Applications

RFL Electronics Inc.

353 Powerville Road, Boonton Township, New Jersey 07005-9151, USA
Phone: (973) 334-3100 Fax: (973) 334-3863
email:rflelect@nac.net
www.rflelect.com

ELECTRICAL AND OPTICAL STANDARDS

Attached is the "ELECTRICAL STANDARDS" as defined in the North American Electrical Digital Hierarchy - 1984. Also attached is the "OPTICAL STANDARDS" as defined in the North American Synchronous Optical Network - 1988. These standards are key in understanding the Bit Rates and capacity each channel level offers and are included for your reference.

RFL Electronics Inc.

ELECTRICAL STANDARDS

(North American Electrical Digital Hierarchy - 1984+)

- Interface Rates and Formats Between Public and Private Networks for Voice and Data

Channel	Bit Rate	Composition
DS3	44.736 Mb/s	28 DS1 Equivalent Capacity
DS2	6.312 Mb/s	4 DS1 Equivalent Capacity
DS1C	3.152 Mb/s	2 DS1 Equivalent Capacity
DS1	1.544 Mb/s	24 DS0 Equivalent Capacity
DS0*	64 Kb/s	DS0 (Voice Channel), DS0A or DS0B Formats
DS0A*	64 Kb/s	2.4 Kb/s, 4.8 Kb/s, 9.6 Kb/s, 19.2 Kb/s, or 56 Kb/s carried on a single DS0
DS0B*	64 Kb/s	20(2.4 Kb/s), 10(4.8 Kb/s), or 5(9.6 Kb/s) multiplexed to a single DS0

* Transmission of these rates (Sub-DS1) for distances beyond the Carrier Serving Area (~12.5 Kft.) normally requires a DS1 or higher multiplexer and a transmission system while DS1 To DS3 Transmission Is Typically Limited To Less Than 1000 Feet

APPLICATION OF TELEPROTECTION EQUIPMENT OVER DIGITAL NETWORKS

by

Gary R. Hoffman
and
Kenneth J. Fodero

RFL Electronics Inc.
Boonton Township, NJ

Presented At The
American Public Power Association's
Engineering And Operations Workshop

Nashville, Tennessee
March 22 - 24, 1994

APPLICATION OF TELEPROTECTION EQUIPMENT OVER DIGITAL NETWORKS

by

Gary R. Hoffman
and
Kenneth J. Fodero

RFL Electronics Inc.
Boonton Township, NJ

ABSTRACT

Over time, communications equipment manufacturers have developed highly specialized "teleprotection equipment." This equipment provides power utilities with very secure and reliable signaling between power substations for the remote operation of power system circuit breakers. The evolution of this equipment understandably has lagged behind the evolutions in the telecommunications field. As new communications systems have become available new types of teleprotection equipment have followed. Up until the introduction and acceptance of high-speed digital networks by power utilities, teleprotection has consisted almost exclusively of analog based systems.

Today, however, these teleprotection systems are taking advantage of higher speeds and bandwidths that were not available using older analog communications networks. Because the telecommunications industry and the teleprotection industries have evolved separately (with different focus on performance criteria), some overall operational discrepancies now exist. These issues are not insurmountable; however, there are application concerns that need to be addressed.

A BRIEF INTRODUCTION TO TELEPROTECTION

The following list depicts some typical protective relaying schemes that use teleprotection:

1. Transfer trip
2. Current differential
3. Phase comparison

In each of these three categories, several application types can exist. However, the overall communications performance requirements can be grouped in this manner. Until the advent of digital communications networks, the primary communications media for these systems has been powerline carrier, dedicated pilot wires, dedicated fiber optics, and audio tones applied over leased services or analog microwave.

Transfer Trip

In most applications, this form of teleprotection involves the transfer of information in the form of a contact closure between two ends of a protected power line. Most systems of this type operate in about 3 ms to 15 ms, depending on the application and not including propagation delays.

Current Differential

Two vintages of current differential relays are in use today: electromechanical, and numerical (or digital).

Electromechanical relays are the oldest type. They were designed for use over dedicated copper pairs. Communication consists of a composite 60-Hz signal that is used for comparison at the remote end.

