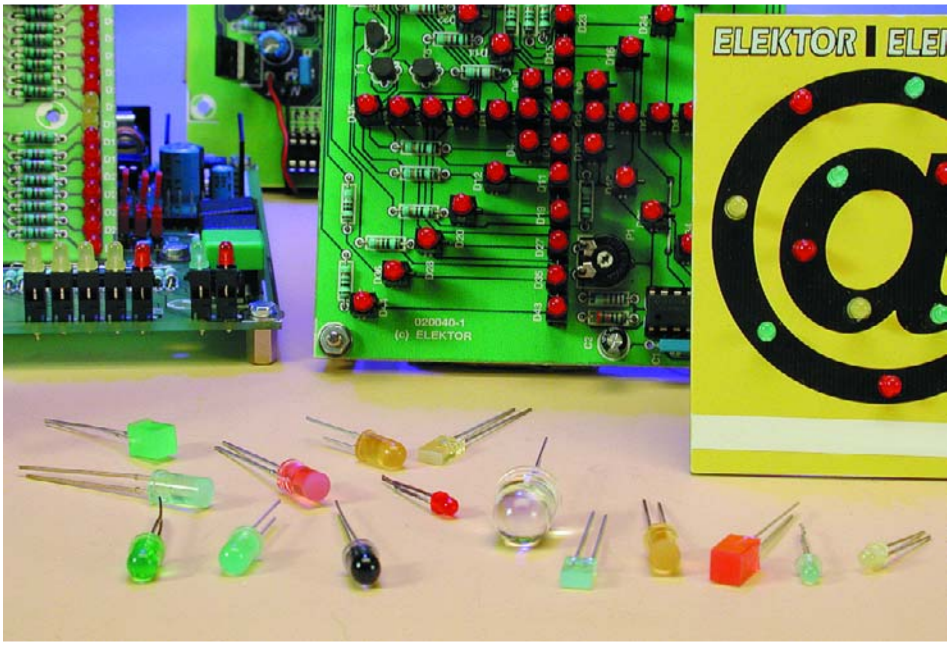
LED Arrays

matrixed clusters for lighting purposes

By K.-J. Thiesler

A handful of high-intensity LEDs is sure to provide new accents in room lighting. In traffic lights and other signalling equipment, they save energy and reduce maintenance cost thanks to their long life expectancy as compared with conventional lamps.



Manufacturers have been able to push the light intensity of modern LEDs to levels where these devices can be used for lighting (illumination) purposes, even if prices are still relatively high. However, LEDs do offer some clear advantages over traditional electrical light sources. For one thing, their life expectancy of up to 100,000 hours is impressive. Also, the optics are integrated in the enclosure to ensure the emitted light is bundled to requirements. A further advantage is the fast on/off time of a LED. In cars, for example, a LED brake light gives a clearly faster response than a conventional bulb. Whereas LEDs respond within 100 ns or so, 'cold' bulbs need to be pre-heated for about 100-300 ms. During that period, they require current peaks of up to 50 times their nominal value.

Of course, there are also disadvantages to the use of LEDs. Bulbs emit lots of infrared light which allows them to keep functioning at high temperatures. LEDs, on the other hand, are passive semiconductors with an associated temperature spectrum. Their high power density causes the maximum chip temperature of 125 °C to be reached at an ambient temperature of about 85 °C. Such a temperature is easily reached, for example, inside a third break light on a bright sunny afternoon in summer. When the chip temperature exceeds 125 °C, the LED stops working as soon as it lights up. This usually happens at the maximum permissible forward current which causes the chip temperature to rise even further. Because the power handling capacity of a semiconductor is inversely related to ambient temperature, worst-case conditions easily arise in simple circuits without compensation measures. The result: the overloaded LED no longer lights and goes open-circuit.

