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The Kjell Henriksen Observatory
UNIS
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Silver Bullet upgrade

New motor drive system for the Silver Bullet spectrometer

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1. Introduction

After 40 years of operation the Silver Bullet motor system died last February (2020) at the Kjell Henriksen Observatory (KHO) (16^{o}E, 78^{o}N). This document describes the hardware upgrades that followed. The instrument is a 1m focal length Ebert – Fastie spectrometer named Silver Bullet.

2. Short historical background

The Ebert-Fastie spectrometer, was constructed by W. G. Fastie at John Hopkins University, Maryland at the beginning of the 70's. Fastie improved the original design of the monochromator made by Hermann Ebert in 1889. In 1978, a 1m and a ½m Ebert-Fastie spectrometer were transferred to the Auroral Station in Adventdalen, Svalbard, from the Geophysical Institute, University of Alaska. One more 1m was installed in 1980.

These instruments are named 1m Green, ½m Black and 1m Silver Bullet according to focal length and chassis color. Since then, the photon counting, and computer electronics have been continuously upgraded in order to enhance both the control and performance of the instruments.

Furthermore, a ½ m Ebert – Fastie spectrometer (½m White) was moved in 2004 from the Skibotn Observatory to Longyearbyen. In 2007 all the spectrometers were moved up to the Kjell Henriksen Observatory (KHO) on Breinosa, close to the Svalbard EISCAT radar. Data from these instruments are widely published and recognized.

3. Basic optics

The main optical components of the instrument are shown in Fig. 1.

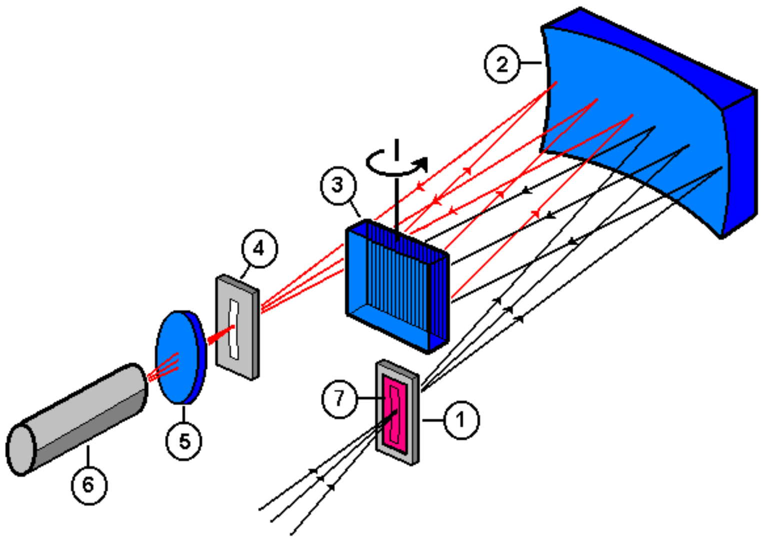


Figure 1. The Ebert-Fastie configuration: (1) entrance slit, (2) concave mirror, (3) plane reflecting grating, (4) exit slit, (5) collector lens, (6) detector, and (7) order sorting cut-off filter.

The principal components of the instruments are one large focal length spherical mirror, one plane reflective diffraction grating and a pair of curved slits. The recorded radiance from the sky is limited by the etendue - the product of the area of the entrance slit and the solid angle field of view. Because of the low intensity of the source, the etendue is made as large as possible. The image of the entrance slit is reflected by one part of the spherical mirror onto the grating. The second part of the mirror focuses the diffracted light from the grating onto the exit plane. When the grating rotates, the image of the entrance slit is swept across the exit slit. A collector lens transfers the output of the exit slit to the front of a photomultiplier tube (PMT). The tube is mounted in a thermoelectrically cooled housing and cooled down to -20C. Signals from the tube are amplified and discriminated before sent to the computer’s counting card. Cut-off filters are used in front of the entrance slit to prevent overlapping spectral orders. The field of view of approximately is approximately 5 degrees. Appendix A lists the fundamental equations for this type of optical configuration.

4. Hardware overview

Fig. 2 shows the Ebert – Fastie spectrometer named 1m Silver Bullet. The main electronics required to run the instrument may be separated in 4 subcategories

1. The detector head.
2. The high voltage supply.
3. The grating sweep mechanism.
4. PC with high speed counter card.

A short description of each subcategory follows.

