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Conversion of the Proprietary ROLM Inter-Node Link from Multimode to Singlemode Operation

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SUMMARY

Many NASA centers have selected ROLM®[1] Computerized Branch Exchanges (CBXs) as their standard telephone exchange. The ROLM 9751 CBX Model 70 with ROLM software release 9005 can inter-communicate as a "multi-node" system over a multimode fiber optic link of 450 to 6,000 meters. Singlemode fiber installations are not supported by ROLM. Two New Mexico-based NASA satellite ground terminals were already connected via a 6 kilometer singlemode fiber optic link. The ROLM Inter-Node Link (INL) was converted from multimode LED transmitters to singlemode laser transmitters and two ROLM CBX systems were interconnected using the modified INL. On activation, the system operated normally and has done so for six months. System testing indicates sufficient margin to drive 45 kilometers of singlemode fiber, an important benefit for widely separated facilities.

[1] ROLM® is a registered trademark of ROLM Systems

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I. INTRODUCTION

The NASA White Sands Complex (WSC) is a tenant of the Department of Defense (DoD) on the White Sands Missile Range (WSMR). The site consists of a space transportation testing facility operated by the Johnson Space Center (JSC) and two Tracking and Data Relay Satellite System (TDRSS) ground terminals operated by Goddard Space Flight Center (GSFC). For external telephone service, the original tenant, White Sands Test Facility (WSTF) is equipped with a fiber optic Main Point-of-Presence (MPOP) from the local exchange carrier (LEC), US West. Copper and fiber optic facilities serve the site telephony requirements from the MPOP.

The original TDRS ground terminal, White Sands Ground Terminal (WSGT), was provided a 600 pair copper facility from WSTF and used an analog Dimension®[2] branch exchange for site telephony. In 1989, NASA constructed the Second TDRS Ground Terminal (STGT) and selected a ROLM 9751 Model 50 with release 9004 software for the branch exchange. By that time, JSC/WSTF had already converted to a ROLM 9751 Model 70 two-node configuration with release 9004 software. STGT was not provided with a point-of-presence by the LEC. NASA contracted US West to install a 6 kilometer long 300 pair copper facility to provide external telephony service via connectivity to the JSC/WSTF ROLM system and the JSC/WSTF MPOP.

As part of an upgrade plan, NASA removed the leased, analog Dimension telephone system and installed a purchased, digital ROLM telephone system at WSGT in March, 1993. The telephone service configuration before these modifications is shown in Figure 1.

A 150MBPS fiber optic MPOP at WSGT was also activated as the external interface. This MPOP was derived from the 280MBPS JSC/WSTF MPOP. The WSC activation plan included installation of a 6 kilometer singlemode fiber optic Inter-Facility Link (IFL) between the two sites. This facility was designed for high data rate transfers of satellite data.

The STGT ROLM system was not capable of receiving high capacity T1 circuits over the 6 kilometer copper facility. Telephone use at STGT was increasing as the station integration and test activity proceeded. Additional capacity through the JSC/WSTF ROLM system was limited. It was decided to interconnect the two TDRSS facilities in a ROLM multi-node configuration.

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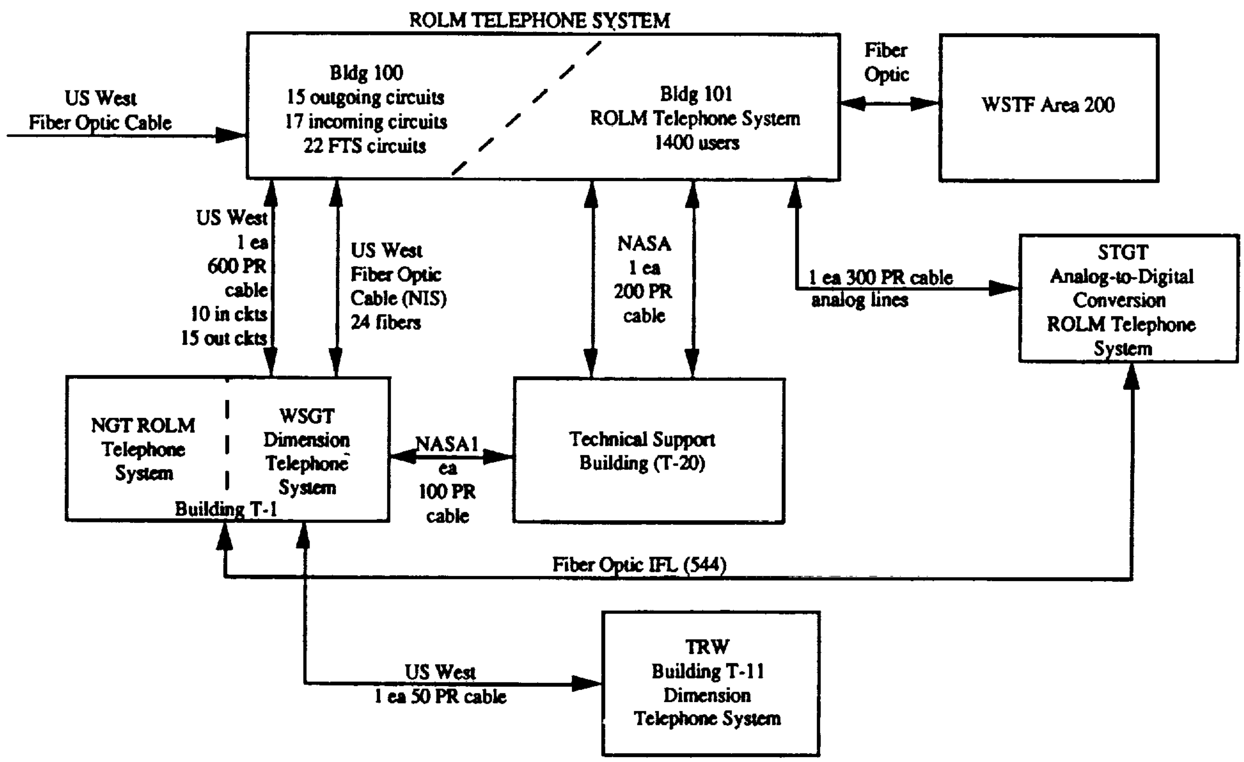
[2] Dimension® is a registered trademark of AT&T



