Session 2-1
Chairman : B. Frammery (CERN)

Measurement, Protection and Controls

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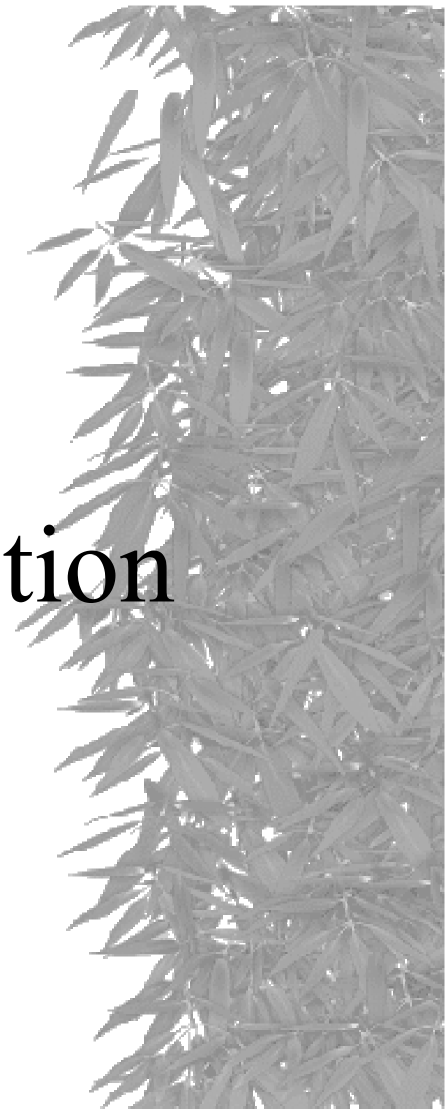
Measurement, Protection & Controls



Session 2-1

- A new interlock system for the TESLA RF-system
J. Kahl & T. Grevsmuehl / DESY

- Muon Collider Test Facility New PFN, interlocks & Controls
P. Prieto / Fermilab

- Klystron Gun Arcing and Modulator Protection
S. Gold / SLAC

- Development of the new CTF3 Klystron-Modulator Controls Interface System
B. Bartholome / CERN

Chairman : B. Frammery

A new interlock system for the TESLA RF-system

J. Kahl & T. Grevsmuehl / DESY

Chairman : B. Frammery

Joachim Kahl
DESY

Torsten Grevsmuehl
DESY

Chairman : B. Frammery

A new interlock system for the TESLA RF-system

J. Kahl & T. Grevsmuehl / DESY

- Traditional interlock system deal with individual sensor signals in a purely hierarchical way.
- A collaborative and predictive approach may be used using fuzzy logic
  - collaborative : status information needs to be assessed or confirmed by more than one sensor (ex : t^{ure} & water flow)
  - predictive : trend curves give information on when security actions have to be performed
- Implementation in ASICS in VME64x crates offers a large number (205) of user-configurable pins suitable for interlock systems

Chairman : B. Frammery

A new interlock system for the TESLA RF-system

J. Kahl & T. Grevsmuehl / DESY

- Comments :
  - approach needed when many equipment in the controlled process to avoid numerous unnecessary stops
  - the logic embedded in this approach needs a thoroughful testing (the smartest, the more testing needed)
  - information needed for the supervision to understand what has been going on !!

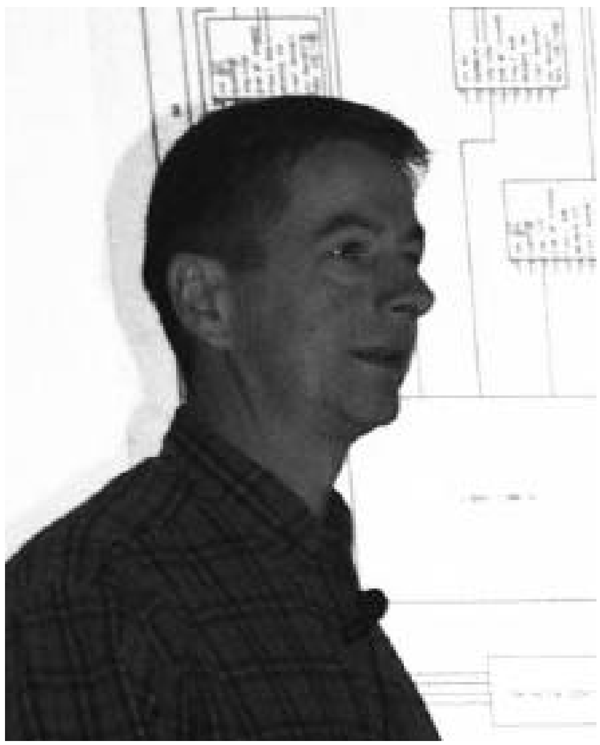
Chairman : B. Frammery

Muon Collider Test Facility
New PFN, interlocks & Controls

P. Prieto / Fermilab

Chairman : B. Frammery

Peter Prieto
Fermilab



Chairman : B. Frammery

Muon Collider Test Facility New PFN, interlocks & Controls

P. Prieto / Fermilab

- 3 Ohm PFN with SCR-based switch (3kA)
- 12MW klystron on a 1:20 transformer
- 6-cell 805 MHz cavity
- Presentation of equipment (see pictures)
- Interlocks and controls to provide local & remote monitoring(VME +Ethernet)

Chairman : B. Frammery

Klystron Gun Arcing and Modulator Protection

S. Gold / SLAC

Chairman : B. Frammery

Saul L. Gold
SLAC

Chairman : B. Frammery

Klystron Gun Arcing and Modulator Protection

S. Gold / SLAC

- High peak power klystrons (35 to 150 MW) raise the problem of very energetic arcs (20 Joules to 70 Joules)
- Measurement & understanding of the arcing process absolutely needed
- Lots of measurements recorded and autopsy of a NLCTA2 tube diode failure
- Experiments with a 10 kV Marx Modulator

Chairman : B. Frammery

Klystron Gun Arcing and Modulator Protection

S. Gold / SLAC

- Arc formation slower than commonly believed (100s ns)
- Line-type modulators OK for 1 & 2 klystron setups
- Direct-switch modulators have the potential to stand higher peak current (but need to be tested)
- A demountable gun would be an asset for precise arcing damage measurement