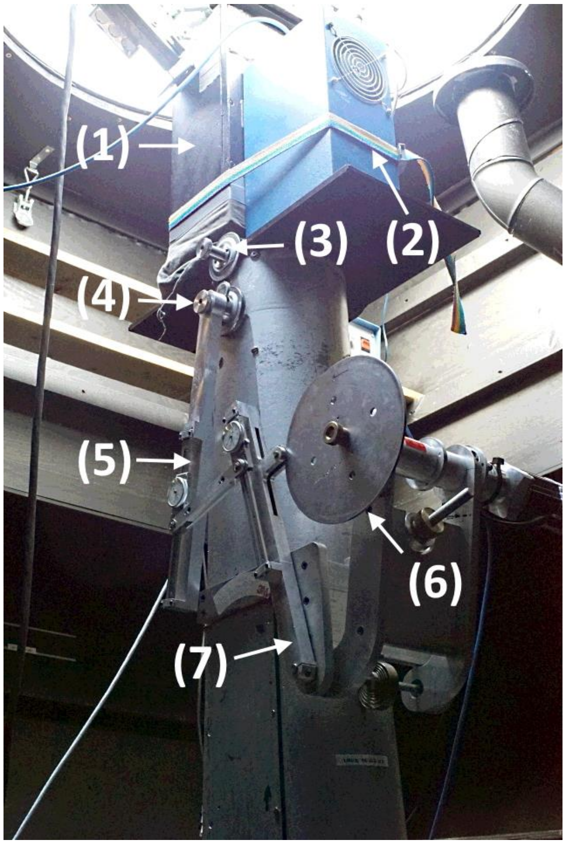


Figure 2. The 1 m Silver Bullet Ebert – Fastie spectrometer. (1) Entrance shutter, (2) Peltier cooler for PMT, (3) slit width adjustment screw, (4) grating shaft, (5) grating arm (normal), (6) sin drive motor system and (7) motor disk arm.

4.1 The detector head

In order to reduce thermo electrical noise or dark current, the photo-multiplicator (PMT) is cooled using the Peltier technique. Simply stated, Peltier cooling is based on the phenomenon of cooling or absorption of heat at the junction of two rods of metal or semi conductor when a current is made to pass through them. For thermoelectric cooling devices to be effective, the absorbed heat must be removed from the hot side of the device.

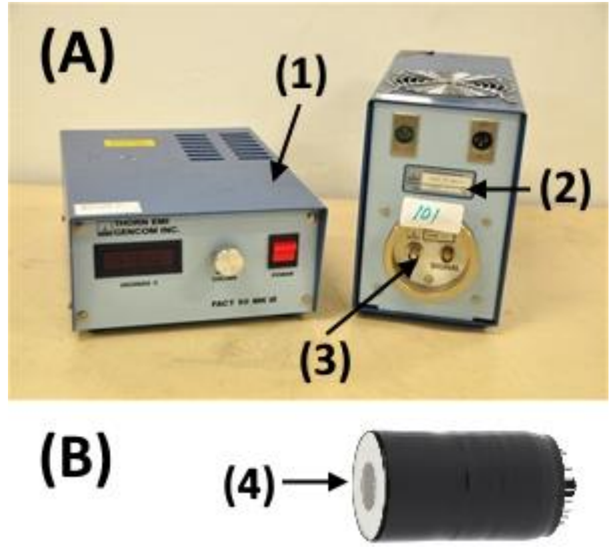


Figure 3. Detector assembly: Panel (A): (1) Power supply, (2) Cooler and (3) Socket. Panel (B): (4) Photomultiplicator (PMT).

In Fig. 2 an air fan is mounted on the top of the housing to blow out / exchange hot air.

The cooler in Fig. 2 is made by the company: Thorn EMI model Fact-50 MKIII. Fig. 3 shows detector assembly. The PMT is from Hamamatsu model R943-02. When a photon hits the photo emissive GaAs cathode of the tube, it emits a photoelectron into vacuum. The electron is then accelerated and directed to the first electrode (dynode), where it kicks loose a secondary electron. Note that high voltage is required to accelerate the electrons. The process continues at the next dynode. Finally, the multiplied result, a train of electrons, is collected by the anode as an output signal. This is illustrated in Fig. 4.

Most of the PMT's we use are from the Hamamatsu Corporation. Some old ones are from Thorn EMI, UK.

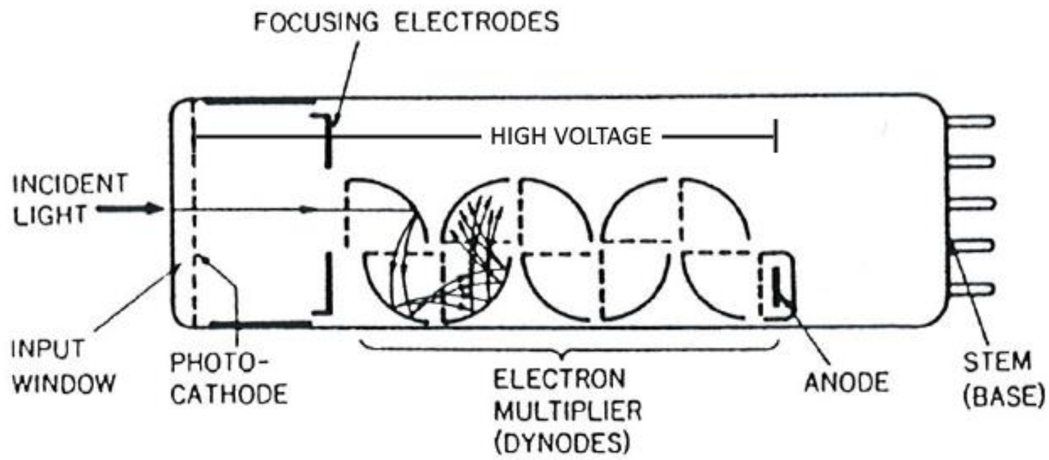


Figure 4. Basic principle of a photomultiplicator (PMT).