White Sands Complex Telephone Systems Before Upgrade
Figure 1

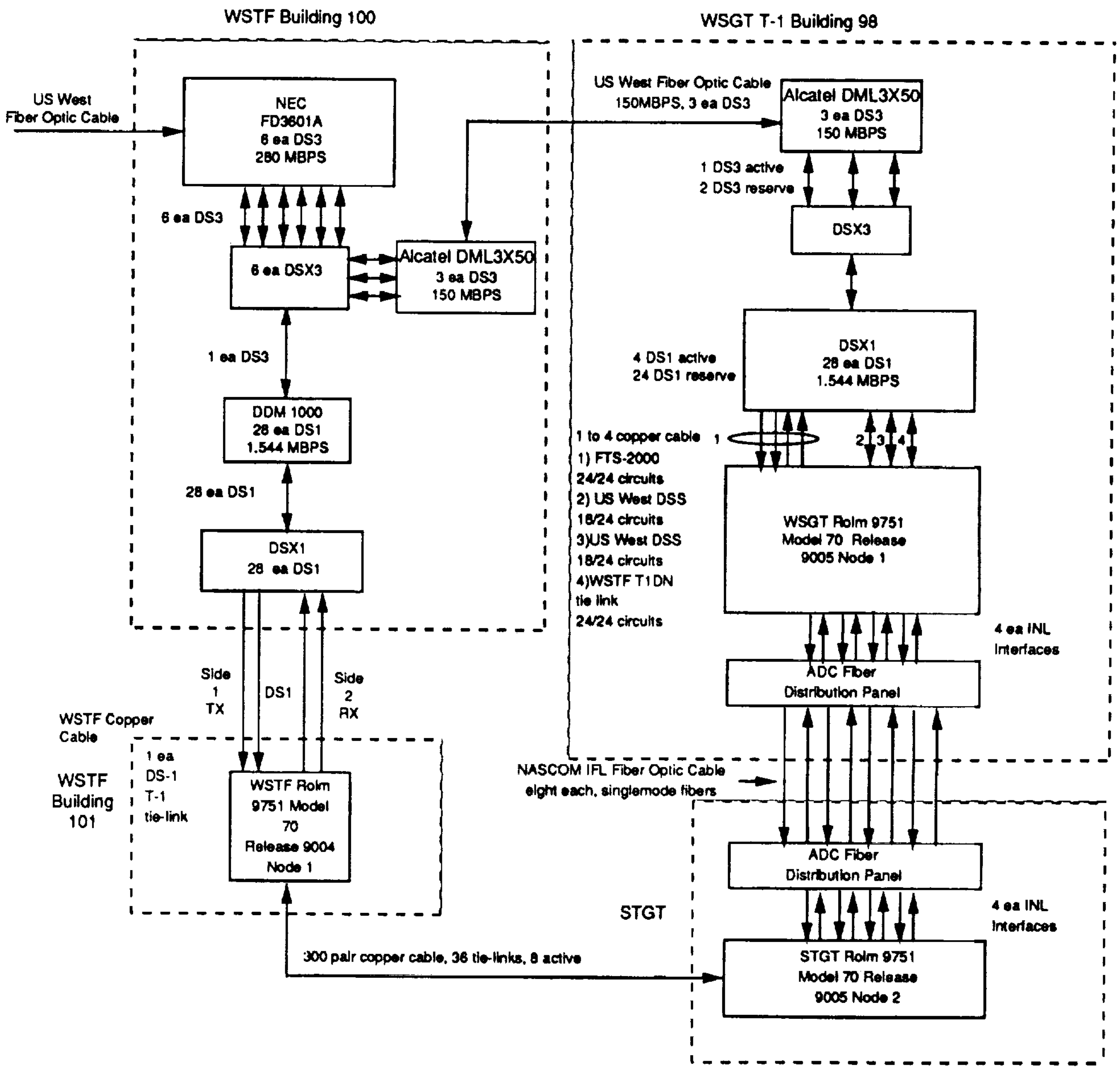
This required conversion of the STGT ROLM system from a 9751 Model 50 to a 9751 Model 70 and from software release 9004 to 9005 along with installation of a suitable distributed node connection between the two CBX systems. As a multi-node configuration STGT would be able to share trunking services from the point-of-presence with WSGT; the two CBXs would be redundant to each other increasing the system availability.