Chairman : B. Frammery

Development of the new CTF3 Klystron-Modulator Controls Interface System

B. Bartholome / CERN

Chairman : B. Frammery

Bernard Bartholome
CERN

Chairman : B. Frammery

Development of the new CTF3 Klystron-Modulator Controls Interface System

B. Bartholome / CERN

- PLC/ fieldbus approach decided to replace an obsolete local control system for the CTF3 klystron-modulators
- the control system handles
  - 50 kV power supply
  - PFN
  - thyratron switch
  - pulse transformer
  - 35 MW klystron

Chairman : B. Frammery

Development of the new CTF3 Klystron-Modulator Controls Interface System

B. Bartholome / CERN

- Interlocks classified as soft (most of them) or hard (the really serious ones!)
- implementation implies
  - a dedicated pulse surveyor board
  - a S7-300 PLC unit (Profibus)
  - a local industrial PC (WNT)
  - the VME-based general control system (through Ethernet)

Chairman : B. Frammery

Development of the new CTF3 Klystron-Modulator Controls Interface System

B. Bartholome / CERN

- The monitoring task run @100 Hz
- User interface developed with Bridgeview
- 2 persons/8 months to get a fully working prototype

Chairman : B. Frammery

✸ The End

Chairman : B. Frammery

A NEW INTERLOCK SYSTEM FOR THE TESLA RF-SYSTEM

Joachim Kahl, S. Choroba, T. GrevsmŸhl, N. Heidbrook, DESY, Hamburg
H. Leich, DESY, Zeuthen

Abstract

The RF system for TESLA requires a comprehensive interlock system. Usually inter-lock systems are organized in a hierarchical way. In order to react to different fault conditions in a flexible manner a non-hierarchical organisation seems to be better suited. At the Tesla Test Facility (TTF) at DESY we will install a non-hierarchical interlock system based on user defined reprogrammable gate-arrays with embedded microcontroller systems. This system could later be used for the TESLA linear collider instead of a strict hierarchical system. We will introduce the non-hierarchical interlock system and give an overview of the consequences for the RF system.

MUON COLLIDER TEST FACILITY NEW PFN AND CONTROLS

P. Prieto , H. Pfeffer, D. Wolff, Q. Kerns, C. Kerns and S. Tawzer
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Abstract
A 3 Ohm PFN was designed with an SCR-based switch and charged to 20 KV with four parallel capacitor-charging power supplies. A 12 MW klystron mounted on a 1:20 pulse transformer powers a six cell, 805 MHz cavity inserted in a superconducting solenoid in the Muon Test Facility. Also a complete set of modulator-klystron interlocks and controls were designed to provide signal monitoring, timing, modulator voltage regulation, as well as interlocking all systems related to the modulator-klystron system. The controls use surface mount technology providing compactness and future technological compatibility. Communication of the system status and data is done through an MVME68040-based system acting as a local node and accepts analog and digital signals relaying them through an Ethernet connection to the main accelerator controls.

1. INTRODUCTIO N

Table 1

Modulator Parameters			
Pulse Length	50 µsec.	Pulse Energy	2.2 KJ
Pulse Rep. Rate	15 Hz	PFN Charge time	60 ms
Peak Primary Voltage	20 KV	Charge Average Power	37 KJ
Peak Primary Current	3.7 KA	Power Rating per supply	10 KJ/sec.
Peak Power	18 MW	# of Supplies	4
Capacitance total	11.0 µF		
Inductance total	99.0 µH		

Table 1 lists the parameters used in designing the modulator.

A PFN topology was chosen for the modulator using eleven inductor-capacitor cells, the inductor coil in each cell was split into two for purposes of tuning. The PFN is charged with four commercially available capacitor charging power supplies connected as masters. The PFN is discharged using an SCR-based switch through a 1:20 step ratio pulse transformer and 12 MW klystron on an on-demand basis.

The design cycle started with calculations for PFN impedance, pulse length, effects of mutual inductance, power supply energy requirements to name a few. Followed by computer modeling for design verification, ultimately leading to the implemented topology. The PFN was tested in stages, first the inductance of the coils was adjusted to obtain the required pulse flatness. Then the diode stack and SCR switch were high-potted for corona, polarity check, and conductance. Followed by the addition of the pulse transformer and a beam-stick as a load, allowing the PFN to operate at full repetition rate and pulse power. At each commissioning step the modulator-klystron controls were also tested using established procedures. The commissioning phase ended when the klystron was installed in the pulse transformer and the RF portion of the controls were tested with the modulator-klystron operating at full power.

2. PFN COMMISSIONING PROBLEMS

2.1 Shoot-through Condition

A shoot-through condition is when the PFN is charged while the SCR switch is still closed making the supplies see the klystron as its load. The primary mechanism used in commutating the SCR switch is by mismatching the PFN impedance and the impedance of the klystron as it's reflected on the primary of the transformer. In addition to this a diode stack of 96 diodes was connected at the anode of the SCR providing an additional 100 volt differential across the switch opening it before the next charge cycle begins. The diode stack has a reverse diode across it for protection but this diode failed, shorting out the diode stack, delaying the opening of the SCR switch and caused a shoot-through condition.

2.2 *Power Supply Power Factor*

The manufacturer of the power supplies claims to have a power factor greater than 0.85, it measured at 0.67 for each phase. This is a problem in a multiple-supply environment since much more power is used and harmonics are induced on the power line with potential damaging effects to elements on the line, like the A.C. power transformer.

3. MODULATOR-KLYSTRON CONTROLS

The controls were designed so they could be used with the FNAL LINAC modulators and the modulators used by TESLA test facility at DESY. Although the controls for the modulator and the klystron are integrated and quite compact, functionally they can be viewed as two sets of controls. One that controls everything on the primary of the pulse transformer and a second set controlling everything connected on the secondary of the pulse transformer.
A distributed approach was taken to implement the controls where no board relies heavily on other boards to operate. This facilitates testing and also reduces board interconnections.
The controls are implemented using six VME-style boards and using surface mount technology for compactness. Two boards are dedicated for the PFN controls and its charging supplies and four for the klystron and related systems. The boards are plugged into an RFI -VME crate providing good noise immunity from RF noise. All cabling is done through the rear of the RFI chassis to the top plate of an enclosed rack. Power to the RFI chassis is generated in an external chassis that has three linear power supplies. Communications to the external control system is done through a FNAL-designed system which digitizes all available analog signals as well as all of the latched status signals. It provides communications via Ethernet and provides remote control of the modulator-klystron by setting operating points and remote permits.

