A SHUNTED RING FIBER OPTIC NETWORK TOPOLOGY PROVIDING FAULT DETECTION, ISOLATION AND CIRCUMVENTION

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ABSTRACT This paper describes an electro-optic and all optical implementation of a novel shunted ring network topology which uses optical waveguide shunts to bypass faults in ring networks. This technique eliminates the need for costly bypass switches and their related deficiencies. "One-by-N" tree couplers are used as the fanout mechanism from an LED or laser to send optical signals to a primary fiber and "N" shunt fibers. These shunt fiber waveguides can be "switched" into the active network when the optical signal in the primary fiber drops below a prescribed level. This permits rapid reconfiguration around a failed node or primary fiber path and minimizes or eliminates the loss of data. In a near term implementation of the concept, the signals from the input primary and shunt fibers are converted to electrical form with standard PIN photodiodes and the signal level is analyzed. If the signal falls below the preset threshold, the output from the shunt fiber(s) is electronically switched into the network node to restore robust network operation. The power budget to determine the number of successive nodes which can be bypassed is identically that of a 1 x N tree network permitting any number of bypasses within the link margin.

BACKGROUND The application of fiber optics technology to local area networks has been impeded by both technological and economic factors. This is especially true for the application to avionics. The fiber optic system must provide clear life cycle cost advantages and performance benefits which greatly exceed those of a comparable wire system if the technology is to be selected as an integral part of the avionic system during the development phase of an acquisition program.

Manufacturers are comfortable with copper cabling and connectors even though this technology does pose reliability and maintenance problems. Fiber optic hardware is much more expensive than their electrical counterparts on a piece-part comparison and the reliability of the components is unproven especially in avionic environments. Fiber optic connectors are perceived as difficult to install, maintain, and repair. Test or repair equipment is costly and additional training is required. There is fear that a fiber or component failure can bring down the entire network and most commercial component standards are inadequate for aircraft. These risk items drive most program managers from selecting the rapidly advancing fiber optics technology for a new platform.

The advantages most readily accepted for fiber optic systems are:

- Very high bandwidth (Unachievable with wire)
- EMI/EMP immunity (Without the need for additional shielding)
- Weight/volume/cost savings over wire for equivalent high bandwidth applications.
- Elimination of spark induced fire hazards.

The decision to use fiber optics in a new platform would be much less risky if the fiber optic networks provide benefits over and above those listed above especially if the benefits are unachievable with wire networks or the most commonly used fiber optic topologies. The projected weight and volume savings alone however may not justify the risk associated with the application of fiber optics technology to a new aircraft unless the fiber optic interconnect is at least as reliable as existing copper wire interconnects or provides other significant advantages. Shunted ring networks can provide such benefits and they are listed below:

- Multiple fiber channel redundancy without the weight, volume, cost, or performance penalties of alternative wire or fiber approaches.
- Built-in fault prediction, isolation, and circumvention.
- In-flight diagnostics and real time reconfiguration of the cable plant.
- Elimination or minimization of data loss during reconfiguration.
- Compatibility with all existing and proposed multi-mode and single mode optical fiber and component technology including plastic fiber.
- Compatibility with the most commonly proposed network protocol standards.

RING NETWORK TOPOLOGY The Ring network topology utilizes an optical source (a laser or LED) and photodetector(such as a PIN photodiode or an avalanche photodiode) at each terminal in the ring. In the repeater mode, when the data is not addressed to the terminal, the photodetector detects the incoming signal, converts it to an electrical signal and then regenerates the optical signal with the optical source for retransmission to the next terminal. When the data is addressed to a specific terminal, the photodetector also serves as the means for extracting optical data from the network by converting it to electrical form for use by the terminal. If one examines this topology, it quickly becomes evident that the entire network consists of a series of point-to-point fiber optic links with a source on one end of the link and a photodiode on the other end and electronics in between at the terminal. (See Figure 1) Thus a major element in the power
budget equation budget, coupler loss, which is a power dividing device used in star or linear network topologies is eliminated. This arrangement permits the use of low sensitivity and low dynamic range receivers since only the next adjacent terminal must be accessed where the optical signal is regenerated with an optical source. This permits the use of reliable low power sources as well as low sensitivity and dynamic range receivers. This topology is ideal for networks with a large number of terminals and can be easily expanded. The margin built into this design can be utilized to good advantage in adverse environments such as military, automobile or factory applications.