In the manufacturing process of LEDs, the deviations in electrical performance is such that devices may be gathered in batches with a lower tolerance. For a single indicator LED used in a standard circuit configuration, some deviation is perfectly acceptable. Not so, however, in the case of LEDs being clustered into arrays and positioned closely together. In arrays, individual LEDs are also connected-up to form sub-clusters, which causes them to elec-

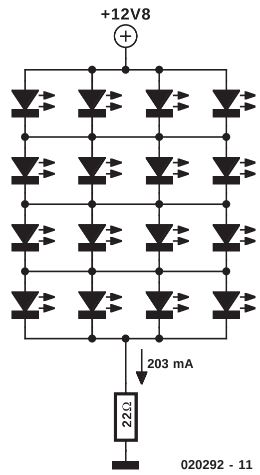


Figure 1. LED array using just one series resistor.

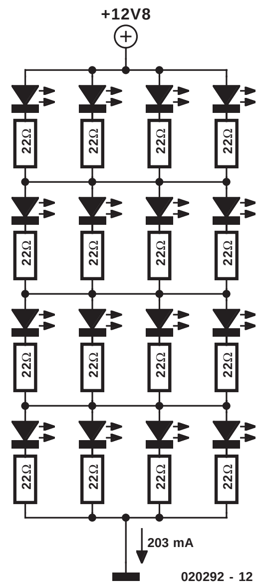


Figure 2. Here, each LED has its own current limiting resistor.

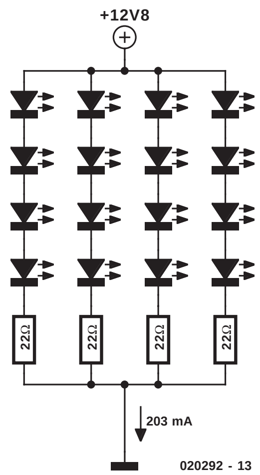


Figure 3. Four independent strings of LEDs, each with one series resistor.

trically 'compete' with each other. A tolerance of 150 mV in the forward voltage specification is not unusual. A finer division and classification is simply not economical. If optical performance tolerance is the yardstick, for example, in the design of multdigit LED displays, LEDs need to be selected for luminosity by eye or by means of optical instruments. For pure lighting purposes, such a time-consuming selection process is not necessary.

Current tolerances

In general, three basic design variants are available when you want to cluster a handful of LEDs into an array which is to be used for lighting purposes.

Figure 1 shows the variant with the array powered through a single series resistor. A very workable solution which also functions with LEDs 'from the margin', i.e., having a forward drop tolerance of up to 150 mV between individual LEDs in the matrix. After all, a small rise in forward current is coupled to a proportional rise in forward voltage. In this matrix, some LEDs having the upper tolerance value will light less brightly than others with a lower forward drop. If the circuit is designed for 50 mA per LED, the forward current of individual LEDs will be between 40 mA for LEDs with the highest, and 62 mA for LEDs with the lowest forward drop.

The advantages and disadvantages of the circuit shown in Figure 1 may be summarized as follows:

When one LED fails, the others will continue to work, albeit with a shorter life expectancy.

The design s simple — only one series resistor is required. The LEDs being connected up in series and parallel, the PCB design remains uncluttered.

Failure detection will only work in case the entire array fails. In the automotive industry, legislation dictates failure indication for direction indicators, which can not be realised using this type of array because the series resistor can not be employed as a sensor.

In **Figure 2**, the LEDs are configured in a different kind of matrix marked by individual series resistors for each LED. Obviously, the resultant PCB will be large and densely populated. The series resistors with each LED makes it less dependent on tolerances of other LEDs. Also, the current 'band' is narrowed down: 46 mA (min.) to 53 mA (max.). The series resistors allow the current through each LED to be dimensioned with sufficient accuracy. This variant is the best for room lighting because failure of LEDs may be observed and their replacement evaluated for cost and effort. Advantages and disadvantages of the circuit:

