THE WET INSTRUMENTATION: FIVE YEARS OF THE VILNIUS GROUP EXPERIENCE

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Abstract. Five year experience of the Whole Earth Telescope (WET) group of the Vilnius University in development and construction of instrumentation for the WET project is considered. The concept of design and fabrication of the WET photometric equipment is presented. Several components of the equipment as well as the complete photometers designed and made by the Vilnius group are described in brief.

Key words: instrumentation: photometers

1. INTRODUCTION

The instrumental group at the Astronomical Observatory of the Vilnius University joined the WET in 1992. We considered that our experience in developing and constructing of photometric instrumentation, acquired during accomplishment of the orders of military and aero-space industry companies of the former Soviet Union, could be also useful for the WET project. We started from the design and fabrication of an amplifier-discriminator – the smallest, but important component of any photometer. Almost ten versions of amplifier-discriminators had been made during three years until the last one, F 316 A, was accepted in 1995 as a standard component of the WET photometer. After that the WET authorities gained some confidence in our possibilities. Some other components, as well as the complete three-channel photometers, have been designed and made for several WET groups since 1995.

2. OUR CONCEPT OF DESIGN

Our concept of design, already discussed at the WET workshops (Kalytis & Meištas 1995) and based on the minimal use of industrially made components in astrophotometers, has proven its validity. We think that for the WET photometer, which is a very specific instrument, optimized solutions of optical, mechanical and electronic design should be used which could ensure not only its necessary technical specifications but also comfortable operational properties. The use of the "off the shelf" components sometimes causes a certain sacrifice in optimality of the solutions.

3. LIST OF THE PHOTOMETRIC EQUIPMENT DESIGNED

During the last five years the main components of the WET high-speed three-channel photometers have been designed and made (Kalytis et al. 1993, 1996, Kalytis & Meištas 1995). They include the light detecting units called "photoelectric heads" which contain photomultiplier (PMT) housings, PMT cooling systems, high voltage (HV) dividers, amplifier-discriminators (A-Ds), filter setting systems, computer interfaces and power supplies (Table 1). Several modernizations of the "Pancake" portable photometer (Meištas 1993) have been made during this time, too. In 1996 we started to design and to fabricate the complete photometers. The first one was the NPL (Nather-Polish-Lithuanian) photometer designed and made for the Suhora Astronomical Observatory, Poland.

The photometric instruments listed in Table 1 were designed for the specific WET or other needs. This equipment can be also suitable for a wider astronomical application, especially for observations of variable stars. Such components as HV dividers, A-Ds, filter setting systems, power supplies, computer interfaces and others can be used in all types of astrophotometers. The photometric instrumentation designed is comfortable to use in expeditions to the remote sites.

4. AMPLIFIER-DISCRIMINATORS OF SERIES F 300

Over ten models of amplifier-discriminators of small size, called A-Ds of the series F 300, have been designed during the last five years (Kalytis et al. 1993, 1996, Kalytis & Meištas 1995). F 316A is the last and probably the final version of an amplifier-discriminator suitable for the standard WET photometer. It is fully approved

Table 1. List of the photometric equipment designed by the Vilnius WET group in 1992–1997.

Type of device	Model	Main specifications
High voltage dividers	D 303 D 304	Both: grounded minus, set for the Hamamatsu PMTs of 14 mm diameter (R 647-04 or like it)
Amplifier-discriminators	F 310 F 316A F 318 F 320	PPR – 8 ns, sensitivity – 100 μ V PPR – 22 ns, sensitivity – 130 μ V PPR – 8 ns, sensitivity – 150 μ V PPR – 6 ns, sensitivity – 150 μ V
Filter setting systems	FD 301 FD 306 FD 308-2	Dual wheel, 5 filters, full feedback One wheel, 5 filters, full feedback Dual wheel, 5 filters, full feedback
Power supplies	A 304 A 305 A 306	HV, +5 V, +12 V, HV, +5 V, +12 V, 4 V HV, +5 V, +12 V, 24 V, 10 V
Photoelectric heads	FEG 304 FEG 306 FEG 310	Spectral range 250–1100 nm, Two-stage cooling system Weight – 1.85 kg Dimensions – 180×110×110 mm Spectral range 250–900 nm Two-stage cooling system Weight – 1.50 kg Dimensions – 160×128×110 mm Spectral range 300–650 nm (R 647P) or 185–850 nm (R 1463P) Two channels One stage cooling system Weight – 0.85 kg Dimensions – 110×70×65 mm
Computer interface	CCLA	Microprocessor – 8032AH, Oscillator – 12 MHz (0.5 ppm) Three counting channels (125 MHz) Filter wheel control
Photometer	NPL	Two units: NPL-1 and NPL-2 Three channels