Numerical or digital relays are the newer types. These relays use more conventional audio tone or digital communications systems. These relays have propagation delay limits, and most cannot compensate for dynamic changes in this delay.

Phase Comparison

Phase comparison systems use tone or digital communications systems. Depending on the vintage, some of these relays have propagation delay limits of 8 ms maximum, and cannot compensate for dynamic changes in this delay.

A BRIEF T1 OVERVIEW

T1 multiplexers and channel banks use time division multiplexing (TDM) techniques to combine twenty-four 64-Kbps channels (or DS0s) onto a single 1.544-Mbps aggregate signal. (See Figure 1.) This aggregate signal is called a "DS1," or Digital Signal Level 1.

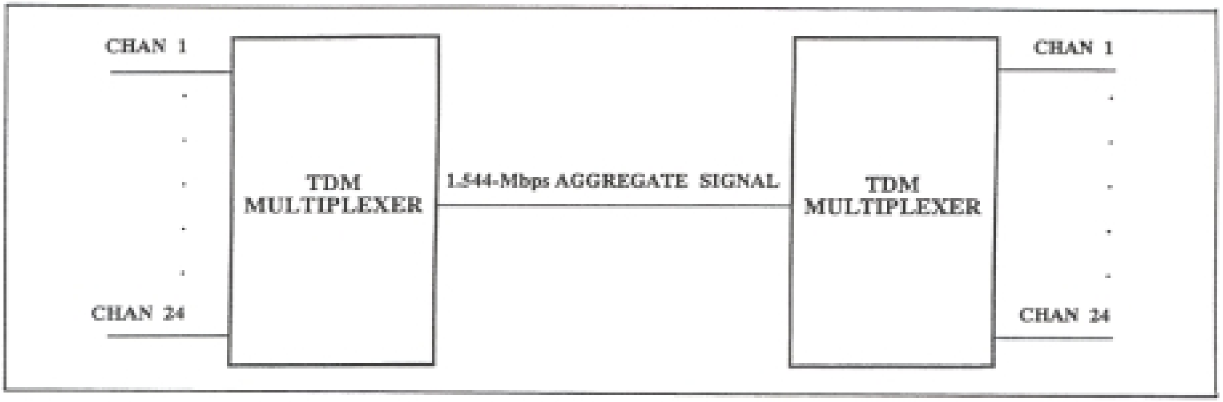


Figure 1. Time Division Multiplexer (TDM)

Each channel or DS0 contains eight bits. When the twenty-four DS0s are combined, they make up 192 of the 193 bits in the T1 aggregate. The 193rd bit is the framing bit (F-bit) and is inserted by the multiplexer for synchronization. Synchronization keeps the multiplexers at each end of the link locked with each other; what goes in on one end on a specific channel comes out the other end on the same channel. The combination of the twenty-four DS0 time slots and the framing bit are also called a "D4 frame." (See Figure 2.)