The signals from the anode are amplified and discriminated to form a square pulse train. This operation is carried out by a PAD (Pulse Amplifier and Discriminator). The current pulses from the anode of the PMT are converted by the PAD to TTL compatible output pulses that are suitable for PC counter cards.

Several PADs have been used from different manufactures. The Golden bricks from the former company SpaCom Electronics has been used up to 2004. As of today, we use the Silver PADs from Advanced Research Instrument Corporation due to availability and durability. Fig. 5 shows the F-100TD Silver PAD and its main specifications.

Max Repetition rate	50 MHz
Input Charge Sensitivity	<20 fC
Input impedance	50 Ω
Input noise level	<0.4 μA p-p
Pulse pair resolution	20 ns
Min. output pulse width	10 ns
Output	TTL
Power supply	+8 – 24 V

Figure 5. The F-100TD Preamplifier / Discriminator from Advanced Research Instrument Corporation with trimmed threshold control.

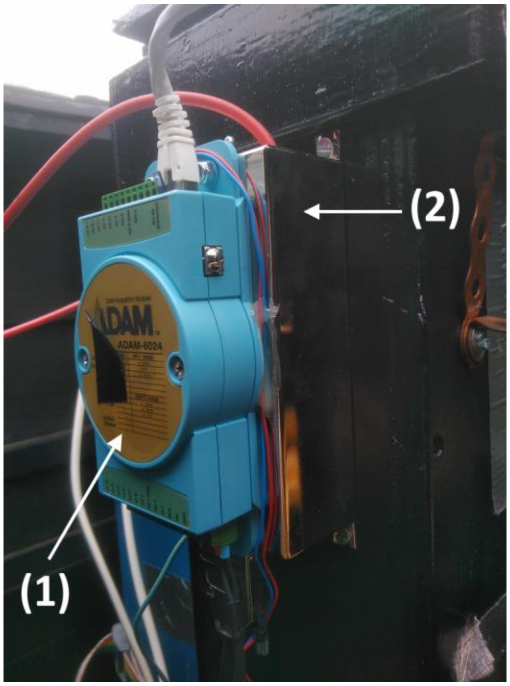


Figure 6. High Voltage (HV): (1) Adam control unit and (2) HV supply.

4.2 The high voltage supply

The high voltage system to the PMT contains the high voltage generator, a signal control module and a couple of DC power supplies. The generator is produced by the company Euro Test in Germany (model # CPn 30 405 125). This unit can produce up to -3kV. The output is controlled by a 12 channel multi purpose I/O module from Advantech Co., Ltd. The ADAM-6024 interfaces through the internet through standard IP- based protocols. Fig. 6 shows a close up of the ADAM module mounted on top of the high voltage generator. The specifications and the connection diagram are shown in appendix B and C respectively.

4.3 The grating sweep mechanism

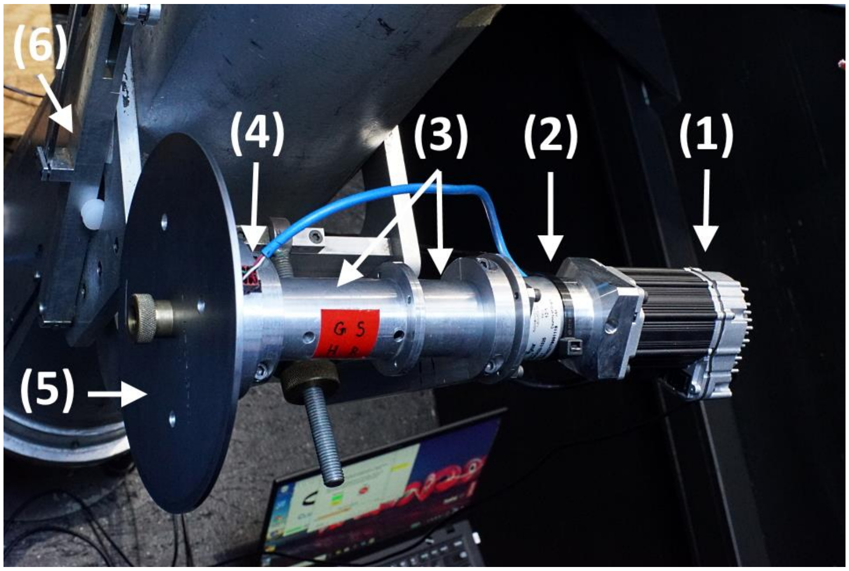


Figure 7. Grating cam motor system: (1) servo motor, (2) gearbox – speed reducer, (3) extended motor shaft housings, (4) fiducial sensor, (5) sinusoidal-shaped rotary cam, and (6) intermediate grating arm with moveable pivot.

