PHOTOMETRIC EQUIPMENT FOR WET

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Abstract. Some existing photometric instruments for the permanent and portable WET photometers are reviewed. Their main imperfections and ways of improving them are discussed. The amplifier-discriminator F316 and the high voltage divider D303, adopted as the standard WET instrumentation, are described. Some technical suggestions concerning the electronics for the WET photometers are presented.

Key words: instrumentation: photometers

1. Introduction

Last two years the Laboratory of Astrophotometry of the Astronomical Observatory of the Vilnius University continued the work on designing, modernizing and manufacturing photometric instrumentation for the WET. The main purposes of this work were to construct a cheap, small and reliable amplifier-discriminator (A-D) (Kalytis et al. 1993) and to modernize the Pancake travelling photometer (Meištas 1993).

At the beginning, we did not have sufficient initial information, and this made our job a bit uncertain. The first and several later attempts to build a suitable A-D (Kalytis et al. 1993) were not successful enough and the samples made were not approved by the WET headquarters for using them in the standard Texas photometer. But the F309 A-Ds, as well as some other components of the photometric equipment, were installed in the Pancake photometer and underwent
successfully several of the WET observational runs (Meištas 1993). Finally, in the middle of 1995 we understood what was wrong and what was right in our (and not only in our) instrumentation, and even Prof. R.E. Nather recognized that: "they have learned from us, we have learned from them, and we can do better science as a result".

2. Some problems with the standard components for the photometric equipment

The modernization of the Pancake photometer and the work on designing and making several modifications of the A-Ds of the series F300 revealed a few problems with the WET photometers.

Some problems arise when "off the shelf" devices such as A-Ds, high voltage (HV) dividers, power supplies, etc. are used. It is obvious that it would be cheaper and faster to use the components made at the factory than to design and build them, but this approach is not always the best. The problems are not always connected with their technical performances. In many cases, the sum of such characteristics as form, size and weight makes the device unusable even if other specifications are perfect. However, the main reason why the factory-made devices are not always preferable, are their technical characteristics which rarely satisfy the specific requirements of astrophotometry.

It is obvious that photomultipliers (PMT) for photon counting systems should be tested and selected as carefully as possible. Astronomers, differently from physicists and engineers, are not happy with the first PMT taken from the shelf. The same situation is also true for CCDs, when one is going to use them in astronomical instruments. This is also true for other components of photometers.

Thus, it must be decided whether to get immediately a comparatively cheap, but not optimized (in various aspects) instrumentation, or to make some time-consuming efforts to design and fabricate what is needed exactly.

The use of the A-D PARC model 1182 is not justified: it is an old-fashioned design, relatively bulky and has a too narrow frequency band-width. It can be installed neither in the PMT's housing, nor in the interface, and long cables are needed for the small and wide-band signal transmission. Modern A-Ds can be made sufficiently small to fit in any convenient place. A comparatively narrow frequency band-width or frequency response of the model 1182 masks...
partially the fast process of ringing in the circuit of the PMT plus divider plus A-D. Therefore, the ringing, which is not always evident, makes the measurements sometimes slightly incorrect, as was discovered in the double-beam miniphot of the WET photometer, where interaction between the two channels took place, especially when the Hamamatsu "off the shelf" dividers were used.

The standard power supplies have excellent technical performance, but do not always satisfy the specific requirements of photometers. Sometimes it is very difficult to find a power supply which provides only the needed voltages.

Using the stepping motors in their standard (step) mode for the filter wheel rotation is one more example of the difficulty of applying standard instrumental solutions to astrophotometric devices. Really, it is inexpedient to force a stepping motor to start and stop in every step for the filter wheel rotation. This operating mode is very useful when stepping motors are used to move precisely lightweight parts for short distances (as in the computer disk drives or printers). The filter wheels in photometers have, as a rule, a greater moment of inertia and are to be rotated, at least, by tens of steps in a regular mode. Thus, using a standard mode, more powerful motors and more energy consumption are required. Our experience shows that the simplest and the most effective solution is to use the AC power supply for a stepping motor which turns the filter wheel from one position to another. The "native" property of a stepping motor must be used only to start, to stop and to fix the filter position. The control electronics circuit design becomes more simple in this case.