Five implementation options were considered to interconnect the two ROLM CBX systems: 1) installing a multimode fiber optic cable between the two sites to support the ROLM multimode INL, 2) installing subscriber carrier equipment to carry high capacity circuits over an existing copper link, 3) using external multimode to singlemode conversion equipment for ROLM INL connectivity via the singlemode fiber, 4) multiplexing T1 circuits for singlemode fiber transmission, and 5) converting the ROLM INL Fiber Optic Extender (FOX) hardware to drive singlemode fibers.

After considering the costs, advantages, disadvantages, and implementation risks of each of these methods, it was decided to convert the ROLM hardware to a non-standard configuration to drive the available IFL singlemode fibers directly. The advantages were lowest cost and easiest installation. The disadvantages were no factory support for the modified configuration and a higher health (vision) risk from the high energy output lasers. This option assumed an operability and reliability risk since the conversion had never been done before. The risk was mitigated by contracting the ROLM Company for engineering support: bench testing the selected laser transmitter with their proprietary INL protocol and field performance testing the modified system. The installed configuration is shown in Figure 2.

II. SYSTEM DESCRIPTION

The ROLM 9751 Model 70 Computerized Branch Exchange is a digital telephone private exchange capable of supporting up to 1045 simultaneous voice or data connections per node [1]. A multi-node 9751 CBX has from two to fifteen nodes functioning as a single system. Three multi-node categories are supported based on the distance between nodes. "Collocated nodes" are up to 61 meters apart and use twinaxial cable for interconnection. "Distributed nodes" are 61 to 6,000 meters apart. When the node separation is up to 300 meters, twinaxial cable is used. When the separation is up to 450 meters, IBM Type 2 cabling is used. For separations



White Sands Complex Telephone Systems After Modification
Figure 2

of up to 6,000 meters, the proprietary ROLM Inter-Node Link (INL) interface is specified. Multimode fiber is used for INL node-to-node connectivity. "Remote nodes" are separated by distances between 6 kilometers and 80 kilometers. Remote nodes use a different ROLM interface known as the Extended Digital Intertie (XDI) operating over standard T1 transmission facilities [2]. The WSC application was at the upper boundary for distributed nodes at 6 kilometers between tracking stations.

The INL operates at 74MBPS and supports 545 channels per link. This is more than sufficient intersite capacity. The system design is robust including a primary and a secondary fiber optic link. Each of the links is redundant. Eight fibers are required for full connectivity: four transmit and four receive fibers. Specifications for the interconnecting fiber optic facility [3] recommend multimode, graded index fiber with 62.5μ core diameter and 125μ cladding diameter (other multimode fibers of between 50μ and 100μ core sizes can also be used). A maximum end-to-end optical power loss of up to 13dB is acceptable for the recommended 62.5μ core diameter fiber. Specifications call for a source central wavelength of 1310 nm.

The ROLM fiber optic extender (FOX) printed wiring board uses a light-emitting diode (LED) multimode transmitter module and a positive-intrinsic-negative (PIN) diode receiver module. Both of these modules are manufactured by the Sumitomo Electric Fiber Optics Corporation and are designed for a central wavelength of 1310 nm.

III. FIBER OPTIC INTER-FACILITY LINK

The ROLM 9751 multi-node installation decision included the use of an existing fiber optic cable between WSGT and STGT for an Inter-Facility Link (IFL). The IFL has the primary mission of transferring user spacecraft data between sites for multiplexing and retransmission to the user's Payload Operations Control Center (POCC) via the NASA Communications System (NASCOM). This mission requires fiber that can support high data rates with low loss.