Fig. 7 shows the upgraded motor system. The grating sweep mechanism is variable in position, amplitude and speed. The position of the sweep is determined by the angular position of the grating arm with respect to the grating shaft. The magnitude of the sweep amplitude (spectral range) is varied by an intermediate arm which has a follower and a moveable pivot on which the grating arm rides. This type of cam system is used on both the 1m Silver Bullet and the ½ m White spectrometer. The speed of the grating sweep is controlled by a servo motor which drives the cam through a reduction gear.

Figure 8. Motor system: (1) servo motor, (2) planetary gear, and (3) power supply.

The new motor is an integrated servo motor named ClearPath model CPM-MCPV-2321S-RQN from the company Teknic. The servo is NEMA 23 in size and has a built-in controller with several operational modes. The default model comes with a 800 line encoder. The system is set to operate in CCW constant speed mode at 25 RPM. It connects to a PC USB port for programming and is powered by a 75 VDC output supply model IPC-5 from Teknic.

The motor shaft of the servo is directly connected to a planetary gearbox with a 10:1 ratio. It is named SureGear model PGN23-1025 and was delivered by the company Lamonde Automation Ltd. With this setup, a 25 RPM motor speed gives a cam rotation period of 24 seconds.

The motor is rotating with constant speed. A slotted optical limit switch (Monsanto MCT81) triggers a high TTL pulse when the cam moves to the end position of a spectral scan. It remains high until the start of the sweep. This signal is called the fiducial and is used to trigger the PC counting sequence. The electrical diagram for the MCT81 is shown in appendix D.

4.4 PC with high speed counter card

Figure 9. NI - PCI 6602

The counter card is made by National Instruments (NI). The NI 6602 device is a PCI bus compatible card. It has four 32-bit counter channels and up to 32 lines of individually configurable, TTL/CMOS-compatible digital I/O. The card has a base frequency of 80 MHz and each counter can detect down to 5 ns wide pulses. The card is installed on a Windows XP operated PC.

In addition, a NI SCB-68 connector box is used to access the cards ports. See appendix E for pin assignments.

The basic idea is that the fiducial signal triggers a pulse signal train, where the period of the pulses is the integration time. This pulse train is used as GATE input to the counter channel (SOURCE). The counter counts the number of falling edges that occur on SOURCE between two active edges of the GATE signal. At the completion of the period interval for GATE, the HW Save register latches the counter value for the software read. Fig. 10 shows single-period measurements where the periods of GATE are 3, 7, 10 and 13 SOURCE falling edges.

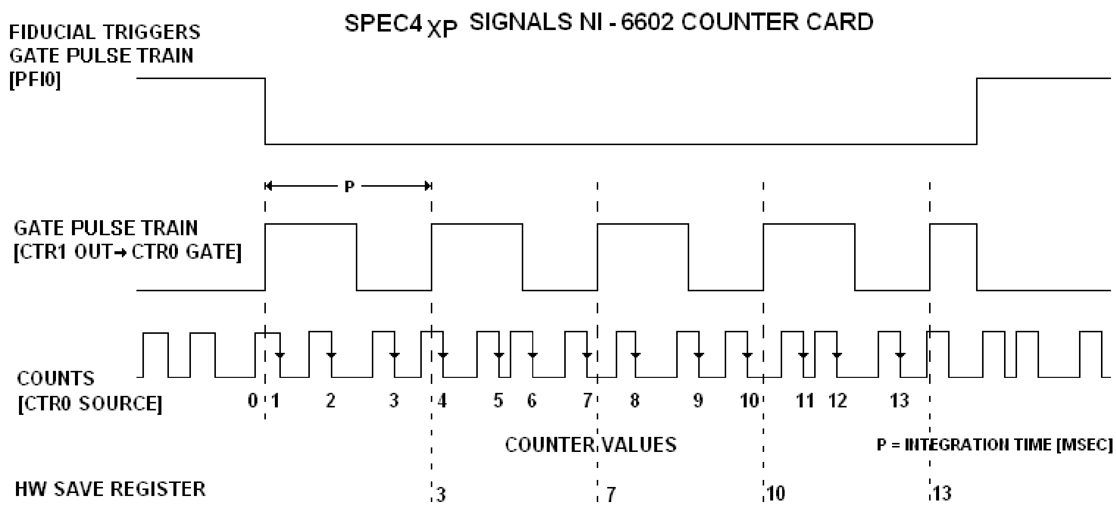


Figure 10. Single period measurement method using the NI-PCI 6602 counter card.

Note that the new fiducial electronics is now powered directly by the NI SCB-68 connector box.

Summary

The new motor system rotates smoothly as expected with the new fiducial electronics compatible with the counter card. Further performance tests and calibrations will be carried out at the beginning of the next auroral season.

