# LED based powerful nanosecond light sources for calibration systems of deep underwater neutrino telescopes


B. K. Lubsandorzhiev, R.V.Poleshuk, B.A.J.Shaibonov, Y.E.Vyatchin

*Institute for Nuclear Research of the Russian Academy of Sciences*

*pr-t 60th Anniversary of October, 7A, 117312 Moscow, Russia.*

*Postal address: pr-t 60th Anniversary of October, 7a, 117312 Moscow, Russia; phone: +7-495-1353161; fax: +7-495-1352268;*
*E-mail:* lubsand@pcbai10.inr.ruhep.ru



**Abstract**

Powerful nanosecond light sources based on LEDs have been developed for use in calibration systems of deep underwater neutrino telescopes. The light sources use either matrixes of ultra bright blue InGaN LEDs or new generation high power blue LEDs. It's shown that such light sources have light yield of up to $10^{10}$-$10^{12}$ photons per pulse with very fast light emission kinetics. The light sources described in the paper are important for use in calibration systems of Cherenkov and scintillation detectors. The developed light sources are currently used in a number of astroparticle physics experiments, namely: the Baikal neutrino experiment, the TUNKA EAS experiment, etc.



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Key words: Light emitting diode, Light emission kinetics, Light yield, Avalanche transistor,


## 1. Introduction.

Ultra bright blue and violet LEDs based on InGaN structures have been getting a rampant development over the last decade. The advances made in this field are really stunning. Just a mere list of the LEDs manufacturers is very impressive. The LEDs are successfully required for a variety of applications. Among the main fields of applications are large size displays, computers, car electronics etc. As for the high energy and astroparticle physics experiments the LEDs are very useful for timing and amplitude calibration systems. With special drivers it is possible to cover using just a single piece of such LED a rather big range in light pulses amplitude staying still in a few nanosecond time domain. It was shown in [1, 2] that with a single ultra bright blue LED one can reach the light yield of $10^9$ photons per pulse. For this kind of application it's very important to have powerful (up to $10^8$ – $10^{10}$ or higher photons per pulse) adjustable light sources with light pulses width as short as possible (1-2 ns (FWHM) typically). For large scale experiments there is a necessity to have light sources with higher light yield.

It was shown in [1, 2] also that a single ultra bright blue LEDs can withstand quite safely nanosecond current pulses with amplitude of up to 3A. The light yield of the LEDs increases almost linearly with increase of amplitude of current pulses. Unfortunately there are no possibilities to increase further current running through the LEDs for safety reasons. But how to increase light yield of light sources without substantial deteriorating their light emission kinetics?

**2.1. Light sources based on ultra bright blue LED matrixes (I).**

The first idea how to increase the light yield is to assemble LEDs in a matrix. There are two ways to do it. The first one is to make a matrix of LED drivers where each LED of the matrix has its own driver. The second one is to drive a matrix of LEDs with common driver.

In the first case the most difficult technical problem is to reach the high level of firing simultaneity of individual drivers and LEDs of the matrix. In order to have the fastest light emission kinetics and the largest light yield of the whole matrix one should select meticulously individual LEDs and tune elaborately individual drivers of the matrix. Taking into account the fact that even ultra bright blue LEDs of the same type supplied by the same manufacturer can differ very much in their light emission kinetics and light yield [2, 3], to reach the high level of simultaneity and equal light yield is quite a job.

We found a number of types of ultra bright blue LEDs having a high level of repetitiveness of their characteristics. We selected the fastest LEDs without slow components and with highest light yield to use in the light sources based on matrixes of LEDs. The LEDs produced by NICHIA, KINGBRIGHT, YolDal, Bright LED and G-nor are among the selected types of LEDs. For each type of LEDs we selected thoroughly the fastest LEDs with very similar light emission kinetics and light yield.

As for electronic drivers for the light source it should be noted that only the drivers based on avalanche transistors can be used to reach the highest level of light yield. We use ZETEX special avalanche transistors in the drivers. In Fig.1 the light source based on the matrix of LED drivers is shown.