**COUNTER-ROTATING RING TOPOLOGY**

While providing the advantages listed above, the point-to-point nature of the simple ring topology presents major reliability concerns since a single point failure in either the optical, electronic, or power supply elements can cause a failure in the entire ring. This failure mode is inherent in serial channels with no redundancy such as the string of Christmas tree lights of old which all failed after the link was opened by a “burned-out” bulb. Counter-rotating rings are the current solution used to prevent a total failure of a fiber optic ring network caused by a single point component failure. Figure 2 shows the counter-rotating ring topology. Totally redundant hardware (transmitters, receivers, fibers, power supplies and/or a bypass device) can be used to obtain fault tolerance in such a ring network. The commercial Fiber Distributed Data Interface (FDDI) standard specifies the use of a dual redundant counter rotating-ring with optical bypass switches providing loopback capability to assure reliable ring operation.

Electro-optic switches are single mode devices and are lossy (typically several dB/cm) and low loss multimode nonmechanical devices are not readily available. The lack of a proven bypass technology for FDDI poses problems for aerospace application. Even if a proven bypass switch were available to circumvent failed terminal nodes, the counter-rotating ring topology is inherently limited to a single fiber break for continued network operation with total interconnectivity. Two fiber breaks permit continuous operation of portions of the network but may cause segmentation so that all the remaining nodes may not be able to communicate.

In most ring networks, such as FDDI which use this counter rotating ring topology to circumvent faults, a bypass switch is used at each terminal to reconfigure the network in the event of a fiber or component failure. These intrinsic coupler losses plus connector losses which add in a linear manner limit the number of successive nodes which can be bypassed before the link power budget is exceeded.

**BYPASS SWITCHES** The Optical-bypass switch is probably the most critical element in an aircraft FDDI network since it is required for both test and fault circumvention purposes. It is required to overcome failures in the active electro-optic circuitry or the optical fibers. This device must be the most reliable component in the system. The most common bypass switch technologies are electro-mechanical, solid state, or electro-optical.

Most commercial switches utilize an electro-mechanical element, such as a spring loaded galvanometer mirror, to deflect the optical signal from one fiber into another once power is lost. Other electro-mechanical approaches use magnetic or piezoelectric drivers to physically move a fiber to align it with different output fiber ports.

Other electro-mechanical approaches for switching use magnetic or piezoelectric drivers to physically move a fiber to align it with different output fiber ports. Most of these devices have very slow response times (on the order of milliseconds) causing considerable loss of data during the switching process. The loss of data increases as the data rate increases and a gigabit per second network would lose a million bits of information during a one millisecond switching period. Electro-mechanical switches are also rather bulky, expensive and environmentally sensitive making them very impractical for aircraft use. Since they are mechanical in nature, they can pose major reliability concerns operating in an aerospace environment subject to temperature and pressure extremes, shock, and vibration. Rather ingenious low mass spring activated silicon substrate mirror designs which appear to be rather rugged are being tested but the risk in the selection of these devices remains high since no flight test data is available.

Solid state switches have been prototyped which utilize beam steering caused by various optical phenomena and devices. These include electro-optic switches, magneto-optic switches, acousto-optic switches, photo-refractive devices, holographic and photolithographically defined diffraction gratings, polarization rotation switches, and liquid crystal switches. Most of these devices are designed for use with single mode fibers and laser light sources which are not specified in current local area network standards. Devices of this type are typically temperature sensitive, lossy, rather inefficient, slow and/or expensive. Because of the cost, speed, weight and volume limitations of optical bypass switches, this capability is only provided in a small percentage of commercial FDDI terminals which specify multimode fiber technology.

Another multimode bypass device has been proposed utilizes evanescent wave coupling from “bent fibers”. This approach offers an alternative to the electromechanical and solid state techniques described above but the devices are lossy and rather expensive. The packaging of these devices for severe environment is still an issue and the long term reliability of the packaged devices is questionable.