3.1 Modulator Controls

The modulator controls provide:

- Personnel safety.
- Equipment protection and operation.
- Signal transmission, signal conditioning, and signal monitoring.
- Pulse amplitude regulation.
- Modulator timing.
- Charging Supply permits and operating reference level.

The first task of these controls is to transmit analog signals from the high voltage environment in the modulator with little or no signal degradation and with high noise immunity. In our system this is accomplished by using a current-driver based analog circuit capable of driving 50 milliamps into a 75 Ohm termination. This impedance is matching the twinax cables used.
A receiver board is used as the analog front end for signals originating at the modulator. The analog board supports sixteen inputs designed around a cluster consisting of a 75 Ohm current receiver using an instrumentation op-amp followed by a gain stage. The signal distributed from there for digitization, front-panel monitoring, and input to a discriminator circuit. A buffer also distributes the signal to on-board dedicated function circuits:

- SCR switch voltage balance.
- PFN pulse amplitude regulation.
- Transformer magnetization current monitoring.

A second board acts as system integrator, receiving digital signals from

- The analog board.
- Contacts from klixons in the modulator.
- Timing signals from the control system.
- Permits from the external safety system and other boards within the modulator-klystron controls.

All of these signals are processed in a programmable gate array (PLA) where transitions are latched and transmitted to the external control system for display on a parameter page. Also the transitions are buffered into memory within the PLA and are arranged according to the order in which they transitioned first. This information is useful when multiple signals are latched and one wants to determine which caused a trip first. The system control PLA also gates raw timing signals through to the timing PLA only when all the trips are cleared.

A second PLA processes timing for the modulator. It’s inputs are the raw charge and fire timing signals from the system control PLA:

- Sets windows inhibiting abnormal charge and fire pulse repetition rates.
- Sets the length of the PFN charging period.
- Sets the delay between end of charge cycle and the fire cycle.
- Limits when the fire cycle can occur within the 15 Hz cycle.
- Distributes the fire pulse to the PFN’s SCR trigger circuit and the charge pulse to the power supplies enable circuit.

3.2 Klystron Controls

The largest portion of the controls is mainly involved with systems related to the klystron. Four boards are used to implement this portion of the controls. Three of the boards have the same basic circuit topology. It is an analog front-end which receives the input and fans it out to a discriminator stage, a front panel monitoring point, and a buffer which drives the signal to be digitized externally. An on-board PLA consolidates all the discriminator outputs and then generates a status produced from the AND’ing of these levels. All of the local board statii are then integrated by one of the PLA’s to generate a modulator permit, RF enable permit, and a remote control permit.

The fourth board has only counters which indicate:

- Klystron filament run time.
- Klystron gun sparks.
- Klystron window sparks.
- Load window sparks.

Circuits were grouped in two of the boards whose functions will inhibit RF in the klystron and also stop the modulator from pulsing on the next cycle. These functions are:

- Pulse transformer, klystron collector, and solenoid temperature.
- Solenoid power supply controller.
- Currents of the six solenoid power supplies and their contactor controller status.
- Collector, Body, Solenoid, Pulse Transformer, Modulator water flows.
- Klystron filament power supply.
- Klystron ion pump power supply.
- Waveguide pressure.
- Klystron window and load window photo-multiplier dark current.

The third board is exclusively dedicated to circuits inhibiting only the RF source in less than a 1 μsecond of a trip but still allow the modulator to continue to operate.

- Klystron or load window spark is detected.
- RF level is picked up using an antenna and it is above a pre-set level.
- Klystron reflected energy or load reflected energy is above a normal level.
- Cavity spark is detected.

4. CONCLUSIONS

The control system works as expected. A revision will clean up board layout problems. Also re-designing of the board holding the RF circuits will make it easier to debug, and fix the problems seen with the FET switches used. The circuits supporting photo-multipliers should be modified to support *pin* diodes instead.

ACKNOWLEDGEMENTS

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KLYSTRON GUN ARCING AND MODULATOR PROTECTION

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Abstract
The demand for 500 kV and 265 amperes peak to power an X-Band klystron brings up protection issues for klystron faults and the energy dumped into the arc from the modulator. This situation is made worse when more than one klystron will be driven from a single modulator, such as the existing schemes for running two and eight klystrons. High power pulsed klystrons have traditionally be powered by line type modulators which match the driving impedance with the load impedance and therefore current limit at twice the operating current. Multiple klystrons have the added problems of a lower modulator source impedance and added stray capacitance, which converts into appreciable energy at high voltages like 500kV. SLAC has measured the energy dumped into klystron arcs in a single and dual klystron configuration at the 400 to 450kV level and found interesting characteristics in the arc formation. The author will present measured data from klystron arcs powered from line-type modulators in several configurations. The questions arise as to how the newly designed solid-state modulators, running multiple tubes, will react to a klystron arc and how much energy will be dumped into the arc.

1. INTRODUCTION

The amount of protection required for a gun arc or a defocused beam in a microwave tube is a continual source of controversy and debate. Historically, tube companies have set protection requirements by their own experience in test. Body current interception was thought to be limited to 10 joules maximum and shutdown within 10 microseconds. In high power klystrons the engineers found out that as the voltage increased, the rate of rise of fault current needed to be limited. 1000A/µsec with a less than10 microsecond maximum shutdown became a typical number used for CW or long pulse tubes with crowbars or series switches. Tube engineers hesitated to put a hard number on the energy that could be dumped into an arc, but 10 joules became a defacto rule of thumb. Thomson in France has listed the highest number I am aware of for allowable arc energy at 40 joules.

High power pulsed klystrons have been classically pulsed using Line-type modulators whose impedance is matched into the klystron by a pulse transformer. In this type modulator the maximum peak current delivered into a gun arc is two times the normal operating current. A klystron was considered to be inherently protected, because of single pulse shutdown and therefore no real attempts were made to measure arc energy levels. SLAC has successfully used this type modulator at high peak power for over 30 years. SLAC continues to require higher peak pulse power and for the NLC (Next Linear Collider) and its Test Accelerator it was decided to operate two klystrons in parallel on the same modulator, which means that the arc current can rise to four times the normal operating current. In fact, the modulator design of choice for the NLC is a solid-state induction modulator, which runs eight klystrons. I decided to try to measure arc energy to see where we are today and feel more comfortable about protecting a klystron. Digital storage oscilloscopes have made this task easier.