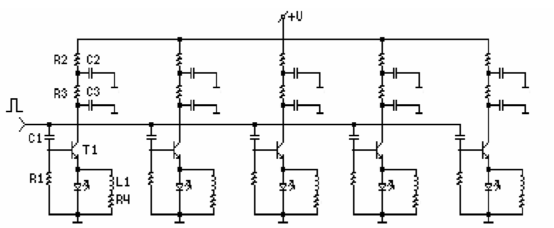


Fig.1. Scheme of a powerful nanosecond light source based on the matrix of LED drivers. The “one LED – one driver” approach.

The LEDs and drivers of the matrix are matched as precisely as possible to each other so the simultaneity of their firing is very high. The accuracy of the matrix LEDs light pulses coincidence in time is well less than 50 ps. In Fig.2 the light emission kinetics of the individual LEDs of the LED matrix shown in Fig.1 is presented. The light emission kinetics of each LED of the matrix is depicted in the figure by different colored curves. The black curve corresponds to the resulting light emission kinetics of the whole LED matrix. One can see from the figure that the deviation of temporal behavior of each LED in the matrix is very small and resulting shape of the matrix light pulse practically follows the light pulses shape of constituting LEDs. The LEDs in the matrix are the “old” NSPB500S produced by NICHIA. As it was demonstrated in [2] the “old” NICHIA LEDs are much faster than the “new” ones of the same type. The “old” and “new” NSPB500S LEDs differ by their manufacturing dates. The “old” LEDs were bought before 1997 and “new” ones in 2000.

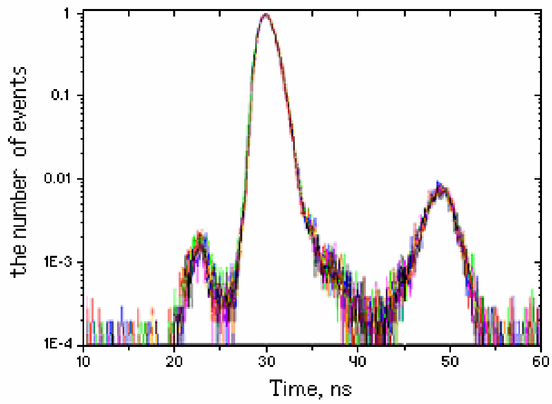


Fig.2. Light emission kinetics of the LED matrix (the black curve) and individual LEDs of the matrix (the colored curves). The “one LED – one driver” approach.

The light emission kinetics of the LEDs and the matrix was measured by a time correlated single photon counting (TCSPC) technique [4, 5]. The light emission kinetics of each individual LED was measured by a fast PMT when all other LEDs of the matrix were masked. A set of neutral density filters was used to decrease the level of the PMT’s photocathode illumination to a single photoelectron level as required by TCSPC technique. The left and right peaks in Fig.2 correspond to prepulses and late pulses of the PMT used in the measurements and have no relations to the LEDs light pulses shapes, we refer readers to [6,7] for more details. To infer the LEDs light pulses widths one should analyze the main peak of the distribution around 30 ns in Fig.2.

Practically the same results are reached with the YolDal, LIGITEK and G-nor ultra bright blue LEDs. The latter are the fastest ones being a bit inferior to others by their light yield.

It should be noted here that the above described approach to make the LED matrixes is the most difficult one. The LEDs and electronics components of the drivers (avalanche transistors, discharge capacitors, resistors and PCB boards) should be selected and prepared thoroughly. The drivers and LEDs should be selected and tuned and matched finely to each other – the avalanche transistors should have very close avalanche breakdown voltages, the rise time of resulting current pulses should be very close too, the nominals of discharge capacitors should nearly identical too etc. Despite the difficulties it is feasible, in principle, to assemble such matrixes with LEDs as many as possible without substantial deteriorating light emission kinetics of the marixes

## 2.2. Light sources based on ultra bright blue LED matrixes (II).

Another approach to make powerful nanosecond light sources based on matrixes of LEDs is to drive several LEDs switched in parallel in one matrix with only one driver common to all LEDs in the matrix. In this case it is necessary to select just fast LEDs with identical light emission kinetics and light yield.