Opto-electronic switches use photodetectors to detect the presence of a signal (or lack thereof) and use a solid state element to switch the signal (now in the electronic domain) to an appropriate circuit for retransmission with LEDs or lasers. Much development is proceeding in this area for optical computing applications. Switching times in the nanosecond and sub-nanosecond range are achievable. The loss of power to activate the switch is a major concern if not properly implemented in a network. The reliability of the device can be extremely high when implemented with state-of-the-art microcircuit technology and silicon since silicon PIN diode and
microcircuit reliability is very predictive and has a well
documented reliability history in severe environments.

Bypass switch technology can prove to be the Achilles heel of
an aircraft fiber optic network since its operation is critical for
assuring reliable and sustained operation of the network in the
event of any hardware or power failure. Its proper operation is
also essential for test purposes since an improper test can cause
needless flight delays and maintenance actions. The commercial
data base on bypass switch reliability is sadly deficient since
only a small portion of commercial FDDI networks incorporate
the bypass function in the networks. The use of an unproven
bypass switch technology can actually detract from total system
reliability and cause catastrophic failure of the entire network.

A SHUNTED RING TERMINAL³ Fault tolerance can be
achieved in a network by the utilization of a terminal containing
a optical passive power splitter (e.g. a 1XN tree coupler), single
or multiple bypass fibers, multiple photodetectors, an optional
delay means, and appropriate logic circuitry serving to activate a
bypass action. (See Figure 3) The use of this configuration
provides a good trade-off between link loss, optical source output
power, receiver sensitivity and dynamic range, and overall
system reliability.

An optical signal is divided to a predetermined ratio through use
of the 1XN optical tree coupler. An equal power division is the
most cost effective approach for most applications. The output
from the primary fiber of the coupler is fed to the photodiode of
the Nth terminal while the other coupler fiber output serves as a
terminal bypass and is fed forward to the photodiode of the N+2
terminal. The bypass is an optical fiber which is totally passive
in nature so that a power failure at a given node does not affect
the rest of the network. The optical signal present at the primary
photodiode input is compared with a reference level determined
by the splitting ratio of the couplers and link margin. This
reference threshold which can be set after installation, can be
utilized to detect optical source degradation and/or connector
fiber breakage. The threshold guard band (e.g. 1 or 2 dB) is
established above the detector signal detection threshold. As the
signal approaches the lower level of this band one is alerted to
the possible onset of failure in the LED or deteriorating
connectors or fibers. The input level can be constantly sampled
and periodically recorded to give a lifetime history of the optical
input to a terminal and provide an alert to the need for
maintenance action on the link. The drop in the signal to a dark
level for a period which violates the encoding criteria signals a
catastrophic failure of the link by a failed source or a severed
fiber. Suitable logic can also be utilized to detect a babbling
terminal or a "stuck-on" LED or laser since these erratic or fixed
non-zero signals would also violate the transmission encoding
criteria. Once a failure is detected, the bypass photodiode input
from the bypass fiber is switched into the terminal and the failure
is taken off line and can be reported to the rest of the network for
corrective action. Multiple bypasses are easily possible and one
can observe that the bypass optical power margin calculation is
identically that of a 1XN tree network.

SHUNTED RING NETWORKS Time division multiplexed
networks (data buses) have provided significant advantages to
the avionics community by reducing the number of connectors
and cables between black boxes within an airframe. In addition,
these buses have provided significant life cycle cost savings by
permitting the rapid update and reconfiguration of the avionics
without rewiring the total aircraft. As the demands for improved
onboard functional performance of our aircraft has grown,
avionics boxes have grown in complexity and data throughput
while increasing in reliability. The increased integration of these
avionics systems to achieve improved system performance has
likewise caused the aircraft network traffic (data rate) to increase
dramatically. Loss of network function can severely impact
completion of the mission so the networks must be designed
with built-in reliability and redundancy.