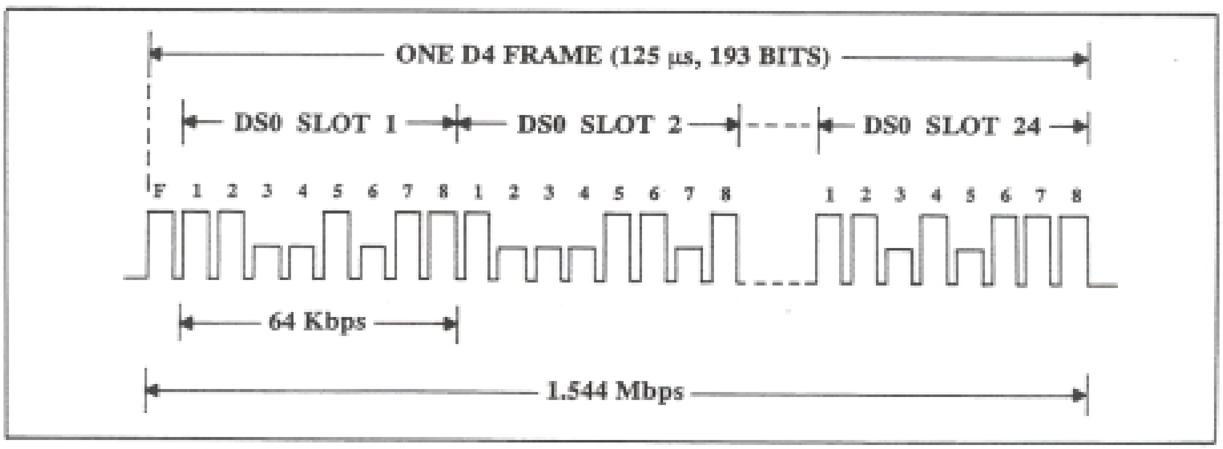


Figure 2. D4 frame

SUPERFRAME

It takes twelve D4 frames to make up what is called a "superframe." (See Figure 3.) The resultant 12 F-bits of the superframe are split into two groups that are used for terminal framing (F_t) bits and signal framing (F_s) bits. The F_t bits identify the framing boundaries while the F_s bits are used to identify the robbed-bit signaling frames (6 and 12) and the associated signaling channels (A and B).

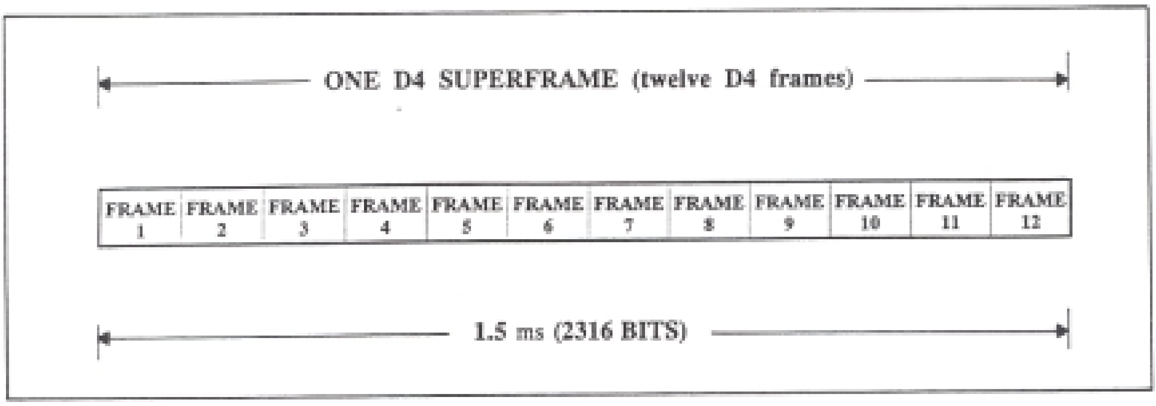


Figure 3. D4 superframe

EXTENDED SUPERFRAME (ESF)

The extended superframe format is made up of twenty-four D4 frames and the F-bit positions are partitioned for three separate uses. (See Figure 4.) Six of the F-bits are used for frame synchronization, and six are block check bits used as a cyclic redundancy check (CRC6) field. The remaining twelve F-bits are data link (DL) bits, used to form a 4-Kbps data channel.

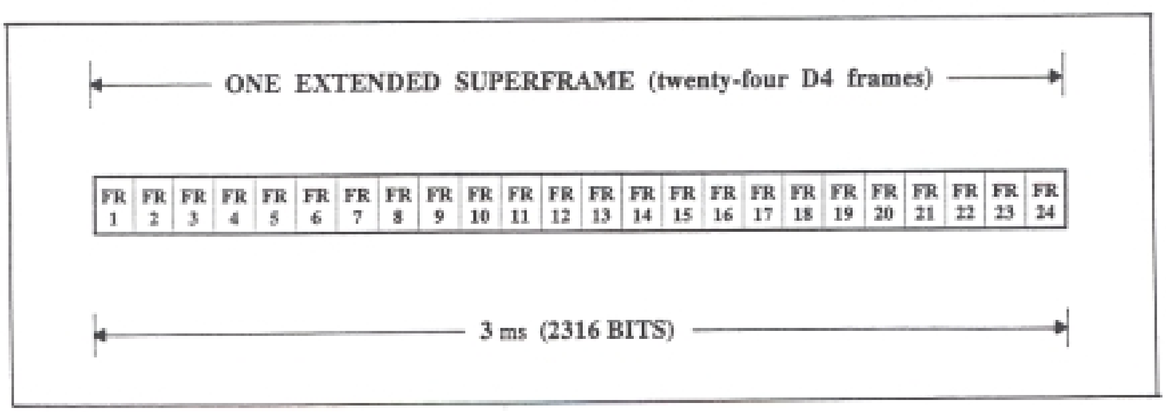


Figure 4. Extended Superframe (ESF)