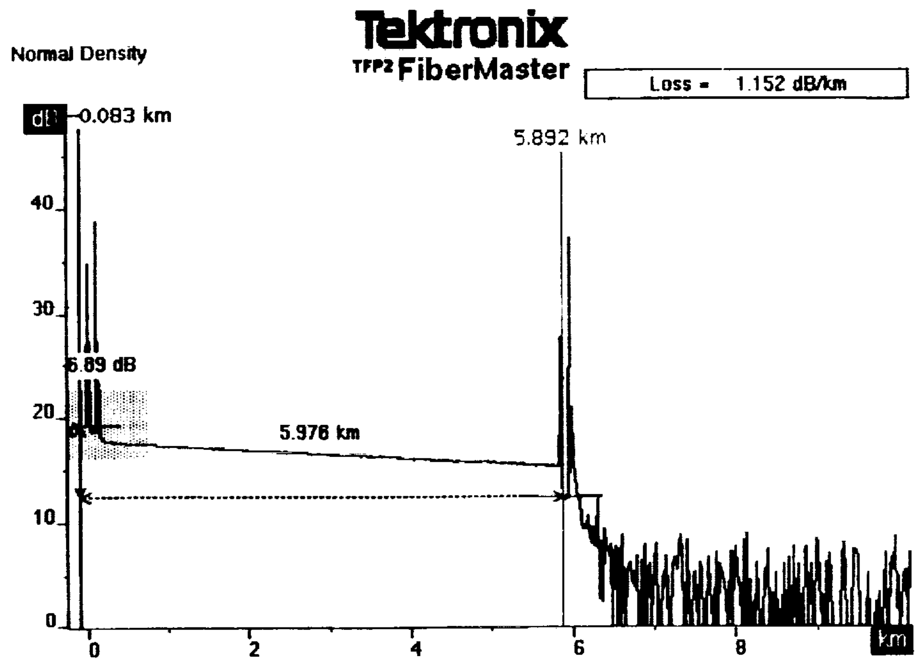
The NASCOM IFL specifications [4] are for 6,000 meter bundles of 144 singlemode fibers. The core diameter of each fiber is 8.3μ with 125μ diameter cladding. The fiber is optimized for dual-window central wavelengths of 1310 nm and 1550 nm. The maximum attenuation is 0.50 dB per kilometer at 1310 nm and 0.40 dB/km at 1550 nm. Each fiber is terminated at each end by fusion splicing into a fiber optic pigtail. The pigtails are part of a patch panel with "ST" type connectors. The specified total link loss (including 6 dB of reserve and future maintenance loss) was ≤ 11.9 dB. The IFL Channel Analysis [5] gives a maximum loss of 5.9 dB for the typical fiber. The IFL has spare fibers. Some of them were allocated for intersite telephony.

The IFL termination racks are located in technical equipment rooms at each site, approximately 50 meters from CBX equipment rooms. A plenum-rated bundle of twelve singlemode fibers was routed from IFL termination patch panels to CBX equipment rooms at the respective sites with patches and splices made to complete an eight fiber link (four spares). At the completion of this task, an optical time domain reflectometer (OTDR) was used to measure the span. A typical OTDR trace is shown in Figure 3. Results from the OTDR measurements for eight operational INL fibers are summarized in Table 1. The extensions added less than one dB to the total loss of the span. This facility had all the qualities to support intra-site telephony <u>except</u> for being the incorrect type of fiber for the ROLM INL. The IFL telephone extension is shown in Figure 4.

Table 1

Optical Loss for Extended Inter-Facility Link Fibers

Fiber Number	Loss, dB/km	Optical Length, km	Total loss, dB
1	1.055	5.976	6.30
2	0.684	5.076	4.09
3	0.661	5.976	3.95
4	0.605	5.976	3.62
5	0.580	5.976	3.47
6	0.703	5.976	4.20
7	1.152	5.976	6.88
8	0.899	6.034	5.42



Current Waveform
Normal Density
Source = Acquisition

Acquired: 2/09/93 - 18:59:21
Averages = 8192 (0:00:39)

Module = 1310SM (L1) - b030127
Pulse Width = 50 ns (5 m) [HR]
Maximum Range = 10.0 km
Masking Type = Off