Ideally, the lifetime of the wiring (including fiber optic cables
and connectors) on a commercial aircraft should equal or exceed
the structural life of the airframe (30-50 years). The components
must withstand cyclic environmental extremes of temperature,
pressure, shock and vibration on a daily basis. Selection of
unproven materials and technology for aircraft wiring and
connectors can result in costly rewiring of the total aircraft due to
environmentally induced and/or catastrophic failures. A recent
failure in a major optical fiber communication line operating at
extremely high data rates caused a telecommunications disaster in
the New York city metropolitan area. The loss of this major
information channel caused unprecedented disruption of the air
traffic control system and the Wall Street financial district's
network as well as the disruption of thousands of long distance
telephone calls. This failure was induced my maintenance
actions on the underground fiber cable. Other failures are also
being reported in other commercial fiber cables and repeaters as
they age. The fact that no redundancy was provided in the
physical layer of these high bandwidth digital channels was a
major cause of these failures. The hardware must be made
"maintenance-proof" so that the abusive treatment to which
aircraft fiber optic hardware is subjected during routine equipment
maintenance and repair must be factored into the original design.

A SINGLE BYPASS SHUNTED RING NETWORK
TOPOLOGY The terminal described above can be used to
implement an extremely fault tolerant shunted ring network (See
Figure 4) utilizing any network protocol including FDDI.
Multiple photodiodes and comparators are used to analyze
incoming signals from the primary fiber coming from the N-1
terminal and a bypass fiber from the N-2 terminal. The optical
power of the incoming signal in the primary and bypass lines is
analyzed and compared to the reference levels. If the signal in
the primary line triggers the fault detection criteria described
above, the signal from the bypass fiber coming from the N-2
terminal can be switched in, thus becoming the input signal to the
terminal. Note that in this network topology the coupler,
bypass fibers, and silicon logic switching serve to implement
the bypass function.

An optical delay line or electronic queue or buffer can be
incorporated in the detector circuit. This delay in the bypass
channel can be used in conjunction with a digital correlator to
provide an in-line bit error detection system when the terminals serve as repeaters and can serve to improve the performance of the network.

Switching speeds are dependant on the technology selected for the comparator and logic and nanosecond switching speeds are achievable. The selected input, the primary or bypass, is utilized by the terminal if the address of the data so designates (or the token is so designated) and data generated by the terminal is placed on the network via the optical source. If the selected input is not designated for use by the terminal, the terminal acts as a repeater to amplify the signal for transmission down the network.

A DUAL BYPASS SHUNTED RING NETWORK Figure 6 shows a dual bypass terminal. Note that this diagram shows the bypass fibers passing through the feedforward terminals for ease of illustration. In an aircraft installation, these fibers could be routed in different physical locations to increase network survivability. The bypass paths consisting of passive couplers and fibers are totally passive so that a power failure at a node will not cause a failure of the total network. Each terminal requires only one source (LED or Laser). These optical sources are the high priced items in a terminal and can be a reliability concern when operating at high output power and high data rate in extreme environments. This topology requires only one source to achieve multiple bypass capability and removes the source from the network in case of failure or can warn of source degradation with ageing. All detectors and fault detection circuitry (including the PIN photodiode) can be implemented with a monolithic silicon chip for a 850 nanometer system or with a very simple hybrid circuit using a separate photodiode. Integrated photodiode circuits have likewise been demonstrated at the longer wavelengths so that monolithic implementation is also possible at the 1300-1500 nm wavelengths.

To achieve a greater degree of fault tolerance than the commercial FDDI network with loopback, a multiple bypass scheme can be utilized. The 1X2 coupler utilized in the single bypass system discussed above can be replaced by a 1XN coupler. The coupler can be physically incorporated in the terminal for ease of manufacture or remotely located to enhance reliability and eliminate single point failure of this passive device if desired. The specific location of the coupler within the terminal can be used to advantage in providing flexibility in achieving fault tolerance and will be discussed later. Additional photodiodes and fibers are also utilized to achieve the required degree of fault tolerance. Thus in order to bypass 2 terminals, 3 photodiodes and fibers are required; and to bypass 3 terminals, 4 photodiodes and 4 fibers would be required, etc. The entire coupler/repeater could be placed on the I/O card of a computer as part of the FDDI network terminal.