Manufactory list

Products for Research Inc.
88 Holten Street, Danvers, MA 01923, USA
Phone: (978)774-3250 – Fax: (978) 762-3593
http://www.photocool.com/

Hamamatsu Photonics K. K.
325-6, Sunayama - cho, Hamamatsu City, Shizuoka Pref., 430-8587, Japan
Phone: (81)-53-452-2141 – Fax: (81)-53-456-7889
http://www.hamamatsu.com

Advanced Research Instruments Corporation
327 Chicago Ave. SE
Bandon, OR 97411 USA
http://aricorp.com

Euro Test
ET System electronic GmbH
Haupstr. 119 – 121
D-68804, Altluβheim, Germany.
Tel.: +49 (0)6205 3948-0 - Fax: +49 (0)6205 375 60
https://www.et-system.de/en/

Advantech Co., Ltd.
No. 1, Alley 20, Lane 26
Rueiguang Road, Neihu District
Taipei 114, Taiwan, R. O. C.
http://www.advantech.com

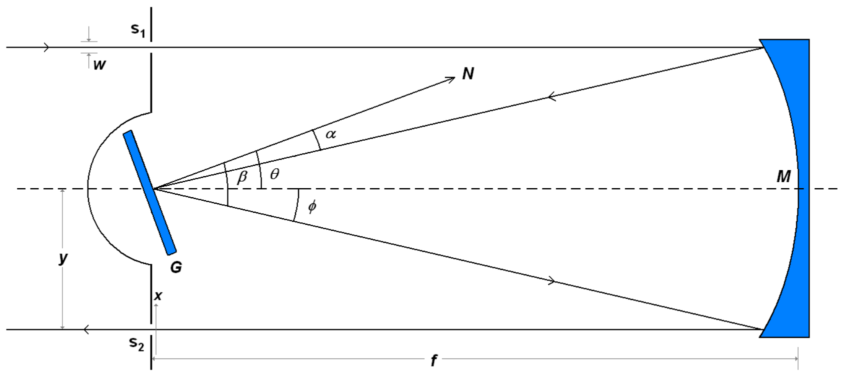
TEKNIC
115 Victor Heights Parkway
Victor, NY 14564 USA
Phone: +1 585 784 7454
Fax: +1 585 784 7460
http://www.teknic.com

Lamonde Automation Ltd.
Unit 3 Lloyds Court
Manor Royal
Crawley
W. Sussex
RH10 9QU, UK
Tel: 020 3026 2670
http://www.lamonde.com

National Instruments
11500 North Mopac Expressway
Austin, Texas 78759-3504 USA
Tel: 512 794 0100
http://www.ni.com/

APPENDIX A

Basic equations for an Ebert-Fastie spectrometer



N – grating normal
θ – grating angle
ϕ – constant
tan $\phi = y / f$
f – focal length
α – incident angle
β – diffracted angle
y – ½ slit – slit distance
a – groove spacing
n – spectral order
w – slit width

Figure 1. Optical diagram Ebert- Fastie spectrometer. G is plane reflective grating, S_1 entrance slit, S_2 exit slit, and M concave mirror.

The grating equation is

$$n\lambda = a\,(\sin\alpha + \sin\beta)\text{, where } \alpha = \theta - \phi \text{ and } \beta = \theta + \phi .$$

Then $n\lambda = a\left[(\sin\theta\cos\phi - \sin\phi\cos\theta) + (\sin\theta\cos\phi + \sin\phi\cos\theta)\right]$ or

$$\Rightarrow \quad n\lambda = 2a\sin\theta\cos\phi .$$

Note that the grating is tuned as the sine of the angle θ. This is the reason for the sinusoidal-shaped rotary cam. Furthermore, angular dispersion is

$$\frac{d}{d\beta}(n\lambda) = a\cos\beta ,$$

and since $dx = f\,d\beta$ then linear dispersion becomes

$$\frac{d\lambda}{dx} = \frac{d\lambda}{d\beta\, f} = \frac{a\cos\beta}{n\, f} = \frac{a\cos(\theta+\phi)}{n\, f}$$

The theoretical bandpass of the instrument is then defined as

$$BP = FWHM = \frac{d\lambda}{dx}\times w = \frac{a\cos(\theta+\phi)}{n\, f}\times w.$$

