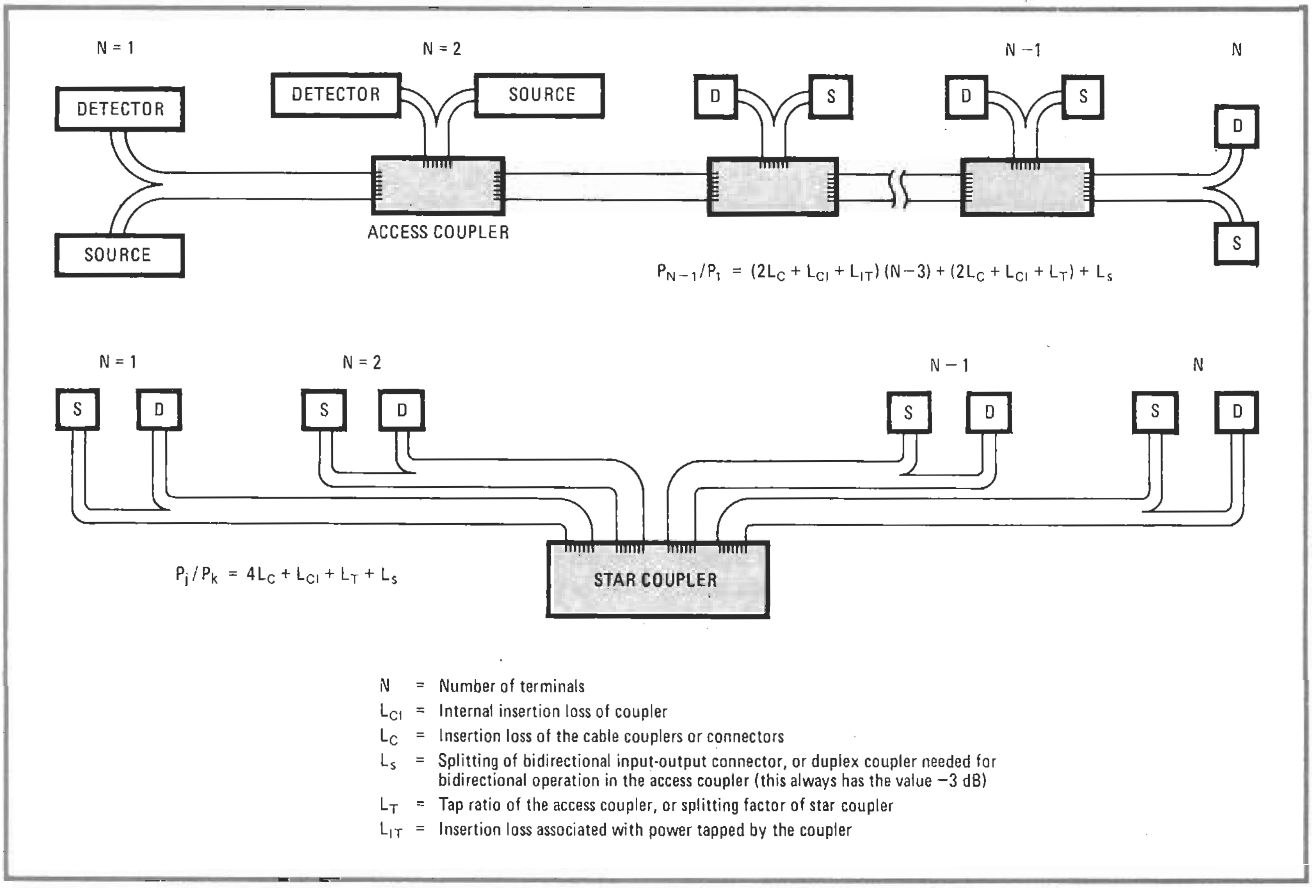
In systems with 20 or more terminals, star couplers outperform 'tee' types

by M. K. Barnoski
Hughes Research Laboratories, Malibu, Calif.

In a multiterminal fiber-optic communications network, light signals have to be tapped at intermediate points along the data bus. The problem is how to tap them most efficiently.

Currently, two fiber-coupling configurations are used for such data-distribution systems, one employing access or "tee" couplers and the other using a radial-arm or star coupler. The equations in Fig. 1 enable their performance to be compared in terms of the loss introduced between pairs of remote terminals by the distribution system itself. These equations show that, in a serial system with access couplers having a constant tap ratio, the optical power decreases as the signal travels through more couplers, while in a parallel system using a star coupler, the optical power is independent of the pair of system terminals being considered.