A TYPICAL POWER UTILITY SYSTEM TELEPROTECTION APPLICATION

When T1 is applied as the communications medium for teleprotection applications, it is usually applied over utility-owned fiber optic cables that are routed between power substations. (See Figure 5.) This yields a serial T1 topology that is best suited for T1 add/drop multiplexers (ADM). (Add/drop multiplexers are also called "drop-and-insert" multiplexers.) Drop-and-insert capabilities allow DS0 traffic to be used between adjacent substations, while allowing re-use of the same DS0 time slot at other locations in the system.

For most teleprotection applications using this topology, the protection signals are primarily point-to-point between adjacent nodes. Other traffic (such as telephone and SCADA) are home-run to the PBX and SCADA master locations.

Timing characteristics in T1 equipment performance will vary from vendor to vendor. Some forms of teleprotection equipment will not operate properly when the teleprotection traffic needs to operate through several nodes. This will depend on the delay characteristics of the multiplexer equipment being used. Some typical delay variances are listed below:

Description	Standard Grade	Protection Grade
Data Buffering (at the channel card level)	1 ms to 2 ms	< 700 μs
Drop-And-Insert Throughtime (at the DS1 level)	125 μs to 250 μs	< 25 μs
Data Buffering (at the DS1 level)	Included above	. . .
Reframe Times	< 50 ms	3 ms to 10 ms

As far as teleprotection systems are concerned, the only types of systems that are affected by the above timing considerations are digital interfaces for the older electromechanical current differential relays. The overall system delay tolerances vary from manufacturer to manufacturer, and range from 700 μs to 1.5 ms. From this data, two facts become apparent:

1. The interface points on the network for these types of systems can affect performance.

2. The characteristics of each system component can make the difference in whether an application will actually work.

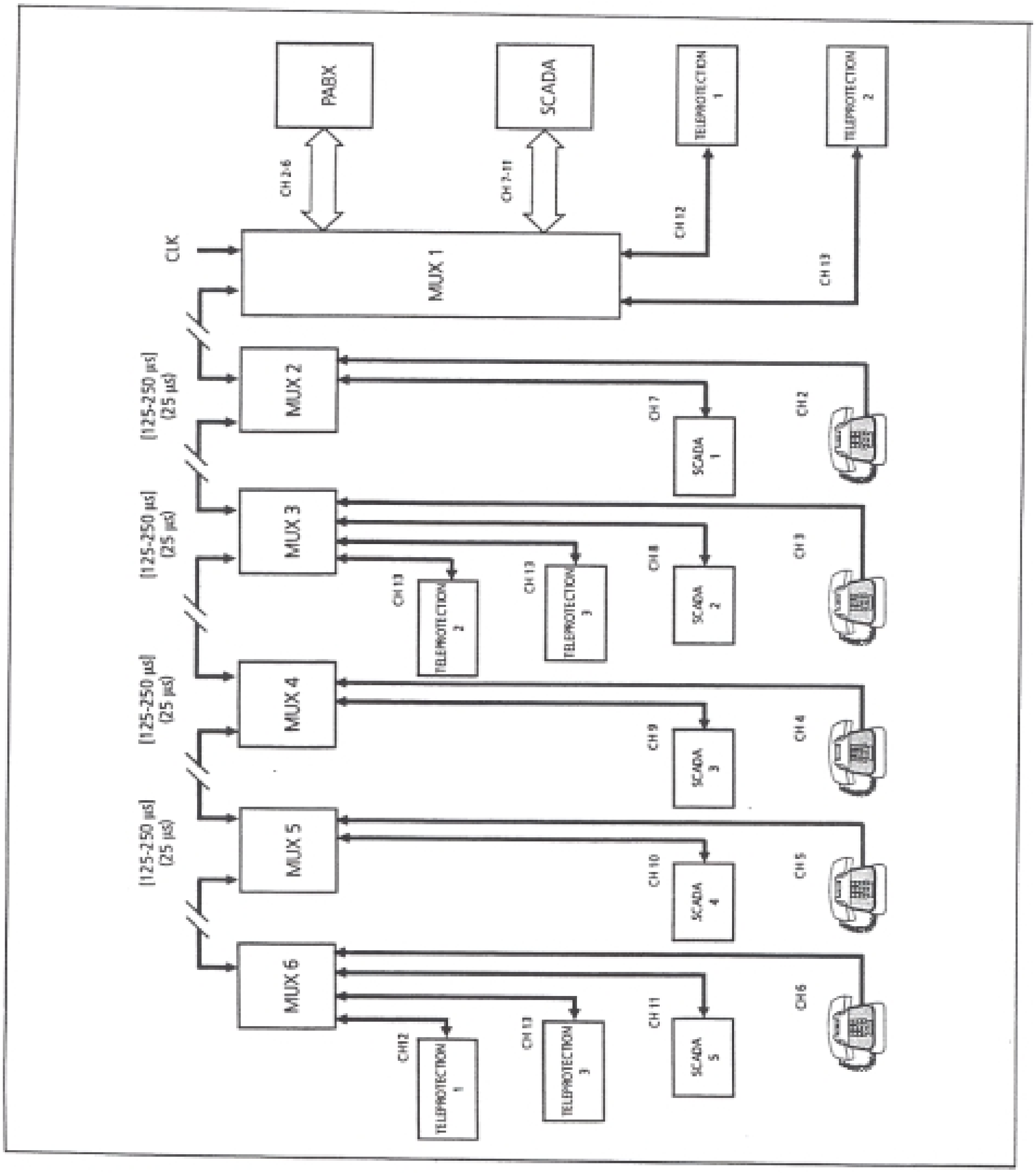
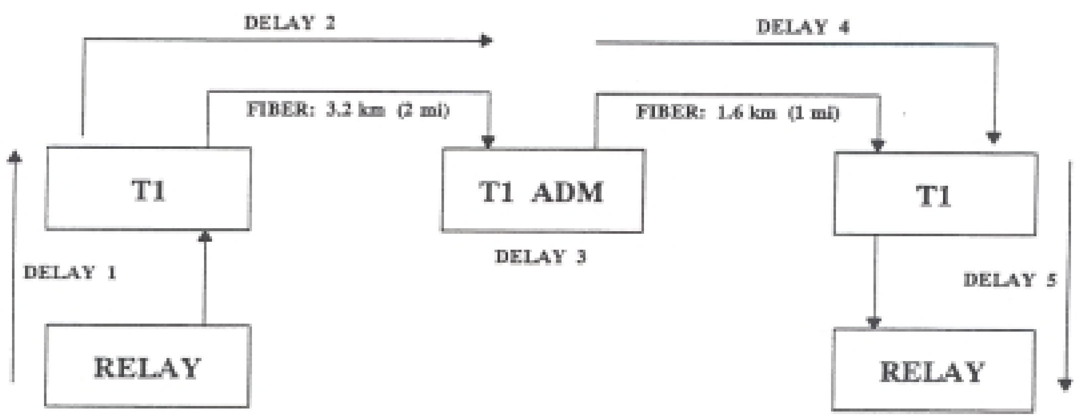


Figure 5. Typical power utility drop/insert teleprotection application

It should be noted that the delay tolerance of some numerical current differential relays can overcome the above limitations. While applications vary, most modern current differential relays should be capable of being used for T1 multiplex systems.

One additional timing element not mentioned so far is the speed of light through the fiber. Although this is a very small number (about 8 µs per mile), it can add enough delay on very long fiber paths to affect system performance. Currently, the electromechanical current differential relay interfacing over T1 is typically the only teleprotection application that has such application restraints. (See Figure 6.)



