SOURCES
High-radiance LEDs have linear response to analog inputs

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For optimum performance, a fiber-optic communications system depends heavily on a light source that can efficiently couple maximum power with adequate bandwidth into the optical fiber. Its wavelength should suffer only minimum attenuation in the fiber and should match the maximum responsivity of the photodetector.

Both light-emitting diodes and laser diodes are highly compatible with doped silica fibers and silicon photodetectors, so the decision which to use depends on other system requirements. LEDs, unlike laser diodes that suffer modal instability, can produce a much more linear power output, making them better suited for analog applications. They also cost less and are much less affected by temperature changes than laser diodes. On the other hand, they are not as fast, and their output power is spread over a wider angle, so that less of it succeeds in entering an optical fiber.

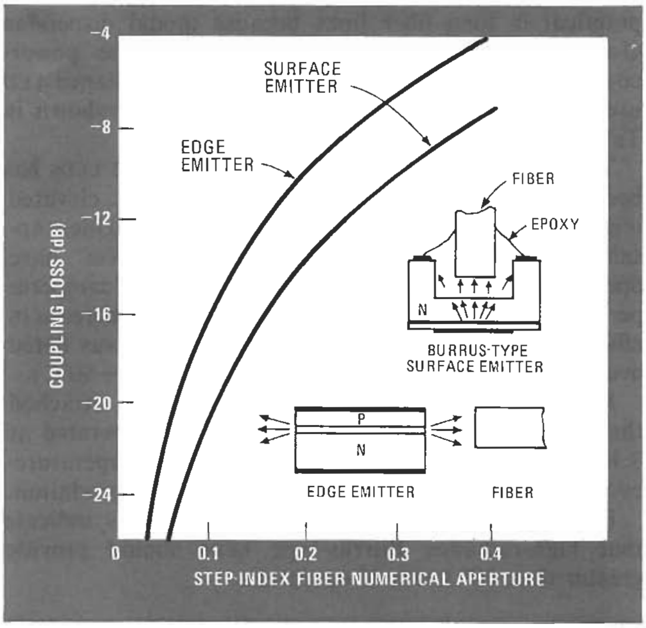
To be more specific, gallium-aluminum-arsenide LEDs produce light at high efficiency (10%) at an 840-nanometer wavelength where the attenuation of silica fiber is as low as 2 decibels per kilometer and the responsivity of silicon photodetectors is a high 0.55 ampere/watt. Their output power is 5 to 20 milliwatts either in a 120°-by-40° beam (edge-emitting type) or in a lambertian pattern (surface-emitting type). Fiber coupling loss is high—for a fiber with a numerical aperture of 0.14, losses are about 14 dB for edge emitters and 19 dB for surface emitters. Only the best (and most costly) LEDs can be modulated at rates of 200 megahertz.

Typical laser diodes, on the other hand, can be modulated at speeds up to 1 gigahertz. They also produce from 5 to 20 mW over a 40°-by-10° beam with a loss of about 3 dB when coupled into a fiber with a numerical aperture of about 0.14.

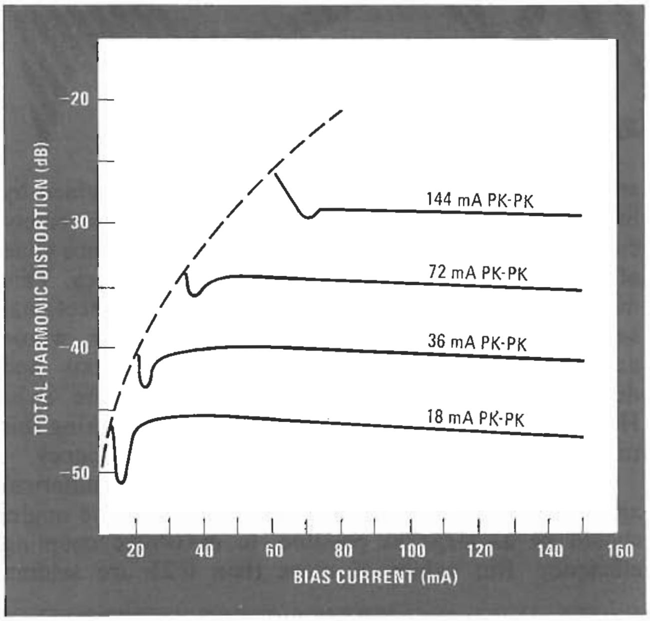
Different types

High-radiance LEDs designed for optical communications are, as already indicated, either surface emitters (usually those of the "Burrus" type first developed at Bell Laboratories) or edge emitters (developed at RCA Laboratories). Although the edge emitter is inherently capable of better coupling efficiency (especially with a cylindrical lens) than a surface emitter, the inferior coupling efficiency of the surface emitter is more than compensated for by its higher total radiated power. Both are shown in Fig. 1.