It seemed that Hamamatsu HV dividers E849-35 or E849-36 were working perfectly in the WET photometers while the PARC model 1182 A-D was in use. A comparatively narrow frequency band-width of the 1182 masked the ringing in the output pulses of the PMT Hamamatsu R647-04 which was caused by the imperfect design of the divider and its accompanying circuitry (Fig. 1a). When the A-Ds of the series F300 with a wider frequency band-width were introduced, the ringing appeared as afterpulses (Fig. 1b). This was the main reason why the earlier A-D versions of the series F300 were not adopted for the WET photometers in the first stage of our work.

The problem of the ringing, if the Hamamatsu dividers are used, could be partially solved by a more careful wiring of the divider, HV filter and signal transmission capacitor. In this case the shortening of the HV wire is especially important. However, the internal pro-
Fig. 1. Here we show how ringing pulses, which are always present in the Hamamatsu HV divider E849-35 output, cause afterpulses in the output of the Vilnius design amplifier-discriminators of the series F300: (a) – using the PARC A-D model 1182 and (b) – using the A-D of the series F300 of the Vilnius design.

cesses going on in the Hamamatsu dividers cannot be eliminated or diminished in any way.

A more detailed consideration of the circuit of the Hamamatsu standard dividers shows that it contains several aspects which are not needed for our case. The standard Hamamatsu divider is designed for a wide spectrum of applications, i.e., it is a general-purpose device. Its resistance is made comparatively low in order to use the PMT in a very wide dynamic range of the signal. Our application, however, does not need this property. On the contrary, we need a high resistance in the divider which allows us to diminish its current
and the heating of the PMT and which introduces a negative feedback in the case of high amplitude pulses or of ultra high illumination of the PMT.

The boosting capacitors, existing in the standard Hamamatsu dividers, serve also to increase the linearity of the PMT plus divider assembly, but again, in the light intensity region which we do not use. The suggestion of throwing out the boosting capacitors seems to be strange enough, but this gives, in our case, a good result by increasing even more the negative feed-back.

Thus, it is obvious that the dividers should be modernized in many respects.

3. Modernization of the Pancake photometer

After the PARC model 1182 was replaced by the A-D F309 (Meištas 1993), the following modernization of the Pancake travelling photometer was made:

- installation of the dual-wheel filter setting system FD 306-2;
- replacement of the third (sky) channel (Ch3) box by the new design channel box, including the HV divider D301 and the A-D F312, both made by our team.

The filter setting system FD 306-2 is a further modification of the analogous system FD 301 (Kalytis et al. 1993) and it operates on the same principles of the filter wheel rotation and its control. But a number of considerable improvements in its operation have been made, which concern the optimization of the circuitry including minimization of the power consumption. On the other hand, the filter wheel can now rotate in both directions.

The system can be controlled by the Quilt9 via the interface of Texas design, but a special EPROM program is needed in this case because of the different principle of the filter wheel rotation and its control comparing with the original one. Complying with our request, Dr. C. Clemens kindly supplied us with a special version of the EPROM program to use it with our filter wheel rotation system FD 306-2. After all the necessary changes were made, the system was attached to the Pancake photometer and worked successfully under the rigorous conditions of Norwegian winter.

The complicated aperture mechanism of Ch3 was replaced by a more simple one. In this design, a small amplitude of the rectilinear movement of the whole Ch3 is used for the search of clean sky. It
allowed us to diminish significantly the size of the Ch3 box, and we are able now to measure sky much nearer to the Ch1 star.

The replacement of Ch3 gave us an opportunity to test the HV divider of the new design. We have noticed a ringing in the output pulses of the PMT, if the standard Hamamatsu dividers E849-35 or E849-36 were used. This ringing appeared due to a non-optimal circuitry of the last dynodes and the wiring of the HV and signal circuits in the standard Hamamatsu dividers. Therefore, we decided to put the divider and all elements of the signal transmission and HV filtering inside the shielding case. The HV divider D301 was made specially for this purpose. D301 assures a good shielding of its circuitry and a minimum ringing in the PMT’s output pulses.

An A-D of the type F312 was used instead of F309 in Ch3. Decreasing the amplifier gain and inclusion of a differential capacitor between the amplifier and discriminator are the main design changes. This has decreased the danger of afterpulses due to a depression of the ringing and saturation effects.

The above mentioned modernization of the Pancake photometer not only improved the instrument but also allowed us to test some of our ideas.

4. The D303 high voltage divider

After testing the D301 HV divider in Ch3 of the Pancake photometer, the new modification of the divider, D303, was designed for use in the single- and double-beam miniphots. The purpose of this design was to replace the standard Hamamatsu HV dividers, E849-35, and to use the modernization suggested above to avoid the interaction between the channels of the Texas double-beam miniphot.

