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A high voltage current monitor for measuring photomultiplier anode current

J.E.McMillan

Department of Physics and Astronomy, University of Sheffield, Sheffield, South Yorkshire, S3 7RH, Great Britain
Presenter: J.E.McMillan (j.e.mcmillan@sheffield.ac.uk), uki-mcmillan-J-abs1-og27-poster

A system is presented which is capable of monitoring currents in the microamp region at a voltage of up to 2.8kV. This can be used for measuring the anode current of a photomultiplier when operated with the photocathode grounded.

1. Introduction

Photomultipliers are susceptible to damage caused by heating of the last dynodes if the average DC anode current is allowed to exceed about 100μA. As part of a test facility intended to prematurely age photomultipliers, it was required to monitor anode current while exposing the photomultipliers to elevated light levels. These ongoing aging studies are intended to provide estimates of longevity of photomultipliers used in long-term particle astrophysics experiments as well as in medical imaging applications.

Measurement of the anode current with the anode at a voltage close to ground and the photocathode at a high negative voltage is trivially simple. However, with the photomultiplier operated with the photocathode grounded and the anode at high voltage, direct measurement becomes problematic. Grounded photocathode operation is usually preferred, since it results in lower noise operation. Similar considerations apply when monitoring photomultipliers used for air cherenkov or air fluorescence detectors.

Frishman and Akerlof [2] used a simple voltage-to-frequency converter (VFC) to routinely monitor the anode current of photomultipliers on an air cherenkov telescope. The VFCs were mounted close to the photomultiplier and the frequency was measured remotely with a multichannel scaler unit. This system was not capable of operating with the anode at high potential but demonstrated the use of VFCs to generate a telemetry signal which could be remotely monitored.

For the Pierre Auger air fluorescence detector, Argirò et al. [1] developed a a circuit based on optocoupled current mirrors, which was the first workable solution to the problem of measuring the anode current at high voltage. The output was in the form of a DC voltage proportional to the anode current. This voltage must either be converted to digital form at the photomultiplier base or it must be transmitted some distance and digitized remotely.

Kliefges et al. [3], also working on the Pierre Auger air detector, rejected the current mirror as too complex and instead proposed a statistical analysis of the signal fluctuations as a measure of the anode current. The calculations for this were performed using part of a field programmable logic array which was already available as part of the experiment. This method appears to depend on knowledge of the photomultiplier gain and on the constancy of the gain over time, neither of which were realistic for the present requirement.

2. Anode current monitoring using a VFC

The method adopted was essentially an extension of the technique of Frishman and Akerlof [2]. The current passing through the anode resistor of the photomultiplier gives rise to a voltage which is used to control a voltage to frequency converter. The output frequency is transmitted from the photomultiplier base and measured