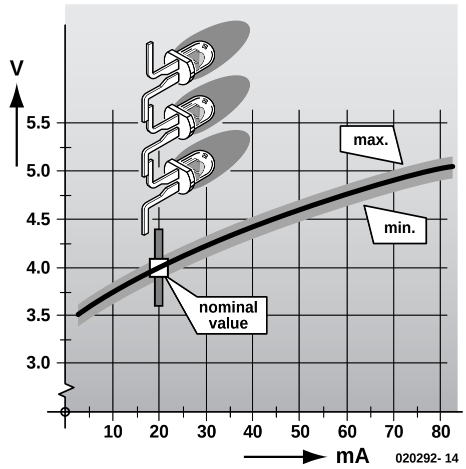
1. When one LED fails, the others continue to function without increased death risk. The total luminosity achieved by the array will hardly suffer.

2. Because failure detection of individual LEDs is far to complex, such a function may be implemented using current/voltage detection on the power regulating device.

In **Figure 3** we've sketched a series configuration with a series resistor for each LED. There are no junctions that force a defined voltage upon each LED row. The four LED columns operate independently. Because the differences in forward voltage remain relatively small at the same forward current (as compared with forward current differences at the same forward voltage), measurement results obtained from this constellation will resemble those of the matrix circuit with resistors for each individual LED. However, the final circuit and PCB layout will be much simpler than with the circuit in **Figure 2**. The series connection into multiple strings does have a disadvantage which will be discussed further on. In a prototype of this circuit, a minimum and maximum current was measured of 47 mA and 53 mA respectively.

The string circuit does not have 'current diversion' abilities because there are no junctions of parallel connected LEDs. If one LED fails, so does the entire string — an obvious disadvantage for room lighting because the resultant light intensity will drop considerably. Also, it makes no sense to replace the entire array just because one LED has failed.

In case of the automotive industry, suitability aspects look rather different. Failure of an LED column is not worrying because the warning indicator functionality is still warranted even at reduced light intensity. Also, the life expectancy of the LEDs in the other columns is not affected by failure of one string. A simple failure detection may be



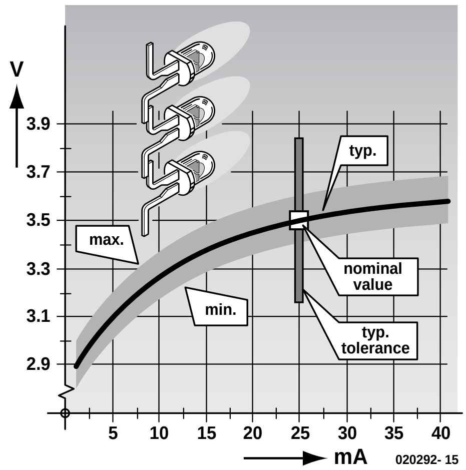


Figure 4. Design data of blue and white LEDs.

Table 1				
Blue LED TLHB4401	**Maximum values**			
Reverse voltage		UR	5	V
Forward current (DC)	at U_F = 4.0 V	IF	20	mA
Forward current, 10% on, t_p < 10 µs	at U_F = 5.2 V, T_A < 60 °C	IFSM	100	mA
Power dissipation		PV	100	mW
Operating temperature		TA	–40 to +100	°C
Thermal resistance		RthJA	400	K/W
Blue LED TLHB4401	**Nominal values**			
Luminosity		IV	32	mcd
Beamwidth	at I_V = 100 %	φ	±10	Degrees
	at I_V = 50 %	φ	±30	Degrees
Wavelength	at maximum I_V	λ	430	nm

realised by employing the series resistors as current sensors.

When one LED fails, so does the entire string. The other strings, however, continue to work normally and the life expectancy of the LEDs in them is not affected.

When the array is used as a direction indicator, brake light or reversing light, failure detection is relatively straightforward since the few series resistors may be used as current sensors.