DELAY FACTORS:

1 - INPUT (RELAY AND T1)	400 µs
2 - FIBER 1 (2 MILES @ 8 µs/MILE)	16 µs
3 - T1 ADM	25 µs
4 - FIBER 2 (1 MILE @ 8 µs/MILE)	16 µs
5 - OUTPUT (T1 AND RELAY)	400 µs
TOTAL DELAY:	849 µs

Figure 6. Electromechanical current differential relay interfacing over T1

SONET

In some applications as they exist today, T1 networks as described previously will interface into larger backbone networks, such as "SONET" (Synchronous Optical NETwork). SONET is a standard that was developed to define a synchronous digital hierarchy with sufficient flexibility to carry many different capacity signals. This was accomplished by defining a basic signal of 51.840 Mbps (OC-1) and a byte-interleaved multiplex scheme. The result is a family of standard rates and formats defined at rates that are multiples of 51.840 Mbps (OC-N). As it is a complex network to describe, only its main properties and implications for teleprotection applications are described in this paper. (The reader is referred to References 1 and 3 for more detailed information.)

A major part of SONET research has been devoted to the achievement of network resilience and survivability. This is not surprising since in 1992, fiber optic cable failure accounted for as many major communication outages in the U.S. as all exchanges with failures. (In this context, "major" refers to outages affecting more than 50,000 people.) Fifty-eight percent of these incidents were caused by dig-ups. As a consequence, a topology involving self healing rings has evolved.

SONET RINGS

Two types of SONET rings are currently defined; they are "Path Switched" and "Line Switched," as defined in TR-496 and TA-1230 (References 2 and 3). Each of these ring topologies offers pros and cons regarding different types of teleprotection applications.

Path-Switched Rings

In a path-switched ring, only the effected Virtual Tributary (VT) is switched. VTs are interfaces within the SONET multiplexer that permit the primary rate to be outputted to DS1 interfaces. An example of this is shown in Figure 7. In a unidirectional path-switched ring, VTs enter the ring at a node and are simultaneously transmitted around the ring in counter-rotating directions. This scheme uses one direction around the ring as the primary signal path, and the other direction as the protected path. If a signal path failure occurs, the affected circuit packs within the SONET multiplexer perform the switch locally. (See Figure 8.)