* Work supported by Department of Energy Contract DE-AC03-76SF00515

2. ARCING IN A VACUUM

To begin to try and understand a vacuum gun arc in a microwave tube one must first consider the fact that the electrode shape, spacing and therefore electric field is chosen to be well below the threshold where an arc would occur. Additionally, the focus electrode (at cathode potential) is intentionally operating at a much lower temperature than the cathode to avoid it becoming an emitter. The most likely cause of the creation of an arc is therefore field emission from the focus electrode. Classically for field emission the potential is raised towards the breakdown threshold of the vacuum gap. At some potential a small electron emission begins (microamperes) after which small changes in voltage will generally produce large changes in emitted current. As the gap is over-voltaged the emitted electrons traverse the gap in less time. Spark gaps, either two pole or triggered, fire in tens of nanoseconds. However, in a microwave tube the cathode voltage remains well below the breakdown threshold and the current builds up slowly (several hundred nanoseconds). This is clearly seen in the experimental data shown below. At the 2000 Modulator Symposium, I reported that Richard Adler of North Star Research "believes, for short pulses the first stage of breakdown is plasma electron emission (private communication). The current increases monotonically until the expanding plasma reaches the anode. The velocity of this expanding plasma tends to be 2-3 cm/microsecond or slower. This is in somewhat agreement with the rise of arc current measured at SLAC[1]. It should be noted that these klystron operate with a vacuum of 10^{-8} or 10^{-9} torr, which enhances voltage hold-off. In another theory field emitted electrons knock off ions on the opposite surface. The ions travel back creating more electrons. The iterative process continues until either breakdown occurs or the voltage goes away.

3. EXPERIMENTAL DATA

3.1 Line-Type Modulator

Development klystrons at SLAC are tested or operated in a number of different modulators with different transformer ratios and impedances. They are Line-type modulators with 25kV charging power supplies, resonant charge and their transformer ratios vary from 15 to 23. Table 1 is a summary of part of the data. Some of this data has been presented previously. The devices tested were S-band and X-band. XL4 klystron arc data was obtained in two different modulators and single and dual tube operation. Examining the data shows that the voltage fall time and the current rise time is much slower than conventional wisdom has believed and takes at least several hundred nanoseconds. During this arc transition, energy is being dissipated and the calculated arc energy is larger than the maximum limits

Table 1
Measured Arc Data - Line-Type Modulators

Klystron	Peak Voltage (kV)	Peak Current (kV)	Energy (joules)	Voltage Fall (ns)	Current Rise (ns)	Pulse PK PWR (MW)
5045 (7)	300.9	550	46.4	3000	400	88.4
5045 (10)	368	525	35.9	1200	200	113
CPI DESY	423	700	47.5	600	300	147
XL4-5A (1)	449.8	600	66.5	1300	800	115
XL4-5A (7)	454	300	59.5	1600	600	76
NLCTA-2 (1739)	443	900	68.5	1000	400	273
NLCTA-2 (1747)	430	900	61	1100	300	269
NLCTA-2 (KL4)	430	1400	60.4	850	1100	120
NLCTA-2 (KL7)	394	1200	23	400	1200	76
XP3-Diode-2	470	477	42	800	600	107
XP3-Diode-3	486	562	41.4	1160	520	116

previously thought allowable. The gap spacing, anode to cathode (focus ring) is large (approx. 2-4cm) as compared with standard spark gap spacing. It takes the arc longer to form and close the gap. It is hard to predict the energy in an arc because it is very dependent upon the arc formation, which is I believe an uncontrolled variable. In the early stages of XL4 development at SLAC, it would take a long time to recover from a gun arc. Discussions about this problem led the klystron engineers to believe that there was poor vacuum at the gun area since the vacuum pump was located a long distance from the gun and there was poor conductance through the X-band circuit. A floating ion pump was mounted at the gun of the XL4. The pump power was supplied from power supply using the klystron heater supply for its input. No other changes were made to the klystron gun and the problem of recovery after a gun arc was gone.

Figure 1 is the voltage waveform taken on an XL4 klystron in the Test Lab on Test Stand 08 and the arc current calculated from the cathode and collector current waveforms. The body current shown at the beginning of the pulse is representative of the capacitive charging current during the rise time of the voltage. This modulator will allow an arc current of approx. 800 amperes. In this case the peak arc current is not very large but the fall time of the voltage is long (1600 nanoseconds) which accounts for the arc energy of almost 60 joules. Figure 2 is an XL4 klystron arc taken in an NLCTA modulator powering two XL4 klystrons. The modulator limiting impedance will allow the arc current to rise to four times klystron operating current, approx. 1600 amperes. During this arc the voltage fall time is faster and the current rise time slower. The current reaches a much higher value but the voltage initially falls in 450 nanoseconds to 50kV and then falls to 0 volts in and additional 400 nanoseconds and the energy in the arc is about 60 joules. The arcs of Figures 1 and 2 are different in current and time but dissipate about the same energy. This data reinforces my belief that the arc formation is an unknown variable with some dependence on the external circuit.