Refractive Index = 1.4710
Slope Calculation = Two Point

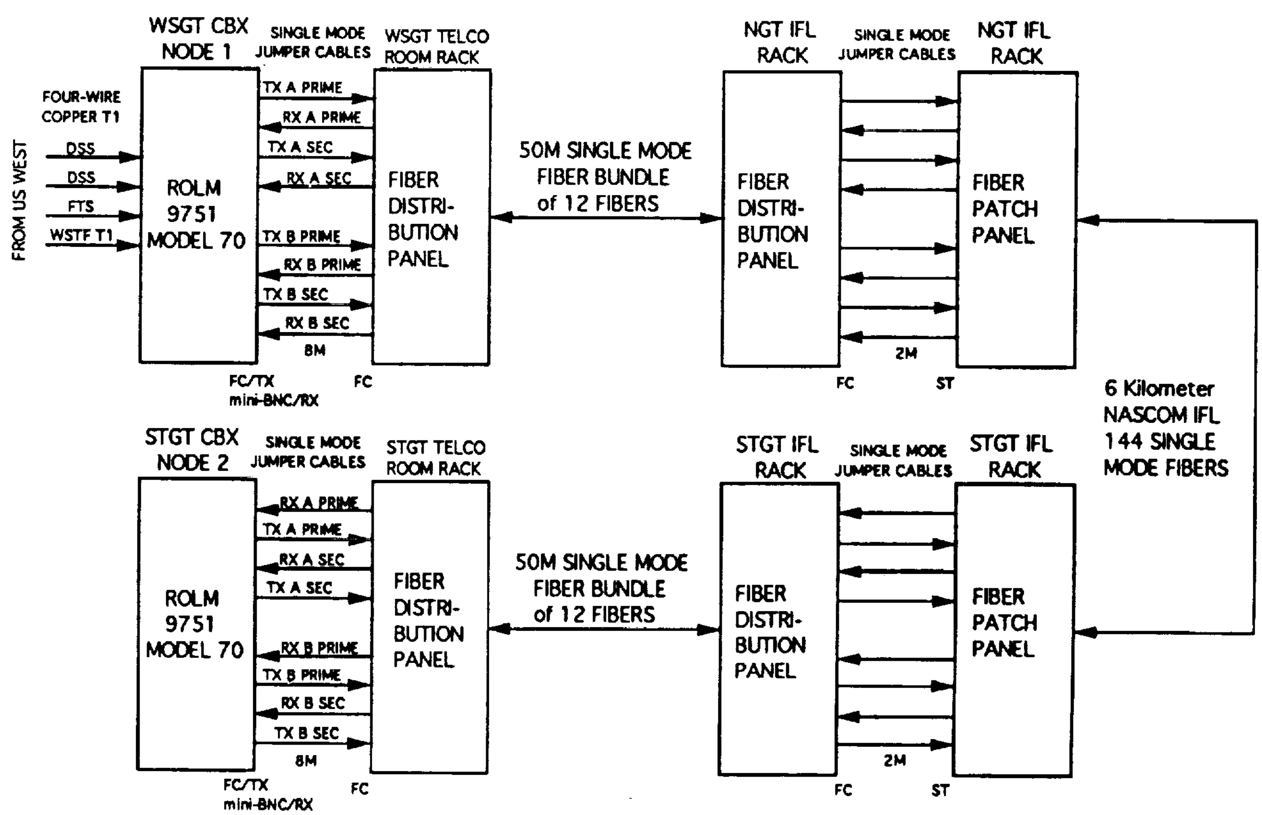
Fiber Id =

Operator =

Notes =

Firmware version = T3.13A

Typical OTDR Trace for the Extended Interfacility Link
Figure 3



Inter-Facility Link Telephone Extensions
Figure 4

IV. ENGINEERING EVALUATION OF CONNECTIVITY OPTIONS

Five options were evaluated before making the decision to modify the factory standard INL configuration to directly support singlemode fiber transmission. Each had advantages, disadvantages, risks, and associated implementation costs.

1. Multimode Fiber Installation

ROLM factory support for INL connectivity requires a multimode fiber communication link, preferably one with a 62.5μ core diameter. This option had the least risk; it was the factory-recommended approach. NASA had already incurred the expense of installing the IFL. This installation was complete and there was no possibility of adding multimode fibers. The costs for trenching in a new fiber were too high to be given serious consideration.

2. Subscriber Carrier Equipment Installation

Subscriber carrier equipment multiplexes individual channels into a data stream carried over copper transmission facilities. This option is like the Remote Node method except it uses copper links. Disadvantages were 1) high cost, 2) lack of ROLM support, 3) use of copper transmission facilities, and 4) equipment self-maintenance. This option also did not receive serious consideration.

3. External Multimode to Singlemode Conversion

Commercially available equipment that could 1) receive multimode fiber optic transmissions for conversion to singlemode and 2) receive singlemode transmissions for conversion to multimode received considerable attention. Numerous fiber optic equipment vendors were contacted. This option had high risk; none of the converter vendors would guarantee success. ROLM would not support this installation and warranty INL functionality. In-house maintenance was required for additional configuration items.

The problem was bit transition density. The format of ROLM INL protocol is proprietary and the specification for bit transition density for transmitter and receiver modules [6] suggested a high duty cycle was required. One vendor intended to support a trial of his equipment, but this option was rejected before a trial could take place. The cost was higher than conversion of the INL to singlemode operation. (After completion of our modification, ROLM Engineering indicated that they were planning further evaluation of external conversion.) This option remains viable.