by E. R. Nather and other WET authorities. The main feature of all A-Ds of series F 300 is a successful solution of their mechanical construction. The construction of fully soldered case has allowed

us to design not only a small-size amplifier, but also to achieve a high level of shielding. Electrical specifications of F 316A (Kalytis & Meištas 1995) are fully compatible with those of modern PMTs and computer interfaces.

For photometers in which “one cable” (Kalytis & Meištas 1995, Kalytis et al. 1997) systems will be used, the model F 318 is foreseen. It is very tempting to conduct the signal and HV into PMT’s housing through the same cable. Now, when all electronic pieces, including amplifier-discriminators, power suppliers and computer interfaces, have become sufficiently small to place them close to the photometer, this way of wiring could be considered as very useful. Tests of such wiring have passed successfully and the divider of the type D 304 (Kalytis & Meištas 1995) has been made for this purpose. The conduction of the signal and HV power supply through the same cable simplifies significantly the circuit of the divider and enables to diminish its dimensions. Moreover, this reduces the number of cables in the photometer by three times.

5. SIMPLE AND CHEAP WAY TO ROTATE THE WHEEL OF FILTERS

In attempting to improve the electrical and mechanical system for drive and control of the filter wheels in WET photometers, we developed a simple and cheap method of wheel rotation. It is based on the use of sine voltage power supply of step motors which are usually used for this purpose. We use the step mode of a step motor only for start, stop and maintaining. The move to the next position of the wheel is accomplished like in a synchronous AC motor, i.e. by using a sine voltage. We use the full feedback in order to get information on the exact position of the filter wheel. The control of the step motor becomes very simple and easily understandable in this case.

Filter setting systems of this series (Kalytis et al. 1997) utilize the main merits of step motors and avoids their imperfections which happen when using them in astrophotometers. Thus, such a system for filter setting has better specifications in comparison with the standard WET photometer where the pulse mode for driving of the step motors is used.

These merits are the following:

- (1) faster rotation of the wheel;
- (2) uniform (soft) turn to the needed position; it means higher reliability of the system due to lower probability for the filters of getting loose due to shaking;
- (3) significantly lower power consumption;
- (4) lower utilization of the computer/interface resources for the control and its simplicity;
- (5) full feedback in each filter position, which ensures a setting of the wheel in the necessary position and a possibility to receive information that this position has been reached;
- (6) very simple construction and circuitry;
- (7) very simple remote control from computer/interface or from a manual remote control desk.

6. WHAT INTERFACE DO WE NEED?

It has been stated during the WET workshops of 1995 and 1997 that the computer interface which is now in use in many of the WET groups needs redesigning.

In 1996 the Vilnius group redesigned this interface and made the card named CCLA (Chris Clemens-Luja-Ališauskas). However, this card has the same circuitry as the original C. Clemens' interface. Only drawing of PCB has been changed in this design.

The following imperfections and related problems have been found in the Clemens' design of three-channel computer interface for the WET:

(1) the third channel is added later on and in a different way than the first two channels;

(2) readout of channels is designed imperfectly, i.e. in consecutive order, which causes:

- time loss (about $0.4 \mu\text{s}$ per one integration time),
- phase shift (about $6 \mu\text{s}$) of integration time between channels,
- artificial narrowing of the frequency range of counters up to 14 MHz instead of 125 MHz rated in the data sheets of the fast TTL used;

(3) problems of timing:

- integration time can be maintained with uncertainty of $1 \mu\text{s}$ at least, even using a 1 kHz accurate time signal,
- comparatively large minimum integration time (about 12 ms),
- the use of the 1 Hz and 1 kHz accurate time signals is not solved completely;

(4) the use of a serial RS 232 port for the data sending to PC limits the possibilities of interface, especially in the case of extremely short integration times.