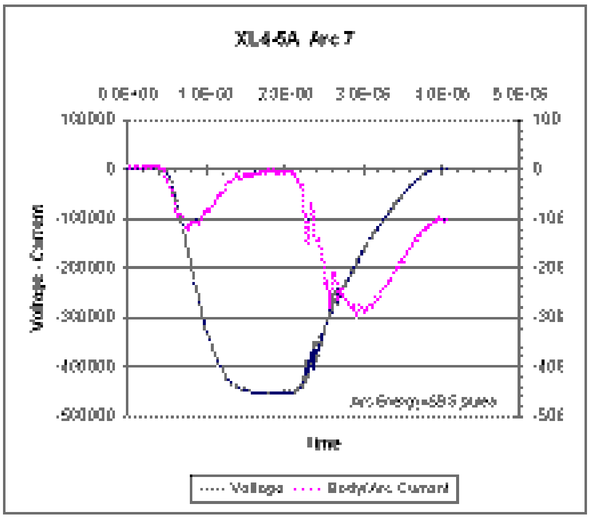


Figure 1. XL4 klystron arc on Test Stand 08

The next version of the 75 MW PPM (periodic permanent magnet) focussed klystron, XP3 (formally known as the DFM klystron) is under construction. The XP3 Diode, a beam stick with a portion of the magnet stack has recently been initially tested in Test stand 13 at SLAC. This tube would nominally operate at 490 kV and

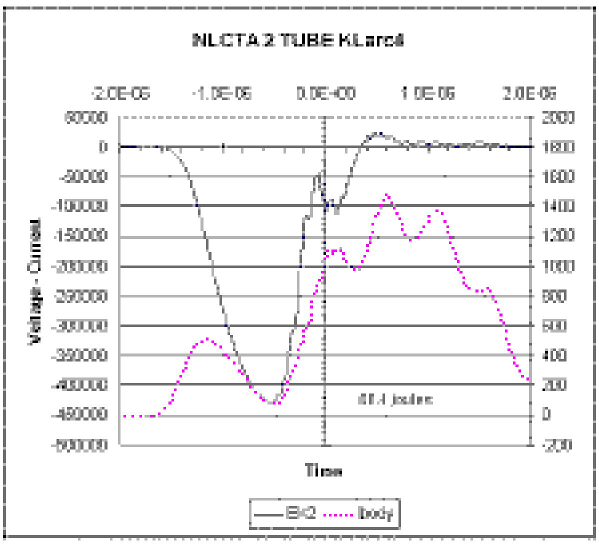
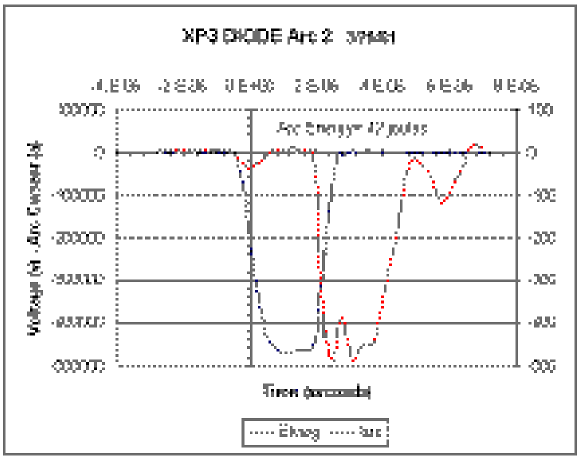


Figure 2. XL4 klystron arc in Two-tube Configuration

265 amperes. Figure 3 is a picture of an arc waveform captured while processing and operating this tube. In this case the arc causes the voltage to drop in 800 nanoseconds and the voltage essentially drops directly to 0. The current rises to almost 500 amperes in about 600 nanoseconds. This arc has a calculated energy of 42 joules. Two arcs were captured on this diode and both were about the same energy although different in waveshape. It should be noted that the XP3 electron gun has a microperveance of 0.75 and therefore has larger cathode to anode spacing than the XL4 klystron whose microperveance is 1.2. It is hard to relate the gap spacing in the electron gun to the rise of arc current or fall of arc voltage at this time. It should take ions longer to traverse the longer gap but there is a larger accelerating potential from the higher voltage.



During modulator testing at NLCTA, a 5045 diode had a arc while operating above 400 kV. We have operated 5045's at this level in the past. However, this time, the 5045 diode would no longer hold voltage. Another diode was still in operation. The diode was returned to the tube shop for a careful autopsy. The arcing took place between the focus electrode and the bell housing near the high voltage seal joint. As can be seen in Figure 4, the stainless steel corona ring shows an area where thin layers of material have been removed. The second photo shows that material plated on the ceramic high voltage seal. This is the same area we have seen

Figure 3. XP3 Diode arc

ceramic seal punctures in the past. The gap between the corona ring and the ceramic is much smaller than the anode to cathode gap. We did not capture the arc that created the damage that we see. Obviously there is enough energy to ablate the surface material. In fact, it is most

probable that the damage did not all occur in one arc, but over a number of arcs. Perhaps some damage occurred during prior operation in another modulator. There was also activity on the anode.

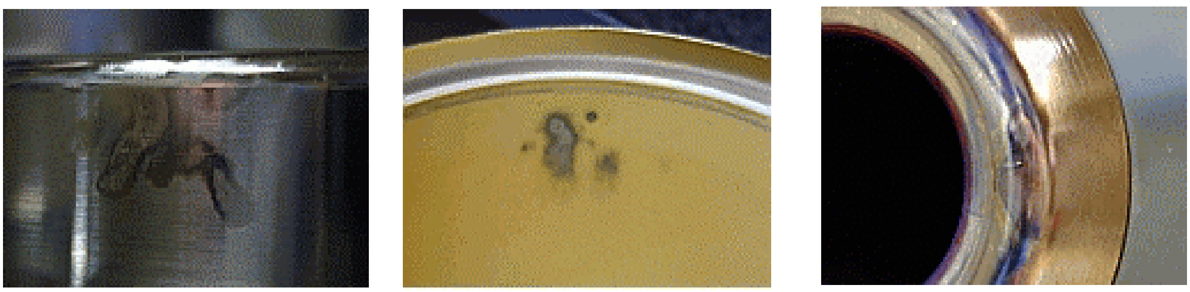


Figure 4. 5045 Diode Autopsy- Focus Ring (Upper left), H.V. Seal (Upper right), Anode (bottom)

3.2 Low Impedance Switch

3.2.1 10kV Marx Switch Modulator

Dr. Anatoly Krasnykh designed a modified Marx modulator for a TWT application at 10kV[2]. Although the voltage and power are much lower than the klystron modulators I was curious what the arc current would look like in this 'Direct Switch' modulator. Dr. Krasnykh made the following measurements with an air arc. The current sensing threshold was set slightly above the operating current and the measured delay in turn-off of the final switches was 700 nanoseconds. 400 nanoseconds was due to the gate delay of the IGBT itself. Figure5 are the voltage and arc current for arcs occurring at the beginning, the middle and the end of pulse.

