for charging cable to 300 Volts.