To eliminate these drawbacks and solve the problems mentioned we suggest the following changes:

- (1) to use a simultaneous parallel read-out of all channels;
- (2) to introduce the circuit of frequency corrector;
- (3) to use a parallel port or other faster port for the data transfer to PC or to use both the parallel and serial ports;

(4) to use the EPROM program only for initialization and loading the working programs from PC; this modification is still a matter for discussion.

These changes would allow one to make the interface suitable not only for WET, but also for general-purpose applications.

The main merits of such a design are seen as the following:

(1) all channels start the signal integration at the same time, and we have exactly the same duration of integration time in each channel;

(2) all problems of timing would be solved; in addition, a new possibility appears: in this case we have the frequency-correction and accurate integration time with only a 1 Hz accurate time signal, i.e. without the oscillator of high stability which could be saved only for the exceptional cases when the time signal disappears;

(3) the ability of counting up to 125 MHz would be fully employed;

(4) a possibility appears to get shorter (up to 20 μ s) integration time.

7. PHOTOELECTRIC HEADS OF SERIES FEG 300

PMTs used in the WET photometers do not need cooling. However, for general-purpose photometers, in which multialkali PMTs are used, cooling is rather necessary. Thus the experience we have accumulated during designing and fabricating the broad-band detector units (photoelectric heads) for ecological needs or for stellar spectrophotometry has become quite useful now. The photoelectric heads (PH) FEG 304 and FEG 306 were made in 1994–1996. In 1997, a new PH, FEG 310, was designed, made and tested. FEG 310 is designed for the three-channel high-speed photometer TTCP of the Capodimonte Observatory, Naples, Italy.

Table 2. Main specifications of the photoelectric heads FEG 306 and FEG 310.

	FEG 306	FEG 310
Spectral range	250 to 1060 nm	300 to 650 nm (R647P); 185 to 850 nm (R1463P)
Maximum error of the light registration	$\leq 1.2\%$	$\leq 1.1\%$
Sensitivity variations	$\leq 2\%$ per 10 hours	$\leq 0.5\%$ per 10 hours
Dead time	20 ± 2 ns	22 ± 2 ns
Output pulses	correspond to fast TTL	correspond to fast TTL
Temperature of PMT	-35°C and -50°C	-5°C and -15°C
The system of PMT cooling	two-stage thermoelectric cooler	one-stage thermoelectric cooler
Dimensions	$180 \times 110 \times 110$ mm	$110 \times 70 \times 65$ mm
Weight	1.50 kg	0.85 kg

The PHs FEG 304 and FEG 306 have a very deep cooling (up to -50°C) because of the use of PMTs with GaAs and InGaAs photocathodes. In FEG 310, the requirements for cooling are not so strict, but it has more complicated size restrictions: the head has to be two-channel and the distance between the two heads (which determines the distance between the first and second channels) should be as small as possible.

In Table 2, the main specifications of the PHs FEG 306 and FEG 310 are presented for intercomparison.

A distinctive design of actively ventilated heat absorber of thermoelectric cooler in both PHs solved the problem of its effectiveness and weight. We avoided the necessity to use water for heat transfer.

8. PHOTOMETERS

8.1. Introduction

When developing separate components of photometric equipment, in 1993 we started to modernize the "Pancake" travelling pho-

tometer (Meištas 1993). This three-channel photometer, initially designed by E. Meištas and J.-E. Solheim and fabricated at the Tromsø University, later on became a training facility for the Vilnius WET group. It was used for checking new ideas and solutions and for testing the new components designed. During the last four years the "Pancake" has suffered three essential modernizations and more less important ones.

The idea of the flat three-channel photometer turned up as very fruitful. Joined with the nice idea of "miniphotos" developed in Texas (Kleinman et al. 1996) this idea has allowed us to design and manufacture the NPL photometer for the Suhora observatory and to engage into the project of the TTCP photometer, the photometer for the Capodimonte Observatory (see Section 8.3).

8.2. *The NPL photometer*

A three-channel astrophotometer NPL was designed and made by the Vilnius WET group for the Suhora Observatory (see Section 3). The first unit NPL-1 was designed as a two-channel (for measuring of a target star and the sky) photometer. The separate one-channel unit NPL-2 was designed and made for measuring a comparison star. The main purpose of this design was to make a sufficiently small photometer which could be added to the existing two-channel photometer of the Suhora Observatory.