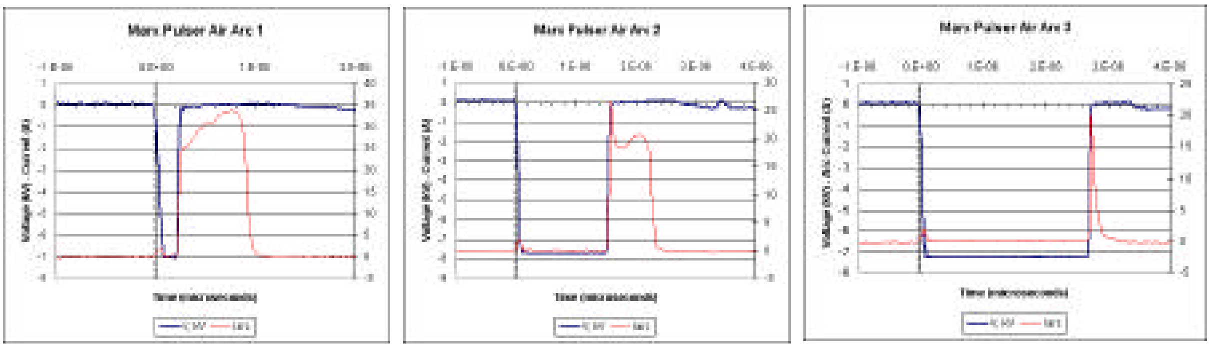


Figure 5. 10kV Marx Modulator Arc- 1) pulse beginning, 2) pulse middle, 3) pulse end

The normal operating load on the modulator was 1 ampere but the peak arc current rose to above 30 amperes. The energy is still low but what if this was extended to 500kV? Would the very high current create a problem or would the rate of rise be such that the voltage will be zero before the current reaches its very high level, thereby limiting the energy? These are unknowns that will only be answered by testing a full scale model. It is conceivable that testing of any of the low impedance 'direct switch' modulators would give enough insight to predict the performance of the others. Diversified Technologies has another SBIR grant to work on a direct switch modulator for 500 kV either with the modified Marx approach or a straight series switch.

3.2.2 Induction Modulator

The data on preliminary arcing into a vacuum gap below 80kV was not fully available at the time this paper was submitted.

4. CONCLUSION

Klystron protection in very high peak power modulators remains an issue that is still not clearly understood. Clearly, a klystron with excellent vacuum (8 to 9 scale), can dissipate more energy in a current limited gun arc than conventionally believed. However, recovering from an arc does not mean that some damage was not done. Surfaces do get electroplated with copper or stainless steel. All of the tubes tested had excellent vacuum in the gun region. We know that the low impedance modulators whether a Marx switch, an induction design or a hybrid with a pulse transformer have the capability of delivering larger peak arc current than a Line-type modulator. What we don't know is how fast the arc will build up and if the current will indeed rise faster or if the voltage will fall at a slower rate. These modulators can have the capability of terminating the pulse upon sensing an arc and depending on circuit speed can shut down the current. The only way we will know is to operate a klystron on these modulators. I am hoping that Diversified Technologies, Inc. will deliver a Hybrid Modulator built on an SBIR for testing at SLAC in the fall. Dick Cassel and company is planning to have a full 500kV version of the induction modulator (affectionately known as the four dog) in test this summer. Therefore, I am encouraged that we should have a better picture of this phenomenon by the end of this year.

Further investigation is necessary to understand klystron arcs and how much energy causes damage. A demountable gun on a diode body would be required to enable examination of the gun electrode surfaces after a set number of captured arcs. The gun would then be reassembled, at least low temperature baked and re-tested.

ACKNOWLEDGEMENTS

I would like to thank Anatoly Krasnykh for his help in trying to understand the nature of the arc. In addition, I would like to thank Richard Cassel for the data on the Induction Modulator and John Eichner for taking data at NLCTA and in the Test Lab.

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Development of the New CTF3 Klystron-Modulator Control System

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1. Introduction

The actual LPI Klystron-Modulator (MDK) control system is 10 years old and uses components that are no longer supported by industry. The policy for the new control system is to use as much as possible industrial elements. These new control elements are integrated into the equipment they will control and also into the overall accelerator controls scheme. In this design, the local control interface is based on a Programmable Logic Controller (PLC) from Siemens [1] with analogue and digital input & output signals that handle the slow changes of the equipment. Additionally, to enable acquisition and interlocking of fast signals of short duration (μS) that are also present in the modulators, a pulse surveyor protection and monitoring system is being developed. This will be connected to the PLC through a PROFIBUS network [2]. This paper describes the local control system, its interface hardware and software and its use with the CTF3 Klystron-Modulators.

2. New design

The control and protection system collects information from the MDK and sends commands to it, as shown in Figure 1.

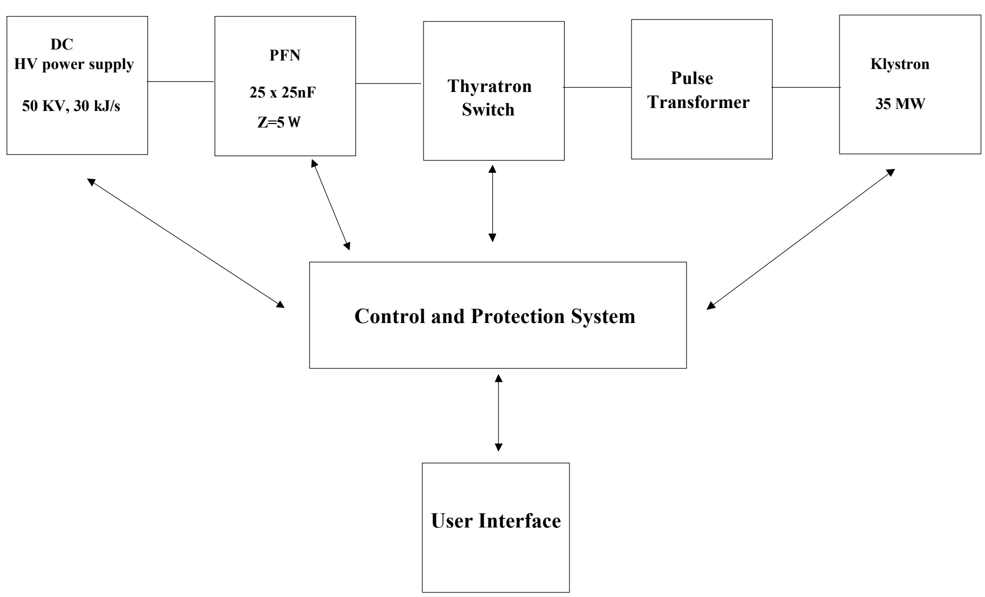

Figure 1. MDK layout.