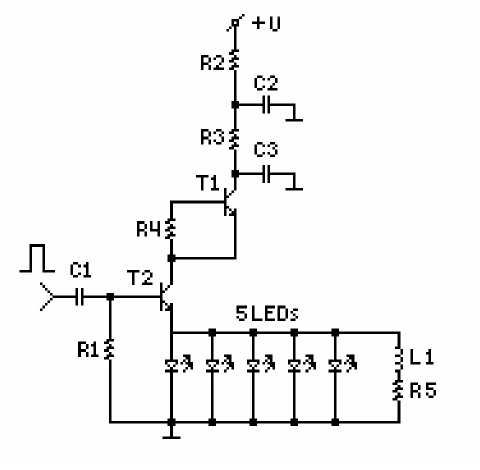


Fig.3. Scheme of a powerful nanosecond light source based on the matrix of LED. The "one driver – a matrix of LEDs" approach.

The electrical scheme of such a light source is shown ion Fig.3. A matrix of LEDs, several LEDs switched in parallel, is inserted into emitter circuit of the driver. A LR filter is switched in parallel to LEDs to cancel the long tail of C3 capacitor's discharge. To increase current pulse running through LEDs two avalanche transistors, the same type of ZETEX transistors, consequently switched are used in the driver. As a result the driver needs higher power supply voltage - ≥ 600V.

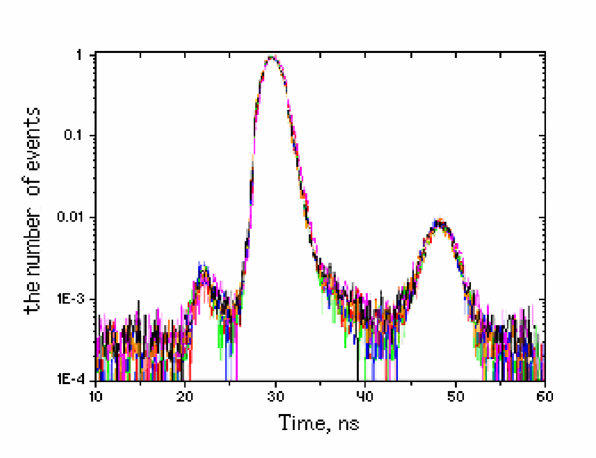


Fig.4. Light emission kinetics of the LED matrix (the black curve) and individual LEDs of the matrix (the colored curves). The "one driver – a matrix of LEDs" approach.

Fig.4 presents light pulses temporal profiles of the LED matrix and individual LEDs of the matrix. As in the previous case, the black curve in the figure corresponds to the whole matrix and the colored curves to the light emission kinetics of the individual LEDs of the matrix measured by the same TCSPC technique and LEDs masking. Once again it is seen that the LEDs of the matrix are almost ideally matched by their emission kinetics and light yield. The coincidence accuracies of matrix LEDs light pulses in both cases are better than 50 ps.

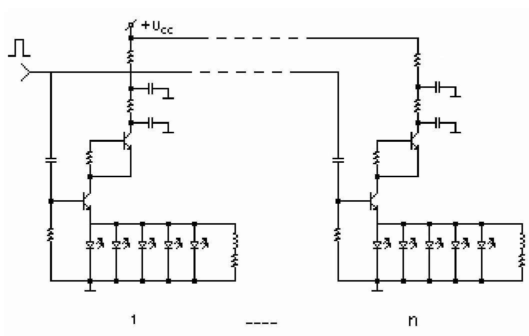


Fig.5. Cluster of *n* matrixes of LEDs.