In Fig. 2, a circuit diagram of the D303 HV divider is presented. D303 is a divider with a grounded photocathode potential. High resistance (1.2 MΩ) resistors are used in this device. Their use allows us to decrease the PMT heating and makes the divider nonlinear. The nonlinearity appears in the final stages of the assembly PMT plus divider when the current of the PMT approaches the current of the divider. It diminishes the amplitude of the largest pulses and shuts down the PMT completely if a very large light flux falls on the photocathode. The divider works linearly through a comparatively wide range of low and moderate light intensity, i.e., in the region we use.
Resistors R10 and R12, mounted in series in the circuits of the last dynodes, lower the quality of the tuned circuit and decrease the ringing in the output pulses. For the best shielding, D303 is enclosed into a μ-metal tube, which shields the divider with the HV filter and the pin-part of the PMT, too. The metal-shield or double-shield cables are used to lead the signal and the HV. The main specifications of the D303 divider are presented in Table 1.

**Table 1. The main specifications of the D 303 type divider**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ground potential electrode</td>
<td>cathode</td>
</tr>
<tr>
<td>maximum supply voltage between case</td>
<td>1400 Vdc</td>
</tr>
<tr>
<td>and terminals</td>
<td></td>
</tr>
<tr>
<td>maximum supply voltage between power supply terminals</td>
<td>1400 Vdc</td>
</tr>
<tr>
<td>total resistance</td>
<td>12.4 MΩ</td>
</tr>
<tr>
<td>maximum current</td>
<td>11 μA</td>
</tr>
<tr>
<td>operating temperature</td>
<td>-20°C to +50°C</td>
</tr>
<tr>
<td>dimensions of unit</td>
<td>15 mm × 72 mm</td>
</tr>
<tr>
<td>(without cables)</td>
<td></td>
</tr>
<tr>
<td>weight</td>
<td>35 g</td>
</tr>
</tbody>
</table>

The shapes of the output pulses of the PMT Hamamatsu R647-04 used with the dividers D303 and Hamamatsu E849-35 are compared in Fig. 3. When the divider D303 is used, the ringing in
Fig. 3. The shape of output pulses of the PMT Hamamatsu R647-04: 
(a) – using the HV divider Hamamatsu E849-35 and (b) – using the HV 
divider D303 of the Vilnius design.

the output pulses of PMT decreases approximately by ten times in 
comparison with using the E849-35.

5. The F316 amplifier-discriminator

The model F316 is the latest modification of the series F300 of 
small size A-Ds designed for the WET photometers. The main pur-
pose of this design was to optimize its power supply and to achieve 
minimum of the power consumption. The performance of F316, with 
regard to high speed, high sensitivity, wide input-pulse dynamic 
range and high reliability is the same as in other modifications of 
this series. The circuit-diagram of the F316 amplifier-discriminator 
is shown in Fig. 4.

In the F316 we use the same type of the wide-band high-
frequency integrated amplifier SA/NE 5205 (or M421104) and high-
speed ECL comparator AD 96685 (or K597CA4) as in earlier modi-
fications of the series F300 (Kalytis at al. 1993).

The essential change made in the F316 concerns the power sup-
ply of the A-D. For the integrated circuits and output stages, only 
one polarity voltage, +12 V, was used. It allowed us to decrease 
significantly unnecessary power dissipation and to achieve a high 
amplitude of the output pulses.
Both the amplifier and the comparator provide an input sensitivity of about 100 $\mu$V, which is limited only by the thermal noise of the input circuit of DA1 and R1.

The differential amplifier, consisting of VT1 and VT2 (BFP 193), is an output amplifier-booster providing positive output pulses of 5.5 V amplitude. The emitter follower, VT3 (BFP 193), with the resistor R23 in series, is used for adjusting the discriminator's output impedance with the input impedance of the cable and for converting the ECL level to the TTL level.

The amplifier-discriminator is mounted on the double-sided printed circuit board enclosed into a soldered $\mu$-metal envelope. This design was also used in the earlier models and has proved itself to be helpful in solving all the shielding and radio frequency isolation problems. A linear layout of the stages and power filtering allowed us to suppress spurious oscillations and to obtain quite good sensitivity.