In the dual bypass configuration, the primary fiber comes from the N-1 terminal. Bypass fibers from the N-2 and N-3 fibers are also entering the terminal. If the primary signal does not meet the required selection criteria, the bypass from the N-1 terminal is selected for use by the terminal. In the event that the bypass from the N-1 terminal is also out of specification, the secondary bypass from the N-2 terminal is selected for use by the terminal. Note that the signal leaving a terminal is fed forward to the N+1 and N+2 terminals in the network. A multi-fiber array connector and a ribbon cabling system would be ideal for this application by minimizing weight, volume and cost.

A three bypass (i.e. four detectors and fibers) network implementation is probably optimum for aircraft applications including flight critical systems. The loss budget for this configuration is that of a four port passive star system. Note that loss of any 3 successive terminals will not disrupt operation of the network. The multiple fibers can be contained in a single cable or ribbons or in individual single fiber cables or ribbons depending if the reliability concern is for fiber breakage within a cable or for damage to the entire cable.

FAULT TOLERANT SHUNTED RING NETWORKS WITH LOOPBACK The use of loopback to obtain fault tolerance can also be implemented with this concept. Figure 7 shows a fault tolerant terminal which uses loopback to prevent network failure if all fibers between a network are severed. A single fiber from the 1XN coupler is fed back to the N-1 terminal while the remaining fiber or fibers provide the feedforward bypass path(s) described above. Multiple bypass systems with loopback can also be easily implemented. The loopback may also incorporate multiple loopbacks to achieve any degree of redundancy in the counter-rotating signal if desired. Since failures are always detected by an operating terminal located one terminal downstream from the fault, an interleaved power supply system eliminates the need for battery backup in a terminal. For optimum safety these multiple interleaved supplies should be built to provide uninterrupted fail-safe power.

FIBER OPTIC COUPLERS A key element required to implement a shunted ring FDDI network for aircraft applications is a fiber optic coupler or power divider. This device splits the incoming fiber signal into the primary and bypass fibers of the network. The star coupler is a device which connects a number of input fibers to output fibers at a common node. Here, the optical power from an input fiber is divided, usually, but not necessarily on an equal basis, into all of the output fibers. The most common implementation of this concept is the fused biconical star. In this device, a number of fibers are twisted together under applied tension while laser energy is utilized to fuse the fibers together. The fused biconical area serves as a mixing region which couples the optical energy from any input fiber into all output fibers. The assembly is then packaged and connectorized. A tree coupler contains only one input fiber with multiple output fibers. Strain on the biconically fused region of biconical fused couplers over aircraft temperature extremes has caused reliability concerns with certain packaged couplers tested to date. To overcome this deficiency, optical biconical fused couplers can be monolithically packaged using "embedded fiber" technology to produce a very rugged coupler.

External devices attached to a fiber such as mirrored surfaces, and graded index mixing rods have also been utilized to fabricate reflective and transmissive star couplers, but in general, they have been inferior to the fused biconical devices.
Multimode and single mode ion diffused waveguide couplers are becoming available which may prove to be an attractive alternative to the fused biconical devices if full MIL-SPEC operation cannot be achieved. These devices currently cannot meet the low temperature aircraft requirements but novel glass fabrication technology is evolving which may be capable of meeting the full aircraft environment.

The most promising commercially available couplers for shunted ring networks utilize pyrolytically deposited silica waveguides on a silicon chip. These chips are very compact devices, and are compatible with integrated circuit technology. This type of splitter would best be suited to a hybrid circuit or multi-chip module (MCM) packaging approach. The losses are quite acceptable and the chips are available in both multi-mode and single mode designs.

**Comparison of Loss Budgets** Since both the commercial counter-rotating ring or shunted ring topologies could utilize the best possible sources and receivers, the topologies must be compared in terms of link loss, component availability and reliability, and total system reliability. A total life cycle cost analysis is required based on documented component test data.