The second approach provides 2-3 times less light yield in comparison with the first one but it is much easier to implement technically. There is no need to tune and match different drivers. One should just select properly LEDs. The light yield reached with the driver shown schematically in Fig.3 is ~5×$10^9$ photons per pulse. He light emission kinetics is almost the same as in the first case. Further increase is the light yield is possible with use of a cluster of several matrixes of LEDs as demonstrated in Fig.5. with such clusters it is possible to reach the light yield of ≥ $10^{11}$ photons per pulse and at the same time staying still in the time domain of 102 ns light pulse width (FWHM).

### 3. Light sources based on high power blue LEDs

It is quite interesting to use a relatively new player in the field – high power blue LEDs which replace LED matrixes described in this paper in the powerful nanosecond light sources. High power blue LEDs can withstand DC current of 1A providing much higher light yield in comparison with ultra bright blue LEDs. The Fig.6 and Fig.7 presents the scheme of the driver and light pulse shape of the LXHL-NB98 high power blue LED produced be LUMILED correspondingly.

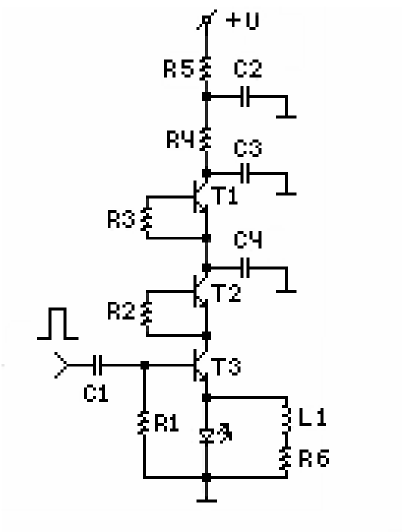


Fig.6. Scheme of a powerful nanosecond light source based on a single high power blue LED – LXHL-NB98.

The LEDs need higher power supply voltage of ≥ $10^3$ V. The light sources based on a single such LEDs provide the light yield of ≥ $10^{12}$ photons per pulse. We tested high power blue LEDs from LUMILED, Cree and G-nor. Their light emission kinetics are relatively slow with ~5-10 ns width (FWHM) as shown in Fig.7.

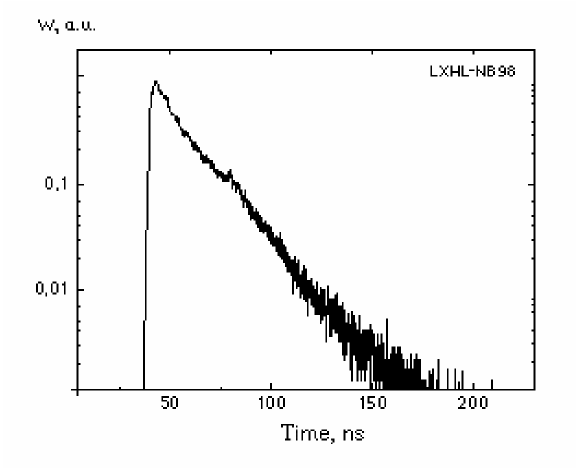


Fig.7. Typical light pulse shape of a single high power blue LED (LXHL-NB98 from LUMILED).

### 4. Conclusion

Ultra bright blue LEDs give excellent opportunities to build powerful, fast and inexpensive light sources for calibration systems of astroparticle experiments. With matrixes of ultra bright blue LEDs it is possible to have light sources with light pulses width of 1-2 ns (FWHM) and light yield of up to $10^{10}$ photons per pulse and even more, and with a cluster of such matrixes – $10^{11}$ photons per pulse without deteriorating its light emission kinetics. New high power blue LEDs allow to have light sources with intensities of $10^{12}$ photons per pulse with a single such LED but their emission kinetics is relatively slow with light pulses width of ~5-10 ns. Powerful nanosecond light sources based on ultra bright and high power blue LEDs have very high long term stability. So they are in many respects very good competitor to the laser systems used widely in calibration systems of many astroparticle physics experiments.


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