The main specifications of the amplifier-discriminator F316 are given in Table 2. Tests of the F316 made with the PMT Hamamatsu R647-04 showed no afterpulses even if the Hamamatsu standard dividers were used. It seems that this modification of the amplifier-discriminator, as well as the HV divider D303 have passed
Table 2. The main specifications of F316

- input impedance: $(30 \pm 10) \, \Omega$
- input pulse polarity: negative
- input RMS noise equivalent: $20 \, V$
- discriminator threshold level (referred to the input of the amplifier): internally adjustable, $100 \, \mu V$ to $500 \, \mu V$
- temperature coeff. of input sensitivity (defined in the range $-20^\circ C$ to $+50^\circ C$): $< 0.2 \, \mu V/^\circ C$
- input pulse dynamic range: $\geq 65 \, dB$
- pulse pair resolution: $(25 \pm 2) \, ns$
- recovery time: $< 2 \, ns$

- output pulse’s:
  - polarity: positive (fast TTL)
  - amplitude (on the $50 \, \Omega$ load): $\geq 3.4 \, V$
  - power requirements: $+12 \, V$ (80 mA)
  - operating temperature: $-40^\circ C$ to $+50^\circ C$
  - input and output connectors type: BNC (or user specified)

- dimensions of unit (without connectors): $82 \, mm \times 28 \, mm \times 16 \, mm$
- weight: $85 \, g$

The expertise of Prof. R. E. Nather and Dr. C. Clemens and will be approved as the standard A-D for the WET photometers.

6. Well, what’s next?

Further work must be concentrated in two directions. The first direction is to modernize the photometers of the Texas design taking into account the problems encountered and the means for their solution, as it is discussed above. The second direction is the need for a portable (travelling) photometer, like the Pancake. This has become urgent for those WET observers who have no permanent observing sites. Thus, the design of the Pancake-2 photometer, with the imperfections of the first Pancake corrected, seems to be the next important measure.
Both directions have many common points: there is a necessity to satisfy all the requirements for the WET photometers, and most of the electronics for both photometers is the same. The main differences in the electronics arise due to mechanical parts of the Texas photometer (especially in the miniphot) which are already made and cannot be changed.

The main modernization of the Texas photometers is to replace the Hamamatsu dividers by the D303 or its analogs. It is clear that the installation of the D303 in the existing miniphots can be made only as a part of further job of fabricating the whole miniphot or housing of its PMT. At the same time, the junction of the miniphot with the main case of the photometer could be strengthened. It seems to us that the installation of a new filter wheel rotation system similar to FD 306-2 would be also important. However, all these changes must be approved by the WET officials.

The second modernization to be made is to replace the PARC model 1182 A-D by one of the latest modifications of the A-D (e.g. F316C). The problems of its mechanical design, attachment to the photometer and the use of the input signal cables should be solved at the same time.

The old version of the interface should not be used in this new box of electronics due to the obsolete components used and a non-optimal circuit. C. Clemens, the designer of the old interface, agrees with the redesign. However, we have no initial information concerning the algorithm of the photometer's operation and, therefore, we cannot propose our own version of the interface. We have tried to design the new electronics maintaining the old software. However, it became clear that this attempt was not completely successful.

The optical-mechanical parts of the new portable Pancake-2 photometer are still under design and fabrication. Thus, only the electronics for this photometer will be considered in this paper.

The Pancake-2 photometer is designed as a small and comparatively lightweight photometer. The box of electronics will be as small as possible. Thus, the length of the signal and HV cables will be sufficiently short, because our small A-Ds will fit inside the box together with the interface. Moreover, we have a plan to use the same cable for the signal and high voltage. Such a wiring has passed the successful tests and a divider of the type D304 has already been fabricated for this purpose (Fig. 5).

The conduction of the signal and the HV power supply through the same cable significantly simplifies the circuit of the divider and
enables us to diminish its dimensions. Then the housing of the PMT and the divider becomes a very compact tube with a single cable coming out. The thickness of the housing becomes similar to that of the PMT with shield, and two housings can be grouped in the double- or single-channel miniphots. Placing the A-Ds in the interface allows us to reduce the size of the A-D, since the boosting stage in this case is not necessary.

Some additional elements are needed to separate the signal from the HV. Fast TTL comparator and pulse counters are used in the present Texas design interface. In the new interface, the ECL comparator and the first counter could be used. Then all the elements for converting the light into the electric signal and its conditioning will be of the same speed, i.e., they will ensure a frequency range up to 250 MHz. It will give a dead time of 5 – 7 ns. It might seem unimportant, as we can get sufficiently good results even with 20 ns, but why should we refuse to get additional possibilities? In this case, some changes in the EPROM program should be introduced.

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Photometric equipment for WET

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