The dual counter-rotating topology consists of a series of point-to-point links. To calculate a power budget, we will assume a total 2 dB worst case loss for each source-to-fiber connector and fiber-to-detector connector for a total of 4 dB. Also, a worst case 2 dB will be assumed for each in-line connector and each connector on the bypass switch. Based on these assumptions, the worst case link loss (L) from transmitter to receiver is:

\[ L = F + 4 + 2B(C) + 4B(B) + BE \]

where:
- \( L \) = Total link loss in dB
- \( F \) = Total fiber loss in dB
- \( C \) = Number of in line connectors
- \( B \) = Number of bypass switches
- \( E \) = Excess loss of each bypass switch in dB

The number of consecutive terminals which may be bypassed due to a failure is limited by this loss calculation. Every terminal will require a bypass switch and two transmitters and two receivers if loopback is to be utilized. Two fibers in a single cable or two separate single fiber cables are required. Only one fiber or cable break can be tolerated without assurance network operation since more than one break may cause segmentation of the network preventing communication between all remaining operational terminals.

A fiber optic cabling system for aircraft should include consideration of a growth capability for the introduction of single mode fibers. "Dark single mode fibers" can possibly be wired into the initial production of aircraft to provide for future bandwidth expansion without the need for rewiring at a later date as we evolve to broadband networks. The weight and cost penalty would be low if included in the basic cabling system especially with a ribbon fiber cabling approach. This option does not exist if a two fiber commercial FDDI type connector/cable approach is selected for use.

The worst case link loss between the transmitter and receiver for the shunted ring topology can also be calculated using the same connector losses which were assumed above. This loss is given by:

\[ L = F + 4 + 2B(C) + 10 \log(N)dB + E \]

where:
- \( L \) = Total link loss in dB
- \( F \) = Total fiber loss in dB
- \( C \) = Number of in line connectors
- \( N \) = Number of outputs from the 1XN coupler
- \( E \) = Excess loss of each 1XN coupler in dB

The number of consecutive terminals which may be bypassed due to a failure is limited by this loss calculation. Only one transmitter is required for each terminal and N receivers. Multiple detectors with a multiplexed output to a single amplifier is an option. A cable with N fibers, N individual single fiber cables, or alternative combinations are required for the system. N-1 fiber breaks can be tolerated without disrupting network operation and N-1 consecutive terminals can be bypassed. A 1XN coupler is required for each terminal and can be included as part of the cabling system or provided as a discrete packaged device.

**Discussion** The trade-off between the counter-rotating ring and shunted ring topologies for a new aircraft must be based on life cycle cost analysis and risk considerations. This is true since either topology will operate based on loss calculations if only one or two consecutive failures must be circumvented in non-flight critical systems. In this analysis, the cost, availability and reliability of multiple transmitters, receivers and a bypass switch for each FDDI terminal must be calculated vis-a-vis the cost, availability and reliability of a single transmitter, multiple receivers, passive couplers and silicon microcircuits in each shunted ring terminal. This analysis must also be performed with respect to the fiber and cabling system reliability during installation, routine use and maintenance actions.

If we assume the same number of in-line connectors and short fiber length for both cases as is typical of an aircraft installation and only a single terminal must be bypassed, the analysis shows relatively similar results. The counter rotating ring link shows a loss of 8 dB plus the fiber, connector and bypass switch intrinsic loss and the shunted ring shows a loss of 7 dB plus the fiber, connector and coupler intrinsic losses.

Where it is essential to bypass at least three consecutive terminal failures to obtain operation in flight critical systems, the shunted ring approach is clearly superior. For a three bypass network required for flight critical systems, the link loss added by the shunted ring concept would be 10dB versus 16 dB for a bypass switch FDDI type topology assuming equal numbers of in-line connectors and fiber loss.
If one examines the above loss equations, one will notice that the link losses increase in a linear manner for the ring using bypass switches and in a logarithmic manner using the fiber bypass of the shunted ring technology. One will observe that this logarithmic loss increase is the same as a star coupled network. Therefore if the link margin, the number of in-line connectors, the optical source power and receiver sensitivity are identical for a shunted ring and star coupled network, the number of bypasses which can be accommodated in the shunted ring are identically that as the allowable number of nodes in the star network. Thus, if one can build an 8 terminal star network with a given power budget, it would be possible to build a 7 bypass shunted ring network with the same sources, receivers, connectors and couplers.