The distribution-system losses (omitting fiber loss) for both serial and parallel configurations are plotted as a function of the number of terminals in Fig. 2. Several different sets of parameters were employed for each format, including the use of multimode-fiber bundles as well as single multimode fibers. As a limiting case, curves are included for both parallel and serial systems when all couplers and connectors are assumed lossless. In



1. Coupling comparisons. The difference in performance between a serial distribution system and a parallel system is partly due to the terminal-to-terminal loss introduced between pairs of remotely spaced terminals by the distribution network itself.

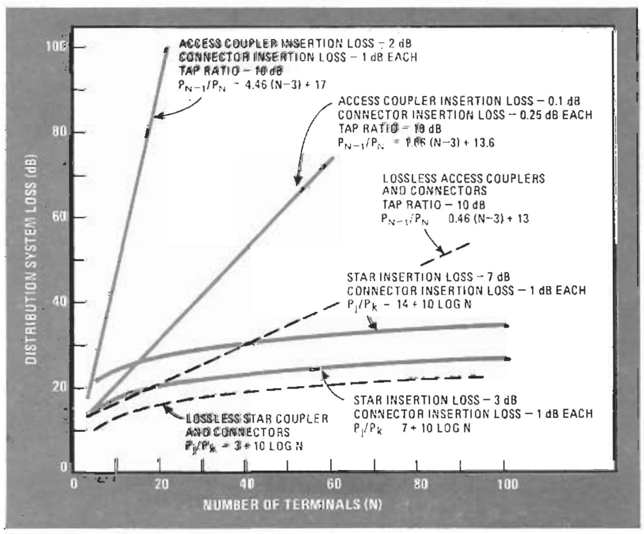
this idealized case, the distribution-system losses result only from dividing power among the various terminals.

The comparison clearly shows that, as the number of terminals in a system increases, the distribution losses of the serial format grows rapidly while those of the parallel format increase only gradually. This signal-level advantage further increases as higher-insertion-loss cable connectors and the access couplers are used, but is relatively insensitive to insertion loss of the star coupler. In a serial system based on fiber bundles, the minimum access-coupler and connector-insertion loss will be limited by the packing-fraction loss of the bundled fibers. As a result, the steep curve plotted in Fig. 2, which uses an access-coupler loss of 2 dB and connector-insertion loss of 1 dB, is very close to what can be expected from fiber bundles having good packing fractions.

Nevertheless, with low-loss connectors and couplers for single fibers, serial-distribution systems should be able to handle at least 20 remote terminals without consuming an unreasonable proportion of the available power budget. For fewer than 20 terminals, the power savings achieved by the star system are not so very large.

However, as more terminals are added and use more of the available optical power budget, the picture changes. Receivers in a serial system must have not only a large dynamic automatic-gain-control range, to handle both strong signals from adjacent terminals and weak signals from remote terminals, but also low enough noise levels not to degrade the weak signals.

Since the parallel system needs only a single mixing point, it doesn't suffer signal-level or dynamic-range problems. The more constant signal level available with parallel systems minimizes the complexity of both trans-



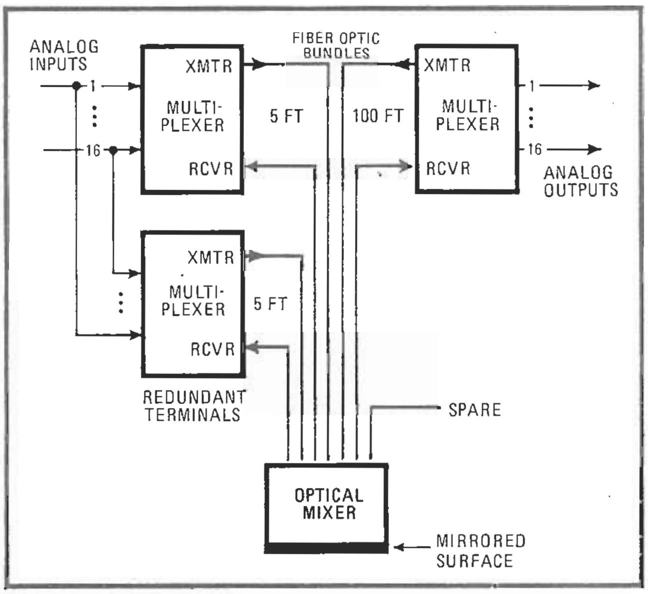
2. System losses vary. Several sets of parameters were used to plot the distribution-system losses as a function of the number of terminals. In the idealized case, distribution losses result only from the splitting power among various terminals.

mitter and receiver design. But the cost of this uniformity is offset by the additional amount of fiber cable needed. The star-coupled data bus, in essence, shortens the main bus length to a single-point mixer, but extends the length of each terminal arm.