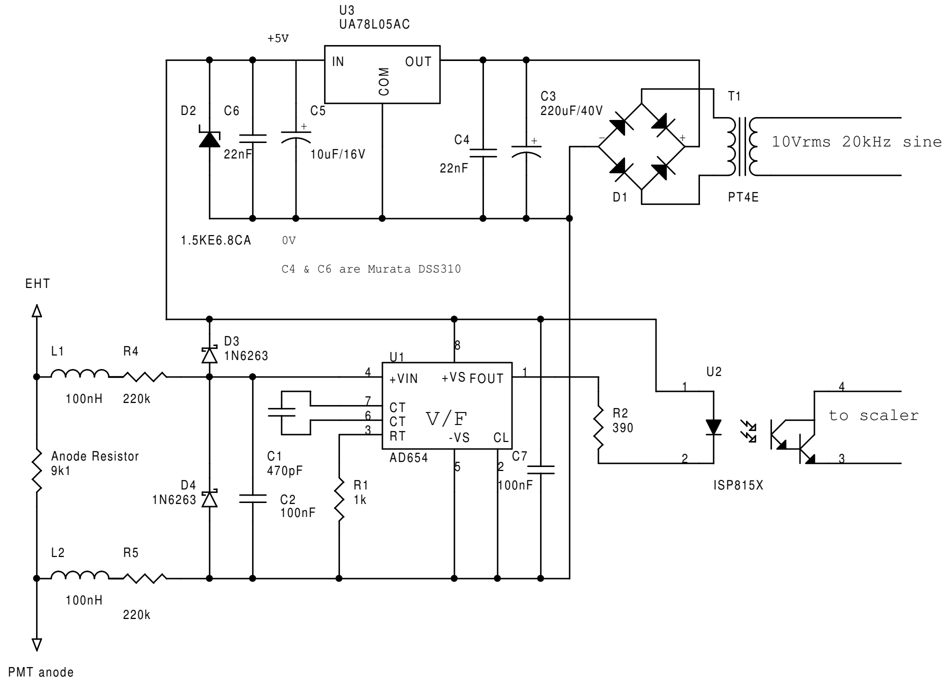

Figure 1. schematic of voltage - freq converter

remotely with a scaler. By passing the output signal through an optoisolator and operating the whole of the VCF circuit at high voltage, the anode current can be measured without damaging the VCF.

The circuit is shown in figure 1. The VFC used was an Analog Devices AD654, providing a better engineered system than the 555-based circuit used by Frishman and Akerlof [2]. The photomultiplier dynode chain was an Electron Tubes C638, a standard printed circuit board constructed with surface mount components, which can be configured for a variety of photomultipliers with only minor alterations. The standard anode resistor provided on the C638 board is 100kΩ. Use of this value would have made the current monitor excessively sensitive, so it was reduced to 9.1kΩ by soldering an additional 10kΩ in parallel. This is illustrated at the bottom left of the schematic together with its connections to EHT and to the photomultiplier anode. It was connected to the VCF via two 100nH inductors (L1,L2) and two 220kΩ resistors (R4,R5). These coupled the DC voltage to the input pins of the VCF, while ensuring that the presence of the VCF did not affect the photomultiplier output pulses. This remained true, even when used with fast photomultipliers of the 9813 type, having risetimes of 2ns. These inductors and resistors were mounted as close as possible to the anode resistor on the C638 board.

In the prototype, the remaining components were mounted on a separate printed circuit board with two short flying leads to the coupling resistors. Care was taken to decouple the VCF power rails adequately and clamp diodes were provided to ensure that the input to the VCF could not exceed the rail voltages in the event of excessive current flowing through the anode resistor.

