cytes excepting during 1970 [16–20 percent]. Most irregularity was simply the absence of pairing for two chromosomes, hardly an abnormal condition, for many cells from the same anther illustrated complete pairing at metaphase I and normal separation at anaphase I." These results based on several hundred plants corroborate the limited data given earlier.

As much as I agree with Parnell that random behavior of chromosomes and environmental stress may indeed be correlated and that polyploids have possible selective advantages in extreme environments, nonrandom distribution of chromosomes during mitosis in primary roots and during meiosis in microsporocytes of plants with supernumerary chromosomes indicates genetic control.

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Reference

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Optical Communications

In "Optical communications research progress" (*1*), Miller states, "The scale on which an optical intercity system will become useful is in the range above 500,000 two-way voice channels, or equivalently over 5,000 two-way video telephone channels. . . ." My own estimates indicate that there is a reasonable chance that some form of laser communication system would be competitive with waveguide or coaxial cable systems at about the 1000 channel level by the late 1970's.

As an example, let us consider a system that is based on the helium-neon laser. [Miller dismisses the usefulness of such lasers. He states, "It's main drawbacks are size (20 to 100 cm long) and limited device life."] For geometrical parameters we will use Miller's example of a 100-beam space-multiplexed system guided by 8-inch (20-cm) diameter focusing elements, 100 meters apart, with pulse code modulation repeaters 50 km apart. Then if we wish the total capacity to be 3000 videophone channels (of which 500 would be kept in reserve to allow for component failure), we would need to modulate each beam at 360×10^6 bits per second, well within the laser art. A loss of light of about 1 percent per focusing element and a requirement of 10^4 counted photons per bit (both quite conservative assumptions) implies that each beam would require less than 1 mw of laser power. Thus, we might use 100 helium-neon lasers of 1 mw output at each repeater. Such lasers cost about $300 each, and laser tubes having an 0.8-year lifetime would cost about $25 if they were mass-produced. Thus, the total laser cost over 25 years would be about $100,000 for each 30 (48 km) miles of system. This is only 3 percent of the assumed $100,000 per mile system cost. Since the extra channels would allow much replacement time for laser tubes that failed without the total capacity dropping below 2500 videophone channels and since the lasers would take of a volume perhaps 2 feet (0.6 m) on a side every 30 miles, Miller's objections appear invalid, and the helium-neon laser seems practical.

The cost of the rest of the repeater also seems low enough, even with very conservative assumptions. Each of the 100 repeaters would have circuitry in the same frequency range (360×10^6 bits per second) as television receivers and would be less complex. So a cost of $100,000 per repeater over a 25-year system life seems a conservative estimate. Then if we assume that solid state light detectors and modulators cost $500 each, the total cost of the repeater components, including lasers, would be $300,000, or 10 percent of the cost per mile.

Finally, if each 8-inch focusing mirror costs about $1000 (corresponding to $30,000 per mile) we are left with something on the order of $50,000 per mile for pipe. But this is the approximate per mile cost of a gas pipeline of appropriate (10-inch) diameter.

Space limitations prevent the discussion of (i) the many tradeoffs and auxiliary inventions possible that increase the likelihood that some system should be cost-effective and (ii) a probably superior system based on semiconductor diode lasers, cooled to liquid-nitrogen temperatures. My estimates imply that such a system would be cost-effective even with a transmission medium loss of 22 db/km, such as might be obtained with the use of lenses spaced 1 meter apart or with optical fibers (Miller states categorically that such a loss is too high).

The question might be asked, at this point, why one should believe that my estimates are more realistic than Miller's. I think the answer is that one should not have to believe anyone's estimates. The government should allow total competition to prevail in the manufacture of high-capacity telecommunication systems. Then it would be worthwhile for the rest of the huge (and now underemployed) electronics industry to explore the feasibility of long-distance laser telecommunications. The prospect of multibillion-dollar sales should draw enough venture research now, research that would, in any event, have to be done sometime.

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Reference

1. S. E. Miller, *Science* **170**, 685 (1970).

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The situation with respect to the anticipated commercial usage of optical systems in which hard lenses or mirrors are employed remains as reported in the original article. However, advances in the art that have occurred since that article was submitted (April 1970) enhance the possibility of a variety of optical systems in which fibers will be used, including intercity systems with communications capacities smaller than cited in my article. These advances in the art include (i) achievement of research models of gallium-arsenide injection lasers which operate continuously at room temperature, and (ii) realization of single-mode optical fibers with observed transmission losses as small as 20 db/km at 6328 Å wavelength. It is still not possible to anticipate exactly when these improved components will be developed to the point of reproducible manufacture, and the cost competition with coaxial and other systems remains to be accurately evaluated. However, low-loss fibers clearly introduce the possibility of earlier use of optical wavelengths, and a vigorous research exploration is now under way not only at Bell Telephone Laboratories, but also in other companies in England, Japan, and the United States.

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Optical Communications

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