APPENDIX B

CPx[1] 30 405 12 5

HV-Modul der CPS Serie

Technische Daten

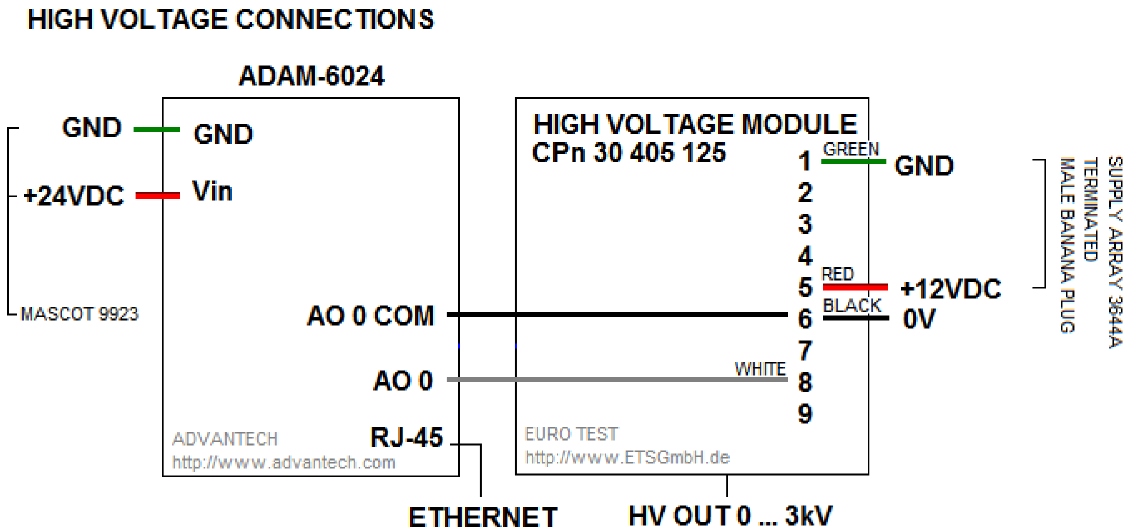
V_{OUT}	[1]x=p: 0 bis 3 kV (bezogen auf GND) [1]x=n: 0 bis - 3 kV
I_{OUTmax}	4 mA
V_{IN}	11,5 bis 15,5 V-DC
I_{IN}	< 1,5 A (V_{OUT}= 0 ; I_{OUT}= 0: < 100 mA)
Steuerung mit	V_{SET} = 0 bis 5 V
Monitoring mit	V_{MON} = 0 bis 5 V
Ripple	typ: 60 mV_{P-P} max.: 150 mV_{P-P}
Stabilität	$\Delta V_{OUT} / \Delta V_{IN}$: $< 1 \cdot 10^{-4} \cdot V_{OUTmax}$ Leerlauf/Vollast: $< 2 \cdot 10^{-4} \cdot V_{OUTmax}$
Temperaturkoeffizient	$< 1 \cdot 10^{-4}/_K$
Betriebstemp.-bereich	0 . . . +50 °C
Lagertemp.-bereich	-20 . . . +60 °C
HV-Ausgang	- Lemo HV-Kabel 9 kV, geschirmt (LEMO 9106330) - Länge = 600 mm - überlast und kurzschlußfest

9-poliger D-Sub Stecker