**IMPLEMENTATION** The network interface electronics interface can be implemented in a hermetically sealed hybrid package (or MCM) containing five elements: (1) the protocol chip set (e.g., FDDI, ATM, SAE, SCI, etc), (2) the logic chip required to perform the fault detection, fault isolation, failure prediction, and switching (3) the optical photodiodes and other circuitry, (4) the LED or laser and driver circuitry and (5) a 1XN chip coupler. The logic chip can be implemented with an application specific integrated circuit (ASIC) or custom VLSI design with relatively inexpensive nonrecurring costs and extremely low recurring costs.

A ribbon cabling system containing a primary optical fiber, bypass fibers and dark fibers is ideal for this application since it minimizes size weight, and volume while providing ease of installation. Recent advances in multichannel silicon V-groove ribbon connectors are also ideal for this application. Both expanded beam and butt joint versions of this connector type are being developed. This cable and connector assembly which can be pre-terminated could be used as the output cable from each terminal's optical source. Individual color coded fibers in the cable assembly can serve as individual "hook up wires" and would "peel off" as dendrites from the main cable assembly at the selected bypass node and attach to the receiver connectors. Dark fibers (including dark single mode fibers) could be included in the cable assembly as spares. The primary and bypass fibers can be placed in separate ribbon cables and routed through the aircraft in different geographical paths for added survivability from battle damage.

**FUTURE DIRECTIONS** The shunted ring topology described above uses electronic repeaters and switches in the terminals to obtain the necessary gain and fiber switching. Both fiber and semiconductor optical amplifiers are receiving tremendous support by the telecommunication industry for "fiber-to-the-home" applications. All optical switching is also rapidly evolving for telecommunication switching and optical computing. These optical amplifiers and switching technologies can be used to construct shunted ring networks which operate in the all optical domain. (See Figure 8) Using these technologies advantages of shunted ring networks could then be extended to the local loop with a large number of users or utilized for CATV with techniques such as broadband, sub-carrier modulation.

Single mode broadband networks using this concept can also be applied to commercial aircraft entertainment systems or military platforms.

**SUMMARY** Shunted ring networks are currently being implemented with "off-the-shelf" hardware capable of operation in severe aerospace environments. The above described implementation alternatives provide for a low risk, cost effective introduction of fiber optic technology into commercial and military aircraft. These networks incorporate unparalleled fault tolerance, fault isolation and failure prediction and represent the state-of-the-art in highly reliable fiber optic networks. The built-in-test and in-flight dynamic reconfiguration of the fiber cable plant can provide enormous life cycle cost benefits and can be extended to a total fly-by-light aircraft. Shunted ring networks represent an extremely low risk approach to introducing this important dual use emerging technology in aircraft because of the availability, proven reliability, and cost of the required optical and silicon components. The concepts can also be applied to the next generation of broadband networks and optical computer backplanes.

**References**


RING TOPOLOGY

T = TRANSMITTER
R = RECEIVER

FIGURE 1

COUNTER ROTATING RING TOPOLOGY

FIGURE 2

SINGLE BYPASS SHUNTED RING TERMINAL

FIGURE 3

SINGLE BYPASS SHUNTED RING NETWORK

FIGURE 4
DUAL BYPASS TERMINAL

A DUAL BYPASS NETWORK

DATA FROM TERMINAL N-1
DATA FROM TERMINAL N-2
DATA FROM TERMINAL N-3

DATA TO TERMINAL N+1
DATA TO TERMINAL N+2
DATA TO TERMINAL N+3

DUAL BYPASS NETWORK

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DATA FROM TERMINAL N-1
DATA FROM TERMINAL N-2
DATA FROM TERMINAL N-3

TO TERMINAL N+1
TO TERMINAL N+2
TO TERMINAL N+3

FIGURE 5

FIGURE 6

"ALL OPTICAL"
DUAL BYPASS TERMINAL

FIGURE 7

FAULT TOLERANT NETWORK
(WITH LOOPBACK)

FIGURE 8