4. Extended Digital Intertie Interface

ROLM requested that the two nodes be connected using an XDI interface with multiple T1 services. Each T1 has a 24 circuit channel capacity. To emulate the performance of the INL, 23 T1s would have to be multiplexed and carried via the XDI. Four T1s were needed to handle the expected intersite telephony traffic. Since several vendors sell commercially available multiplexer/demultiplexer equipment; this option was very viable. Most of the vendors could support the singlemode IFL and provide the multiplexing capacity that was initially needed with expansion potential by adding modules. This option was almost selected. It had higher cost than option 3, but was ROLM supported. Disadvantages included self-maintenance of transmission equipment and lower channel capacity than the INL. Because the multiplexing and transmission equipment was well proven in numerous field installations by commercial telephone companies and was ROLM supported, this option had low risk.

5. Conversion of ROLM INL to Singlemode Operation

This option had the highest risk. The ROLM INL had never before been operated over singlemode fibers and the factory recommended against it. They would not support or guarantee INL performance. The modified fiber optic extender (FOX) printed wiring boards would not be under warranty nor vendor repaired if they failed. ROLM objected to using laser modules on their boards because of Underwriter Laboratory certification. The LED multimode module was UL certified, but the laser module was not. NASA has configuration management procedures for "altered items," so factory objections were not sufficient for rejection. The UL safety issue could be managed by placarding modified equipment with warning labels.

The fiber optic transmitter and receiver module vendor had a pin-for-pin replacement singlemode laser module. This part was expensive, but the overall cost for direct conversion was much less than any other option. The IFL transmission facilities to use the direct conversion were already in place. Discussions with the vendor indicated that the multimode receiver would operate with output from singlemode transmission facilities. The vendor had a concern of overdriving, or saturating, the receiver module. (Which could have been solved with in-line optical attenuators.) The remaining risk issue was performance. This was mitigated by contracting with ROLM for engineering support. Bench testing the laser transmitter module with the stock receiver module and ROLM INL protocol was performed before altering the FOX printed wiring boards. Bit-error-rate testing indicated the transmitter module's electrical input would be compatible with the printed wiring board's ECL output logic and that the receiver module worked with optical input from a singlemode laser. The decision was made to convert the ROLM INL from multimode to singlemode fiber optic operation.

V. MODIFICATION CONSIDERATIONS

The FOX printed wiring boards were modified after bench testing. Each one had the LED multimode transmitter module removed and replaced by a laser singlemode module. Each altered board was remarked with a new part number for configuration management. The boards were marked with a warning label for "Laser Output." The modified FOX boards were reinstalled into ROLM CBX INL shelves and were connected to the extended IFL via suitable singlemode fiber optic patch cables. The extended fiber installation had "Laser Output" warning labels located where a connection presented a potential vision hazard. The modification was straightforward and required no special precautions besides electrostatic discharge prevention.

1. Multimode Transmitter Characteristics

The standard INL multimode fiber optic transmitter module is a Sumitomo DMT-54 Optopia®[3] module (also listed as DM-54-TA). The DMT-54 transmits digital data signals at rates from 1MBPS to 125MBPS in non-return to zero (NRZ) formats. The transmitter uses an InGaAsP LED light source and launches -17 dBm into $62.5\mu/125\mu$ fibers. The electrical input is differential ECL logic and is certified for data duty cycles of 45 to 55%. The optical output connector is a mini-BNC [7].

2. Multimode Receiver Characteristics

The standard INL multimode fiber optic receiver module is from the same Sumitomo Optopia family. It is the DMR-54 module (also listed as DM-54-RA). It operates at the same data rates and duty cycle as the transmitter. It uses an InGaAs PIN photo detector receiver and has a differential ECL output. The optical input connector is a mini-BNC. The receiver has an optical input sensitivity, or carrier detection level, of -34 dBm with input from a 62.5μ fiber [8]. The input power saturation level is -8 dBm [9]. Dynamic range is 26 dBm.

[3] Optopia is a registered trademark of Sumitomo Electric Industries, Ltd.

3. <u>Singlemode Transmitter Characteristics</u>

The Sumitomo DM-91-TD is a high speed fiber optic laser transmitter module. It supports digital data transmission over singlemode fibers with NRZ data rates ranging from 1MPBS to 250MBPS. It uses an InGaAsP FP laser diode output with a peak emission wavelength of 1.3 μm and a launch power of $\geq$-10 dBm. The electrical input is differential ECL. It is a pin-for-pin replacement for the DMT-54. The optical output connector is an "FC" [10].

4. <u>Transmitter Replacement Considerations</u>

Several testing and verification objectives for the modification were established. A test plan to validate these objectives [11] was prepared and testing was conducted to assure that the DM-91-TD laser transmitter module could replace the DMT-54:

- Verify that the laser transmitter module is physically and electrically compatible with the LED transmitter module.
- Verify that a simulated link is functional and reliable; i.e., no bit transition pattern dependency and a bit error rate under 1 X 10E-12 at minimum and maximum line attenuation for the INL data rate of 74MBPS.
- Measure system attenuation and attenuation margin.
- Verify pseudo-random data performance in INL operation.