2.1 Signals and commands to be treated

Tables 1 to 6 show the location of the interlocks, measurement signals and control commands that are to be treated by the new PLC control system.

Interlock (contact)	**Analogue signals to be measured**	**Control commands or references**
-Doors -Earth rod -Filter temperature -Thyratron fan -Faraday cage Fan	-Thyratron current -EOLC (end of line diode circuit) current -Front line current	-Ross relay

Table 1. PFN signals.

Interlock (contact)	**Analogue signals to be measured**	**Control commands or references**
-Contactor ion pump power supply -HV ion pump cable connected	-Focal current A,B,C -Premagnetisation current -Klystron heater current -Klystron heater voltage -Thyratron heater current -Thyratron heater voltage -Pump voltage -Pump current -Pump state	-Focal A,B,C current reference (Potentiometers) -Premagnetisation current reference (Potentiometers) -Klystron heater current reference (PLC) -Thyratron heater current reference (PLC) -Contactor ion pump power supply

Table 2. Focusing coil and heater power supply signals.

Interlock (contact)	**Analogue signals to be measured**	**Control commands or references**
-Doors -Emergency stop	-Average current (master, slave1, salve 2) -Output voltage (master, slave1, salve 2) -Status (master, slave1, slave 2) -HV output state -V divisor	-Voltage reference -HV on -Fast inhibit -Remote on

Table 3. High voltage power supply signals.

Interlock (contact)	**Analogue signals to be measured**	**Control commands or references**
-Emergency stop All the interlocks are routed to the PLC to be treated.	All the klystron fast signals are treated by the pulse surveyor crate linked to the PLC	All the control signals are coming form the PLC

Table 4. The control rack signals.

Interlock (contact)	**Analogue signals to be measured**	**Control commands or references**
-Water flow	-Klystron voltage -Klystron current -Body water in temperature -Body water out temperature -Tank temperature	

Table 5. The klystron tank signals.

Interlock (contact)	**Analogue signals to be measured**	**Control commands or references**
-Contactor focal A,B,C -Contactor Premagnetisation -Contactor klystron heater -Contactor thyratron Heater -Contactor HV supply -Contactor trigger amplifier		-Contactor focal A,B,C -Contactor Premagnetisation -Contactor klystron heater -Contactor thyratron heater -Contactor HV supply

Table 6. Low-power distribution signals.

2.2 The MDK can be found in one of four control states:

OFF, HEATER, STANDBY, PULSING

To each of these states, the corresponding interlock conditions have to be satisfied that allow appropriate commands to be sent. When an interlock is activated, the MDK goes to a predetermined state corresponding to the level of the activated interlock.

2.3 Hard-wired interlocks

Personal security interlocks are treated both by software and hardware. For example, opening a door of the Faraday cage will cause the HV power supply to be disconnected from the 380 V and the PFN shorted to earth potential even if the PLC were to be faulty. Other interlocks, such as the klystron water flow, which would be very damaging for the klystron, also have hard-wired contacts that prevent power being applied to the klystron.

3. Local control of an MDK.

The new control system for CTF3 MDKs is based on a Siemens S7-300 PLC, which is integrated into each modulator's control and protection system. Slow changing signals are monitored and directly connected to the inputs of the PLC. The faster signals are treated by a new pulse surveyor crate (under development) which will be linked to the PLC through a Profibus network. For now, the old pulse surveyor cards are linked directly to the new PLC digital inputs. Local supervision and control commands are made with an industrial PC which is linked to the PLC via the Profibus network. Remote control of an MDK will be possible using with a VME card connected to the actual CTF3 control network. The general layout of the control system is shown in Figure 2.

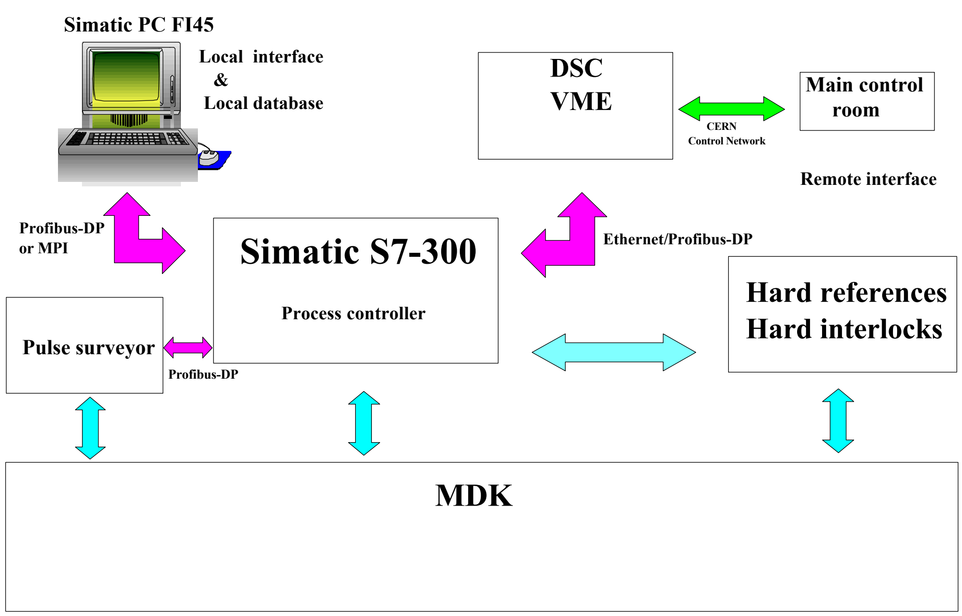

Figure 2. Control layout.