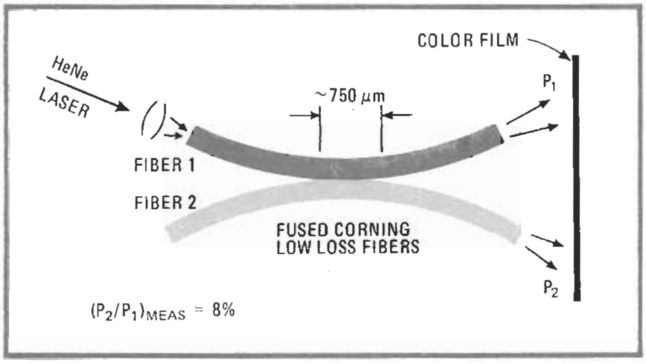
A star coupler or optical mixer was basic to a prototype, fiber-optic multiterminal aircraft data link for carrying flight control signals from cockpit to controls. The optical bus operated for the full duration of a 40-minute flight test aboard an Air Force C-131 aircraft without any detectable errors.

The system used three terminals (one for redundancy) to multiplex and demultiplex 16 analog electrical signals (Fig. 3). It was "wired" with Corning fiber bundles, each containing 61 multimode low-loss glass fibers loosely packaged in an extruded polyvinyl chloride jacket. Two of these bundles entered each terminal, one for the transmitter and one for the receiver. Maximum terminal-to-terminal spacing was about 100 feet, but since each terminal in the system monitored its own transmission, the longest path traversed by an optical signal was 200 ft.

Commercially available components were used: gallium-arsenide light-emitting diodes as sources, silicon p-i-n devices as photodetector/amplifiers, and modified BNC connectors for input and output coupling. Nominal optical output power incident on the receiver photodiodes was −28 dBm. Source power was about +11 dBm. Although the optical bus was designed for a 10-megahertz bandwidth, the actual information transfer rate was determined by other system considerations and



3. Flight-tested. A three-terminal redundant system for carrying flight control signals aboard a C-131 aircraft used a star coupler and seven fiber bundles to multiplex and demultiplex the 16 analog electrical fly-by-wire signals.



4. Mixing modes. One method of coupling light between single fibers is to bring the cores of the optical fibers so close together for a selected interaction length that the light modes of one fiber mix with those of the other fiber.

was only 0.5 megabit per second for all three transmission systems evaluated.

Although fiber bundles were used in this feasibility demonstration, a single-fiber configuration could service a network of 427 terminals (61 fibers times 7 bundles). For such a network, the distribution loss extrapolated from Fig. 2 would be 40 dB, assuming 1-dB cable connector loss and 7-dB star-coupler insertion loss.

However, in systems using a single fiber as a communication channel, it should also be possible to use serial distribution of data, since packing fraction loss is no longer a factor. Of course, adequate techniques of coupling between single fibers would first have to be developed.

One possible approach to fabricating such an access coupler (Fig. 4) parallels the techniques used in integrated optics. In essence, two multimode fibers are laid side by side and fused together for part of their length, and this fused region subverts (as it were) the tendency of each to keep all its light to itself. For in this situation, since light propagates in these fibers in many modes, the modes in one fiber mix with those in the other, producing coupling between mode groups. The exact degree of coupling is determined by the core-to-core spacing and the interaction length (the fused region). When one end of one fiber was excited with a laser beam, radiation was observed from the opposite ends of both fibers. For the coupler used in this experiment the ratio of power emitted from the access channel fiber to that of the main channel was 8%.

It's worth noting how neatly this approach avoids the need for the critical mechanical alignment tolerances that are essential in access couplers using conventional optical components like lenses and beam splitters. In fact, several research laboratories are currently investigating fabrication processes for such a "tee" fiber coupler. The preliminary results indicate that the insertion loss of single-strand access couplers could come down to about 0.1 dB or 0.2 dB, so all that remains is to produce practical low-cost versions of these experimental devices. □