Conclusion: for all designs, it is important to realise what happens when one LED fails. Current overloading coincident with excess chip temperature causes a LED to be electrically damaged to the extent that an open-circuit occurs. In the matrix circuit shown in Figures 1 and 2, this has dire consequences because the 'adjacent' LEDs are forced to operate at worse conditions. In the row that contains the failed LED, the other paralleled LEDs are strained to handle the current of the failed LED. The fewer rows and columns that make up the array, the graver the effects of the increased current. This is acceptable when the LEDs are operated way below their maximum current specification which, in turn, reduces the changes of failure. Alternatively, the number of LED columns is such that the 'deviation' current hardly presents an extra load to individual LEDs, as compared with the consequences of the 150-mV tolerances.

Boosting brightness

Table 1 shows some typical design data for a blue LED. By implication, it shows the LED will light at 100% at a continuous current of 20 mA. The LED intensity may be raised when the current is increased in a certain way. This is done, for example, in remote controls in order to increase their range. However, simply increasing the continuous direct current through the device will cause its (fairly imminent) death. To achieve higher luminosity, the LED should be operated in pulse mode.

By pulsing an LED at 100 mA for 10 µs and a repeat rate of 1 kHz, the radiated intensity may be increased by a factor of 10 whilst the maximum case temperature of 65 p is used (which also boosts the directivity). If a constant current of 20 mA is set up, the LED may be on all he time. If, on the other hand, a much higher current is sent through the LED, the 'on' time should be reduced considerably. This allows the LED to cool down during the (relatively long) 'off' time. Some DC step-up regulator ICs have a shutdown input to which a PWM signal may be applied to create a brightness control. The important aspects to keep in mind are the maximum operating temperature of the LED and its maximum power dissipation. Although the datasheet indicates a value of +100 °C as a purely physical value, a more realistic value of +60 °C should be observed if the device is to be operated in the SOA (safe operating area). At +100 °C, the LED already lights with considerably reduced intensity.

Tolerances

The typical forward voltage of a white LED is of the order of 3.5 V ±10%. This is a nominal value often found in datasheets. The variation range is shown in **Figure 4**. At 20 mA forward current, the voltage drop across the LED may lie between 3.15 and 3.85 V. If this white LED is operated in current sensor mode using an uncalibrated but regulated voltage, the forward current will vary across an even larger range. This variation of the forward voltage causes considerable variation of brightness variance between individual LEDs.

To operate single or multiple white LEDs, regulator ICs like the LM2791/2, MAX1698, MAX1848, MAX1912, LT1618, LT1932, LTC3200, LTC3400 and LM2585T-ADJ are available. The use of the latter IC was demonstrated in the article

'White LED Lamp' in the July/August 2000 issue of *Elektor Electronics*. Its function in this the circuit is that of a boost regulator in control of a 10-element LED array. A particularly interesting IC is the LT1618 from Linear Technology because it offers simultaneous current and voltage feedback, plus features a disable input for LED brightness control. Besides, the LT1618 is housed in a space-saving MSOP-10 case and capable of switching at 1.5 MHz, which considerably reduces the component volume as compared with the venerable LM2585T-ADJ.

Many of these regulators may be used in current-sense mode, which has a positive effect on uniform luminosity. After all, the control of the bias current is more accurate and takes into account the specific forward voltage of each LED, whether 3.15 V or 3.85 V.

However, the bias current graphs do not account for the maximum power loading of LEDs. LEDs may only be pulsed using forward currents greater than 25 mA (nominally), when complying with the following constraints allowing operation up to 100 mA or in some cases 50 mA: switching frequency 1 kHz, mark/space ratio 1:10 and 25 °C ambient temperature.

Some manufacturers of super-bright LEDs select devices for uniform luminosity within ±1.6 mcd, specially for use in traffic indicator equipment. To avoid blending effects, the selection is purposely not for maximum brightness as you might have expected. In traffic lights, Indium-Gallium-Nitride LEDs are employed with a luminosity of 'just' 180 mcd. By contrast, LEDs with a luminosity of 9,000 mcd (!) (like the L5-W54S-BS) are preferred for room lighting, solid-state torches and so on.

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