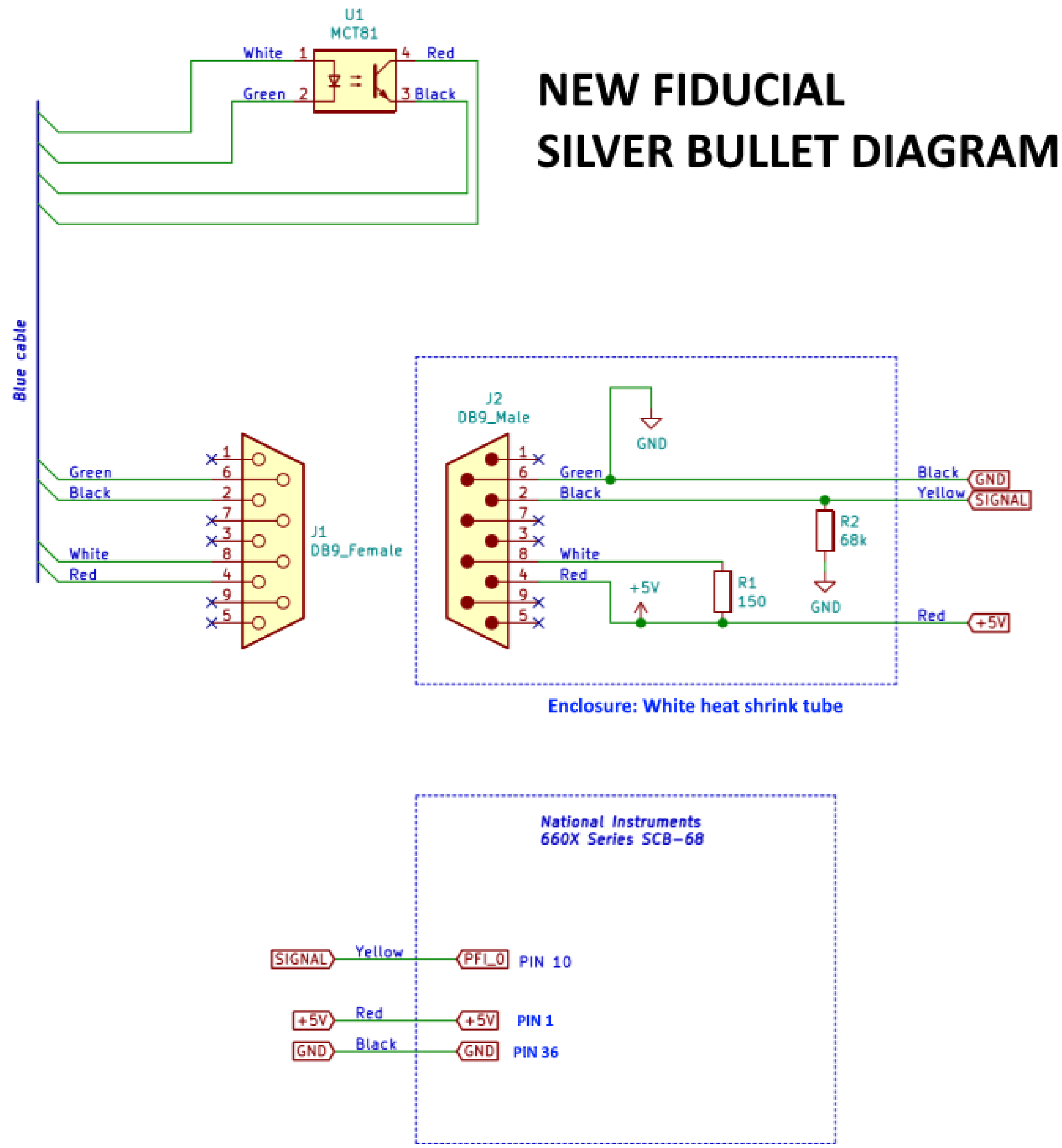
PIN	Name	Beschreibung
1	PWR_0V	Power 0 V (verbunden mit PIN 6, GND und Gehäuse)
2	V_I_{MON}	Monitorspannung entsprechend I_{OUT} I_{OUT}= 0 bis I_{OUTmax} ⇒ V_{2-6} = 0 bis V_{MON}
3	INH	INHIBIT (TTL-Pegel, LOW=aktiv ⇒ V_{OUT} = 0)
4	V_I_{SET}	Hardwarestrom-Limit: V_{4-6} = 0 bis V_{SET} (R_i = 10 kΩ gegen V_{REF}) ⇒ I_{OUT} = 0 bis I_{OUTmax} n.c. ⇒ I_{OUTmax} ist möglich
5	PWR_+	+ V_{IN}
6	V_{SET}_0V	Signal 0 V (verbunden mit PIN 1, GND und Gehäuse)
7	V_V_{MON}	Monitorspannung entsprechend V_{OUT} V_{OUT}= 0 bis V_{OUTmax} ⇒ V_{7-6} = 0 bis V_{MON}
8	V_V_{SET}	Spannungssteuerung: V_{8-6} = 0 bis V_{SET} ⇒ V_{OUT} = 0 bis V_{OUTmax}
9	V_{REF}	V_{9-6} = 5 V (1 mA) Interne Ref.-spannung für ext. Poti (Schleifer an V_V_{SET} und/oder V_I_{SET})