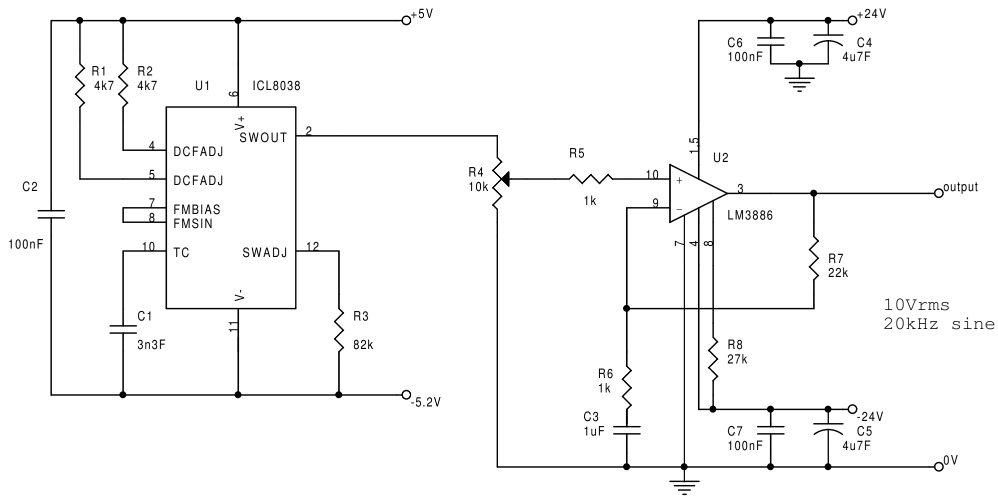

Figure 2. schematic of power supply

3. Powering the VCF

The optoisolated VCF circuit floated to high voltage is only half of the design. The circuit requires power to operate, admittedly not a great deal, but no configuration could be found in which it was powered directly from the photomultiplier EHT supply. With a +5V power supply and the optoisolator specified, the circuit required around 6mA. For initial experiments the VCF was battery powered and this remains a possibility. However, it was intended to use the circuit over a period of many months and batteries remain unreliable under such conditions. DC/DC converters were rejected since current models produce a large level of switching noise with harmonics extending into the 100MHz region. They are incompatible with typical photomultiplier anode pulses of a few millivolts and durations of a few nanoseconds.

Instead it was decided to provide power using a classical linear power supply. This consisted of a transformer which provided the required high voltage isolation between its primary and secondary windings, followed by a bridge rectifier, smoothing capacitors, a three-terminal regulator and further decoupling components, which are illustrated in the top half of figure 1. While it would have been possible to send mains voltage to the circuit and to find stepdown transformers with sufficient isolation, this was rejected both on the grounds of safety and because available mains transformers were all too bulky.

Small high-voltage isolation transformers with 1:1 turns ratio are widely available and experiments were performed on a range of these. The chosen transformer was a PT4E from Oxford Electronic Devices (OED), intended for use as a pulse transformer in thyristor and triac trigger control applications. It was specified to have a bandwidth of 3kHz to 1MHz and 2.8kV voltage isolation. Its physical size was $15 \times 15 \times 16$mm. Attempts to operate it (or any of the other transformers tested) at 50Hz were futile, as at this frequency it was extremely inefficient and saturated easily. Instead the supply frequency was raised to 20kHz where it worked perfectly. The result was an AC/DC power supply operating perfectly with 2.5kV DC offset between input and output and less than 1mV ripple and noise on the 5V output line.

Clearly 20kHz is not a standard supply frequency, so this was generated using an ICL8083 function generator chip driving a LM3866 power amplifier module, as shown in figure 2. These were housed in a standard NIM module and derived their power from the standard crate power connector. The +5V and -5.2V rails marked on figure 2 were derived from the +12V and -12V crate supplies via three-terminal regulators. Eight current monitors could be driven from the unit simultaneously, being connected using twisted pair ribbon cable.

The returning signals from the optoisolators were also buffered in this unit before being fed to a Hytec EC727 multichannel scaler module. This is a 32-channel Camac scaler, the other channels of which were already in use to monitor photomultiplier noise rates. This buffering consisted of reconstructing the VFC output waveform by passing the signal through a Schmitt trigger, then converting to differential ECL required by the scaler module. A simple computer routine was used to convert the frequency measured back to anode current, using a linear function based on the calibration data.

4. Conclusions

The circuit, as constructed, measured low currents at high voltage without introducing noise into the circuit being measured. It was fully linear over the required range of 1–100μA. While it was designed for the specific purpose of monitoring photomultiplier anode current, it would be useable wherever DC currents at high voltage need to be monitored. Higher currents can easily be accommodated by reducing the value of the sensing resistor from 100kΩ, while lower current measurements can be attained by increasing this resistor. The input resistance of the AD654 is specified as 240MΩ, so the sensing resistor can be increased to 10MΩ without problems, giving a range of 10–1000nA.

The limitations on the maximum voltage the circuit can be operated at are determined by the 1:1 isolation transformer and the optoisolator. The optoisolator could easily be replaced by a system which transmitted the frequency over an optical fibre giving considerably higher isolation. Powering the circuit at much higher voltages is more problematic since transformers capable of much greater isolation are not widely available.

5. Acknowledgments

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