3.1 The PLC hardware

The PLC hardware contains:

- 1 CPU S7-318-DP (Siemens)
- 1 power supply 924V/10A)
- 72 digital inputs
- 24 analogue inputs
- 8 digital outputs
- 4 analogue outputs
- 16 relays

The PLC cycle has to be shorter than 10 ms as the maximum pulse-to-pulse repetition rate of the MDK is 100 Hz, and for this reason the CPU 318 was chosen. It has a bit-operation time of 100 nS and the Profibus-DP coupler that is also integrated can follow this data rate.
To achieve accurate measurements and settings, the PLC analogue to digital and digital to analogue converters have 16 bit resolution.

3.2 The PLC software

During each cycle the PLC looks at all the interlocks and signals corresponding to the MDK operational state and makes on-line a decision to ensure the security of the MDK equipment and local operators. Periodically all the information contained in the PLC is sent to the General User Interface (see bellow, 3.3) through an OPC server (see bellow, 3.4) to be shown on the user panel. To allow after the event diagnostics to be made, all the faulty interlocks are stored in a database. The PLC works in stand alone mode, even if the GUI is faulty, and there is a watchdog to ensure that the PLC is running. If the PLC becomes faulty this then event will switch off the MDK.

3.3 The General User Interface (GUI)

The GUI is an industrial PC running under Windows NT linked to the PLC through the Profibus network. A Bridgeview [4] application program running in partnership with a OPC server, allows the user to see the MDK status and to send commands to it.

3.4 The OPC server

The OPC server (Object Linked Embedded (OLE) for Process Control) [3] installed on the GUI is linked to the PLC through the Profibus network. It receives periodically all of the interlock information and all measurements. It sends commands to the PLC when needed. The OPC server is read by, and written to, using the Bridgeview control command application program.

3.5 The local control command program

This user application program displays graphically the operating states of the MDK. It allows the user to locally command the MDK, set up the interlock levels of the measured signals, and set the HV reference or the heating parameters. The display is designed to help the user to rapidly find where a fault has developed. In the future, this application will be able to send detailed electronic messages to the user when an error occurs, and thus shorten the delay before repair.

3.6 The new pulse surveyor card.

The new pulse surveyor card is still being developed [5] and will deal with all the fast measured parameters coming from various parts of a klystron-modulator. These Signals are:

- Klystron voltage
- Klystron current
- Eolc (end of line diode circuit) current
- Thyratron current
- PFN voltage

The new pulse surveyor card, will be fully controlled by the PLC. Interlock levels, time window widths and signal attenuation are set via the PLC. In addition, on each card, there is an AD converter and an on-board memory which will store the last 100 waveforms. This will be very helpful to diagnose a malfunction of the MDK. Once an error occurs, the storage is stopped and, if asked, the digitised waveforms are downloaded to the GUI for visualisation. The layout of the pulse surveyor card is shown in Figure 3.

4. Conclusion

This control system has been tested and is in operation on the new MDK33 klystron modulator. The results are very encouraging and the system is easy to use and permits rapid diagnostics. The remote control interface of the MDK is still under development, and will be completed soon to enable the new modulator to be integrated into the CTF3 controls system for start-up at the end of this year.

Due to the flexibility of the new PLC control system, programmed optimisation of all parameters is feasible. In particular, the requirements for having automated control of the high power parameters during RF conditioning of all waveguides and accelerating sections become possible without reducing any of the MDK protection conditions that apply during normal operation.

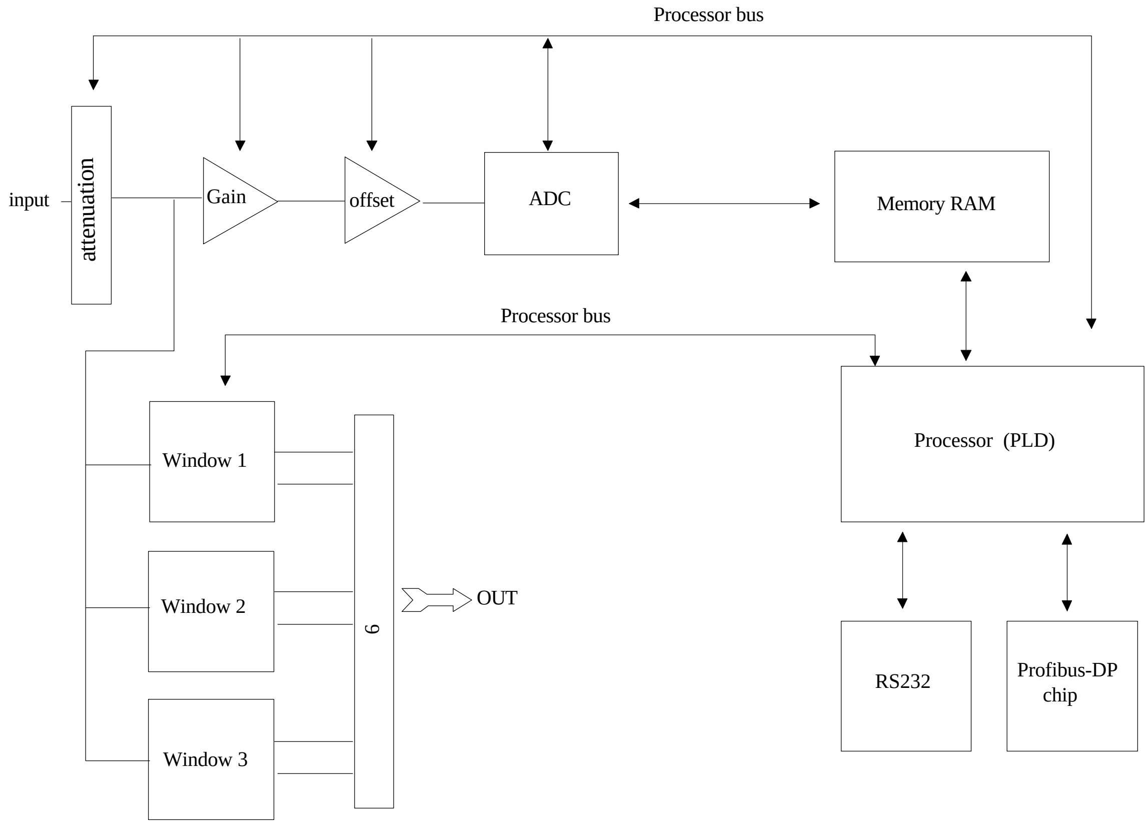

Figure 3. New pulse surveyor card layout.

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