VI. BENCH TEST AND VERIFICATION RESULTS

Bench tests by ROLM verified the physical and electrical compatibility of the DM-91-TD module with the FOX printed wiring board. The replacement module needed to be a form, fit, and functional replacement. This included the physical size and the power requirement from the on-board 5.2 VDC ECL power supply.

1. <u>Physical and Electrical Compatibility</u>

A) Physical Compatibility

The DM-91-TD has the same 24-pin package as the DMT-54. The output connector is an "FC" instead of the mini-BNC. This is a preferable connector, especially for singlemode fibers, since it is noted for good optical alignment and low loss. Singlemode patch cables with FC connectors are low cost off-the-shelf items.

B) Power Consumption

The DM-91-TD current requirement from the -5.2 VDC ECL power supply was measured to be 120 ma, which was 30 ma less than the current requirement for the DMT-54.

2. Bit Error Rate Testing

Bit error rate testing with different data patterns will show if there are pattern dependencies and attenuation ranges for low error rate performance. The BER was ≤ 1 X 10E-12.

A) Data Pattern Dependency

A BER test series showed that there were no bit pattern or transition density dependencies with pseudo-random data and word lengths of up to 2E23-1 bits.

B) INL Data Rate BER Performance

Tests of the bit error rate performance were made at two data rates: 74MBPS and 125MBPS. For both tests, the BER was less than 1 X 10E-12.

C) Receiver Input Power Performance

The maximum input power for the receiver was -8 dBm. BER performance degraded at higher input power levels. The receiver saturated at -4 dBm.

D) Fiber Optic Cable Attenuation Margin

The simulated fiber optic cable attenuation was varied until the BER increased beyond 1 X 10E-12. The line attenuation must be between -5 dBm and -25 dBm for acceptable BER.

VII. FIELD TEST AND VERIFICATION RESULTS

On installation and activation, the two-node ROLM 9751 CBX system operated normally with the modified INL. ROLM diagnostic tests revealed no problems. Field testing (with assistance from the ROLM Company) verified performance margins and provided additional customer assurance.

1. Optical Power Margin Test Results

Optical power measurements assured that each component of the system was good and quantified the optical losses through the entire link. Table 2 summarizes these results. The apparent discrepancies have been attributed to the optical alignment and coupling of the power meter cable. Optical output of the transmitters ranged from -3.6 to -6.9 dB. The average measured optical loss through the system was -6.3.

Table 2

Optical Power Measurements for Modified INL

Fiber Number	Node 1 CBX dB	Node 1 IFL dB	Node 2 IFL dB	Node 2 CBX dB	Total Loss dB	OTDR dB
1	-3.6 Transmit	-5.1	-9.9	-10.1 Receive	-6.5	-6.30
2	-13.7 Receive	-10.0	-6.7	-5.6 Transmit	-8.1	-4.09
3	-6.9 Transmit	-7.2	-10.5	-11.8 Receive	-4.9	-3.95
4	-9.6 Receive	-7.3	-4.4	-3.9 Transmit	-5.7	-3.62
5	-5.9 Transmit	-6.9	-10.5	-11.4 Receive	-5.5	-3.47
6	-11.5 Receive	-10.2	-6.9	-5.9 Transmit	-5.6	-4.20
7	-4.8 Transmit	-6.0	-11.0	-11.5 Receive	-6.7	-6.88
8	-12.0 Receive	-9.0	-5.6	-4.7 Transmit	-7.3	-5.42
Averages	-5.2 Transmit			-11.5 Receive	-6.3	-4.57

2. Attenuation Margin Test

An optical attenuator was inserted at the receiver end of the active INL link. Attenuation was added until the INL receiver lost lock as indicated by an LED on the FOX board driven from the carrier detect circuitry on the receiver module [12]. Insertion of 20.6 dB of optical loss was required to break the INL lock. The INL specification for fiber attenuation is 0.5 dB/km. The attenuation test would then indicate the this system is capable of driving an additional 41 km for a total of 47 km. With a one dB margin, the system could drive a 45 km long fiber, or longer fibers if a lower loss cable was used.