The most promising use a double-heterojunction design, being fabricated by sandwiching a thin active



1. Charting coupling loss. Power coupled from a LED into an optical fiber depends on the numerical aperture of the fiber. Typical LEDs produce light over very wide beam patterns that make the fiber's light acceptance angle and placement critical.



2. Determining distortion. Source linearity is very important in analog systems. From curves taken at different modulation depths for several BNR LEDs, it is possible to determine the optimum dc bias for minimum total harmonic distortion.

TABLE 1
HIGH-RADIANCE LED CHARACTERISTICS

BNR device	External quantum efficiency (%)	Radiant intensity (at 150 mA dc) mW/sr	Response time (10–90%) (ns)	3 dB electrical bandwidth (MHz)	Spectral half width (nm)	Max. power launched into 0.2 numerical aperture step-index fiber, 150 mA dc (mW)
(A)	7	3	14	25	40	370
(B)	4.6	1	4	88	45	250
(C)	2.3	2	7	50	45	125

TABLE 2
COUPLING CHARACTERISTICS OF HIGH-RADIANCE LEDS

Characteristic	Fiber			
	BNR 7-1-A	BNR 7-2-A	Corning	BTL
Numerical aperture	0.20	0.22	0.19	0.22
Core diameter (μm)	100	100	85	50
Type	Step	Graded	Step	Graded
Coupled power (μw)	370	280	340	140

Current density = 4.5 kA/cm^2 Emitting area = 65 μm diameter

layer of gallium arsenide between two layers of GaAlAs that absorb no energy and (in the case of edge-emitter types) act as light guides. The peak emission wavelength of double-heterojunction GaAlAs LEDs can be varied from 850 nm to 780 nm by increasing the aluminum content with no significant change in device efficiency. This allows the system designer to match fiber and source for minimum attenuation. Both peak emission wavelength and half-power spectral width show little change with drive current.

On the assumption that a fiber-optic-system designer opts for a LED source, the best device depends not only on total coupled power but also on speed, reliability, spectral width, cost, and (in analog applications) linearity.

Tradeoffs

Harmonic distortion curves are shown in Fig. 2, and other performance characteristics of typical high-radiance LEDs are listed in Table 1. The three devices illustrate the tradeoff between efficiency and speed of response. Device A is optimized for total light output and device B for speed of response, whereas device C represents a compromise between the two. By reducing device capacitance, LEDs with response times of less than 2 ns have been fabricated.

These devices all have nearly linear light-versus-current characteristics up to 250 milliamperes in continuous operation and a 1-ampere, 10-microsecond pulse in pulsed operation at 10^5 pulses per second. The temperature dependence of the light output of these devices is typically 0.2% per °C.

In wideband communication over long distances, chromatic dispersion in the fiber may limit repeater spacing. Because the velocity of light varies with wavelength, the different spectral components separate out as the light propagates down the fiber. The optical bandwidth-length product at which this effect becomes significant is determined by the spectral width of the light source. The spectral half-width of a typical BNR LED, for example, is 35–45 nm at 840 nm. This would limit the optical bandwidth-length product to 100–140 MHz-km.

The optimum coupling efficiency between a surface-emitting LED and an optical fiber is usually obtained by butting the fiber to the emitting area. But extremely close butting is unnecessary if the light-acceptance cone of the fiber encloses all of the LED emitting area. This means that the ratio of source-to-core cross-sectional area can be optimized for graded-index fiber, whose acceptance angle is largest at the fiber axis and decreases with increasing distance from the axis. However, for a close-butted step-index fiber, making this ratio less than 1 does not improve coupling efficiency.

It would seem to follow from this that the numerical aperture of a fiber, which defines its acceptance angle, should be as large as possible, to maximize coupling efficiency. But values of more than 0.25 are seldom practical in long fiber links because modal dispersion also increases with numerical aperture. The power-coupling characteristics of a typical high-radiance LED used with several types of low-loss fibers are shown in Table 2.

The reliability of high-radiance Burrus-type LEDs has been investigated at room temperature, at elevated temperatures, and during temperature cycling. Unencapsulated devices, following a qualification test, have operated for longer than 3,000 hours at 3 kiloamperes per square centimeter and 130°C without any decrease in efficiency. Moreover, no change in efficiency was noted over temperature cycling (20 cycles, −40° to +80°C).

Packaged encapsulated devices with fibers attached that passed further qualification tests were operated at 3 kA/cm^2 and 25°C for 10,000 hours and temperature-cycled (5 cycles, −30° to +30°C) without degradation.

Extrapolations from accelerated aging tests indicate that high-radiance Burrus-type LEDs should provide greater than 10^5 hours of operation.