ET System electronic GmbH
Hauptstr. 119-121
D – 68804 Altlußheim Germany
Email: info@ETSGmbH.de
http://www.ETSGmbH.de
Tel ++ 49 (0)6205 / 39 48 - 0
Fax ++ 49 (0)6205 / 37 560

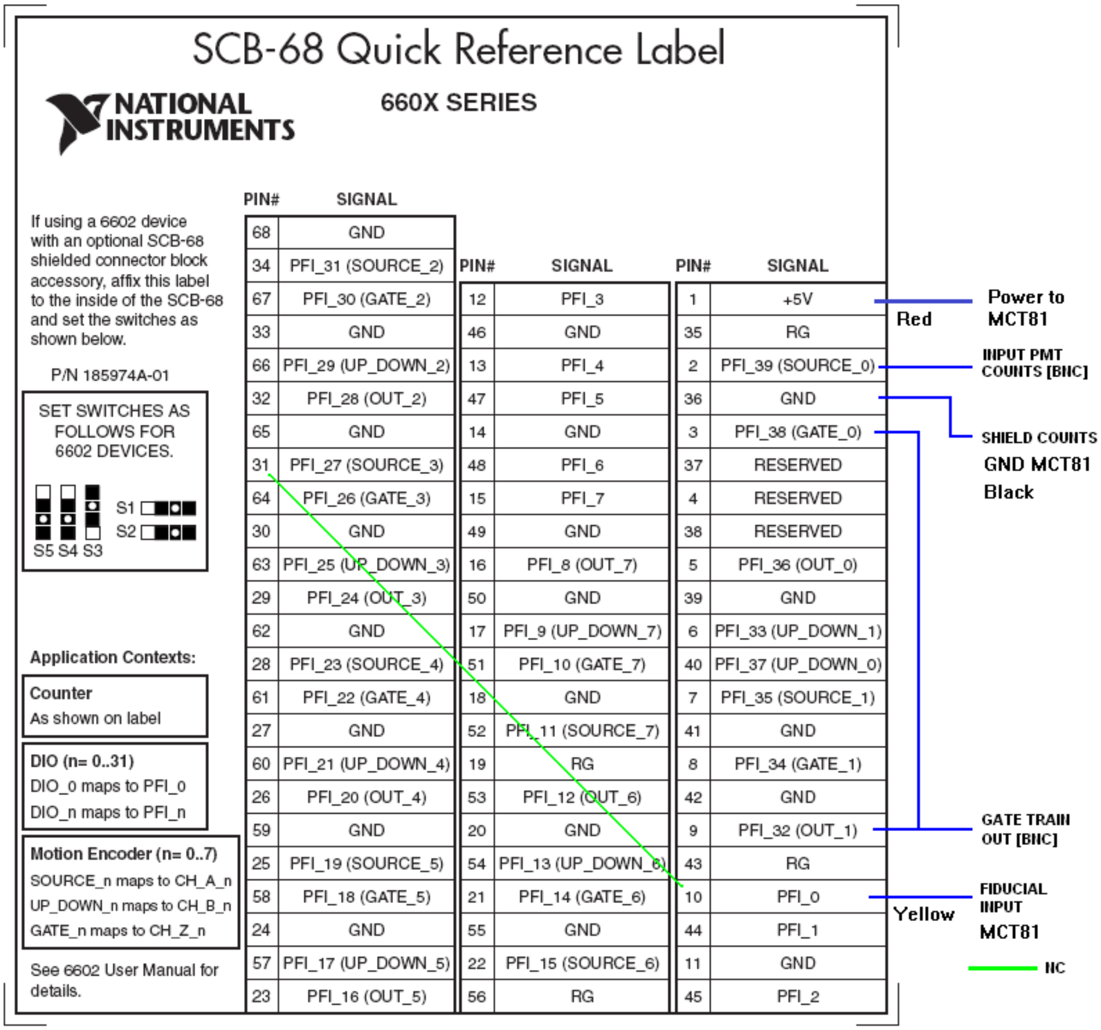
APPENDIX C


HIGH VOLTAGE CONNECTIONS
ADAM-6024
GND
+24VDC
MASCOT 9923
GND
Vin
AO 0 COM
AO 0
ADVANTECH
http://www.advantech.com
RJ-45
ETHERNET
HIGH VOLTAGE MODULE
CPn 30 405 125
1
2
3
4
5
6
7
8
9
GREEN
GND
RED
+12VDC
BLACK
0V
WHITE
EURO TEST
http://www.ETSGmbH.de
HV OUT 0 ... 3kV
SUPPLY ARRAY 3644A
TERMINATED
MALE BANANA PLUG

APPENDIX D


U1
MCT81
White
Red
Green
Black
NEW FIDUCIAL
SILVER BULLET DIAGRAM
Blue cable
J1
DB9_Female
J2
DB9_Male
GND
Green
Black
White
Red
+5V
R1
150
R2
68k
Black
Yellow
GND
SIGNAL
+5V
Enclosure: White heat shrink tube
National Instruments
660X Series SCB-68
SIGNAL
Yellow
PFI_0
PIN 10
+5V
Red
PIN 1
GND
Black
PIN 36

APPENDIX E


SCB-68 Quick Reference Label
NATIONAL INSTRUMENTS
660X SERIES
If using a 6602 device with an optional SCB-68 shielded connector block accessory, affix this label to the inside of the SCB-68 and set the switches as shown below.
P/N 185974A-01
SET SWITCHES AS FOLLOWS FOR 6602 DEVICES.
S1
S2
S5 S4 S3
Application Contexts:
Counter
As shown on label
DIO (n= 0..31)
DIO_0 maps to PFI_0
DIO_n maps to PFI_n
Motion Encoder (n= 0..7)
SOURCE_n maps to CH_A_n
UP_DOWN_n maps to CH_B_n
GATE_n maps to CH_Z_n
See 6602 User Manual for details.
PIN# SIGNAL
68 GND
34 PFI_31 (SOURCE_2)
67 PFI_30 (GATE_2)
33 GND
66 PFI_29 (UP_DOWN_2)
32 PFI_28 (OUT_2)
65 GND
31 PFI_27 (SOURCE_3)
64 PFI_26 (GATE_3)
30 GND
63 PFI_25 (UP_DOWN_3)
29 PFI_24 (OUT_3)
62 GND
28 PFI_23 (SOURCE_4)
61 PFI_22 (GATE_4)
27 GND
60 PFI_21 (UP_DOWN_4)
26 PFI_20 (OUT_4)
59 GND
25 PFI_19 (SOURCE_5)
58 PFI_18 (GATE_5)
24 GND
57 PFI_17 (UP_DOWN_5)
23 PFI_16 (OUT_5)
PIN# SIGNAL
12 PFI_3
46 GND
13 PFI_4
47 PFI_5
14 GND
48 PFI_6
15 PFI_7
49 GND
16 PFI_8 (OUT_7)
50 GND
17 PFI_9 (UP_DOWN_7)
51 PFI_10 (GATE_7)
18 GND
52 PFI_11 (SOURCE_7)
19 RG
53 PFI_12 (OUT_6)
20 GND
54 PFI_13 (UP_DOWN_6)
21 PFI_14 (GATE_6)
55 GND
22 PFI_15 (SOURCE_6)
56 RG
PIN# SIGNAL
1 +5V
35 RG
2 PFI_39 (SOURCE_0)
36 GND
3 PFI_38 (GATE_0)
37 RESERVED
4 RESERVED
38 RESERVED
5 PFI_36 (OUT_0)
39 GND
6 PFI_33 (UP_DOWN_1)
40 PFI_37 (UP_DOWN_0)
7 PFI_35 (SOURCE_1)
41 GND
8 PFI_34 (GATE_1)
42 GND
9 PFI_32 (OUT_1)
43 RG
10 PFI_0
44 PFI_1
11 GND
45 PFI_2
Red
Power to MCT81
INPUT PMT COUNTS [BNC]
SHIELD COUNTS
GND MCT81
Black
GATE TRAIN OUT [BNC]
Yellow
FIDUCIAL INPUT
MCT81
NC