3. Pseudo-Random Data Testing

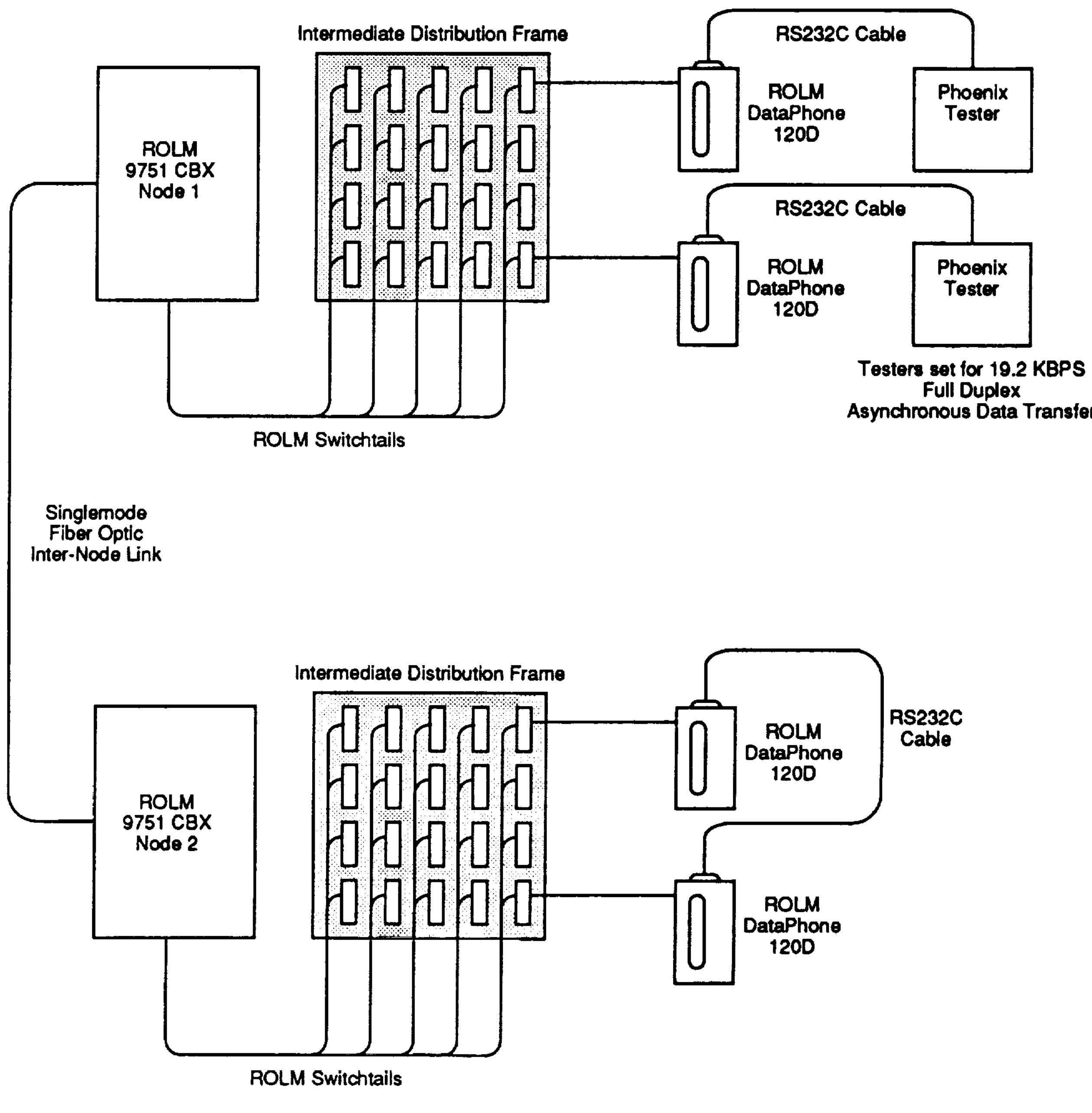
For confidence, the modified INL was tested with pseudo-random data. Two 120D ROLMphones®[4] were configured for data transmissions at each site and full duplex communications were established. The test configuration is shown in Figure 5. Pseudo-random data at 19.2KBPS was sent through the system from one 120D through the pair at the remote end and back to the other 120D. The test was bi-directional. Each 120D was transmitting and receiving simultaneously. This test ran error-free for two days. This was insufficient time at that data rate to establish a bit error rate, but it did add customer confidence for the operational performance of the modified Inter-Node Link. The system has been in service since March 1993 without any operational problem related to the modification.

VIII. CONCLUSIONS

The ROLM 9751 CBX Model 70 with software release 9005 can operate in a multi-node configuration using the ROLM Inter-Node Link over singlemode fibers. Using singlemode optical fibers requires modifying the ROLM Fiber Optic Extender printed wiring boards to accept laser transmitter modules in place of the LED transmitter modules. When installed with a low-loss singlemode span (0.5 dB/km or less), node separation can be up to 45 kilometers. This node separation distance is comparable to that for "remote nodes," yet the channel capacity remains high (545 channels per INL) and the cost is less than for Extended Digital Intertie interfaces. This application is of interest to ROLM users with widely separated facilities or ones with existing singlemode fiber facilities.

Using external multimode to singlemode optical converters for the same function could be investigated further. This was evaluated, but was not pursued for this application. A key advantage is not having to modify and void warranties on the ROLM FOX printed wiring boards. Commercial converters would have UL certification.

[4] ROLMphone is a registered trademark of ROLM Systems



Test Configuration for Data Transfer over the INL
Figure 5

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