8.2.1. Structure of the NPL

The photometer consists of four main parts:

- (1) two-channel unit or photometer NPL-1,
- (2) one-channel unit or photometer NPL-2,
- (3) electronic module FE 305 including three amplifier-discriminators of type F 316 A,
- (4) electronic unit for the filter setting system FD 308-2.

NPL-1 consists of the following modules:

- (1) housing for two photomultipliers Hamamatsu R 647 and two high-voltage dividers D 303,
- (2) module of the shutter,
- (3) filter wheel,
- (4) microscope module,
- (5) module of the apertures,

(6) assembly for rotation and focusing of the photometer.

NPL-2 consists of the following modules:

- (1) housing for PMT and HV divider,
- (2) module of the shutter,
- (3) filter wheel,
- (4) microscope module,
- (5) module of the apertures,
- (6) assembly for finding the star.

The dual-wheel filter setting system FD 308-2 consists of two filter wheels on the axes of step motors in both units, NPL-1 and NPL-2, and a separate electronic unit for drive and control.

The electronic module FE 305 consists of two main parts: power supply A 306 M and computer interface.

Main specifications of the two-channel photometer NPL-1 and one-channel photometer NPL-2 are given in Table 3.

8.2.2. Electronic module FE 305

The module FE 305 includes all electronic circuits necessary for the power supply and control of the NPL photometer, except of that for the filter setting system FD 308-2, which is designed as a separate unit. All circuits are placed into one box with the input and output connectors.

FE 305 consists of the power supply A 306M and the interface card. A 306M is a slightly modified power supply of the type A 306, designed especially for WET. The power supply is designed as a two-stage voltage changer. It is mounted on one-sided PCB in one of chambers of the electronic module. The power supply A 306M provides all voltages necessary for PMTs, amplifier-discriminators and interface card. These voltages are the following:

+12 V for the amplifier-discriminators F 316A,

+5 V for the interface card,

HV (+600 V to +1100 V) for the HV dividers D 303 (PMTs R 647-04).

The interface card is the latest version of the standard WET three-channel interface card (Clemens 1993). This card is designed to operate as a computer interface of the standard three-channel WET photometer. It ensures the data acquisition from three photon counting channels, the control of two filter wheels and the facilities of all timing circuits. If a suitable external time signal is available,

Table 3. Main specifications of the NPL photometer.

Specifications	NPL-1	NPL-2
Number of channels	2	1
Distance between the channels	16 mm	—
Number of filters	five pairs (5×2)	five
Diameter of filters	15.1 mm	15.1 mm
Time of setting of the next pair of filters	0.25 s	0.25 s
Number of apertures	six pairs (6×2)	six
Diameters of apertures	0.35; 0.50; 0.7; 1.0; 1.4; 7.3 mm	0.35; 0.50; 0.7; 1.0; 1.4; 7.3 mm
Diameter of field apertures	7.3 mm	7.3 mm
Magnification of microscope	25	25
Diameter of the field of microscope	9 mm	9 mm
Diameter of Fabri lenses	14 mm	14 mm
Focus length of Fabri lenses	30 mm	30 mm
Diameter of outcoming pupil	2.5 mm	2.5 mm
Dimensions of field for finding the comparison star	—	ring ($d_1=36$ mm, $d_2=84$ mm)
Dimensions of the photometer:		
height	265±3 mm	260 mm
diameter (including microscope)	408 mm	290 mm
diameter of the main frame	96 mm	92 mm

the interface can process and use this signal for the accurate timing, too.

The electronic module FE 305 is designed as a box including two chambers separated by the inner plate which is joined with the front and back panels and covered by lids. Mounted on the front panel are three BNC connectors for inputs of the three channels.

8.3. The TTCP photometer

In 1997 our group started designing and fabricating a three-channel high-speed photometer for the 1.5 m telescope of the Capodimonte observatory. This photometer, named TTCP (Toppo Three Channel Photometer), should be the first photometer built by the Vilnius WET group, which corresponds to all requirements of the standard WET photometer (Kleinman et al. 1965). On the other hand, the solutions which we are going to realize in the design of the TTCP are result of our earlier experience and especially of our experience acquired during the last five years.

The TTCP has to be a photometer with all three channels parallel to the main axis of the telescope. The second feature of TTCP is its suitability not only for WET, but also for usual multicolor photometry.

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