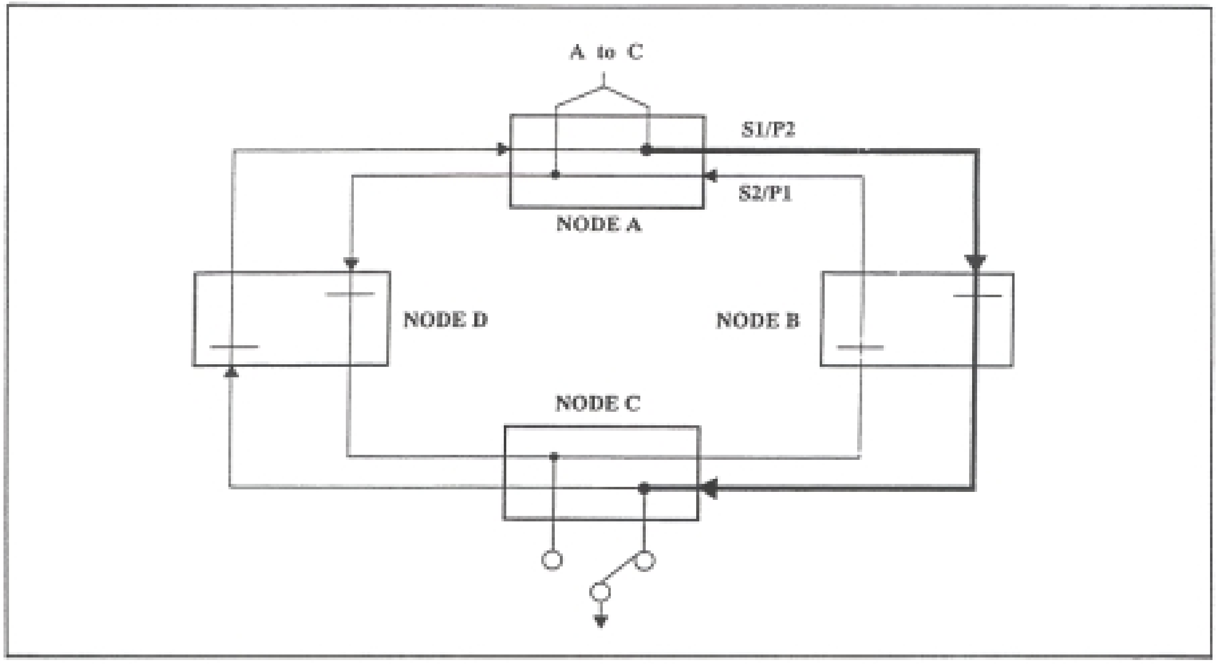


Figure 7. Unidirectional path-switched ring

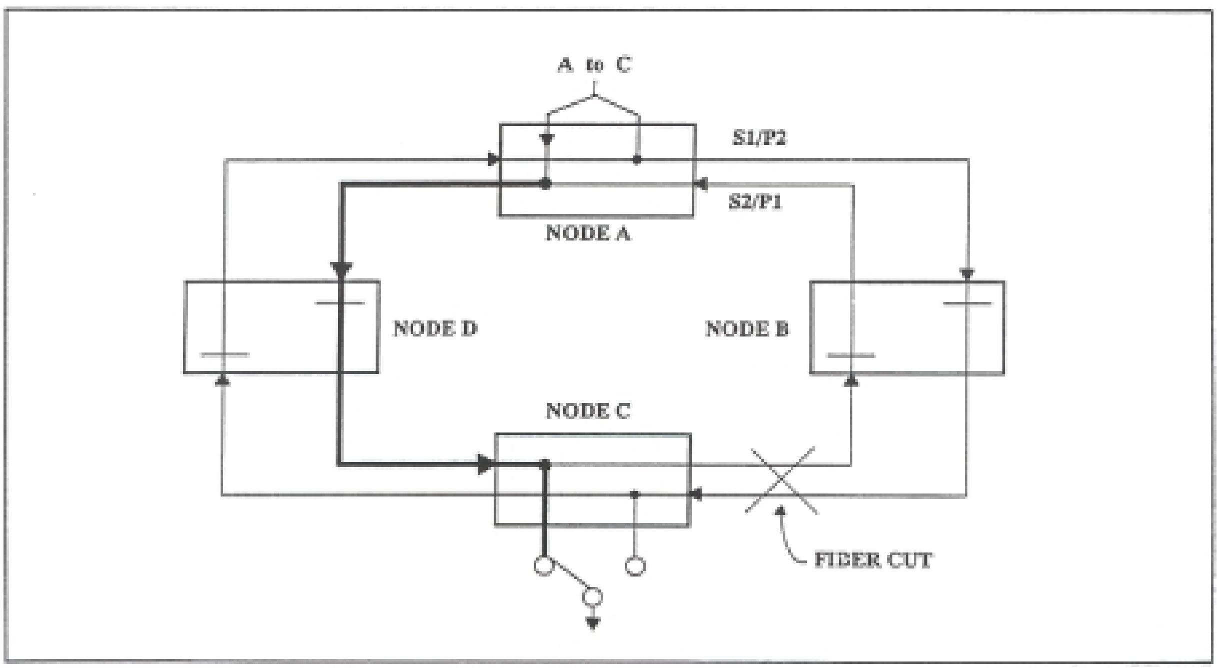


Figure 8. Protected traffic flow in unidirectional path-switched ring

When applying teleprotection over this type of ring topology, some precautions need to be taken. For example some current differential and phase comparison systems cannot compensate for unequal channel delays between the transmitter and receiver paths. These same systems have been designed with fixed propagation delay compensation. This means that substantial changes in the receive path propagation (which can occur during path switching) could result in false operations in the protection system. Modern current differential systems that can dynamically compensate for these conditions do exist, and are well-suited for these applications.

Line-Switched Rings

In the two fiber bidirectional line-switched ring (BLSR), switching occurs at the line rate (OC-N). The two fiber limitation requires that half of the available channel bandwidth be reserved to provide the protected path.

When applying teleprotection over this type of ring topology, the precautions required are slightly different than with the path-switched ring. For example, the same current differential and phase comparison systems that cannot compensate for unequal channel delays between the transmitter and receiver paths are no longer affected. The systems that have been designed with fixed propagation delay compensation could still be vulnerable to false operations, depending on the size of the network.

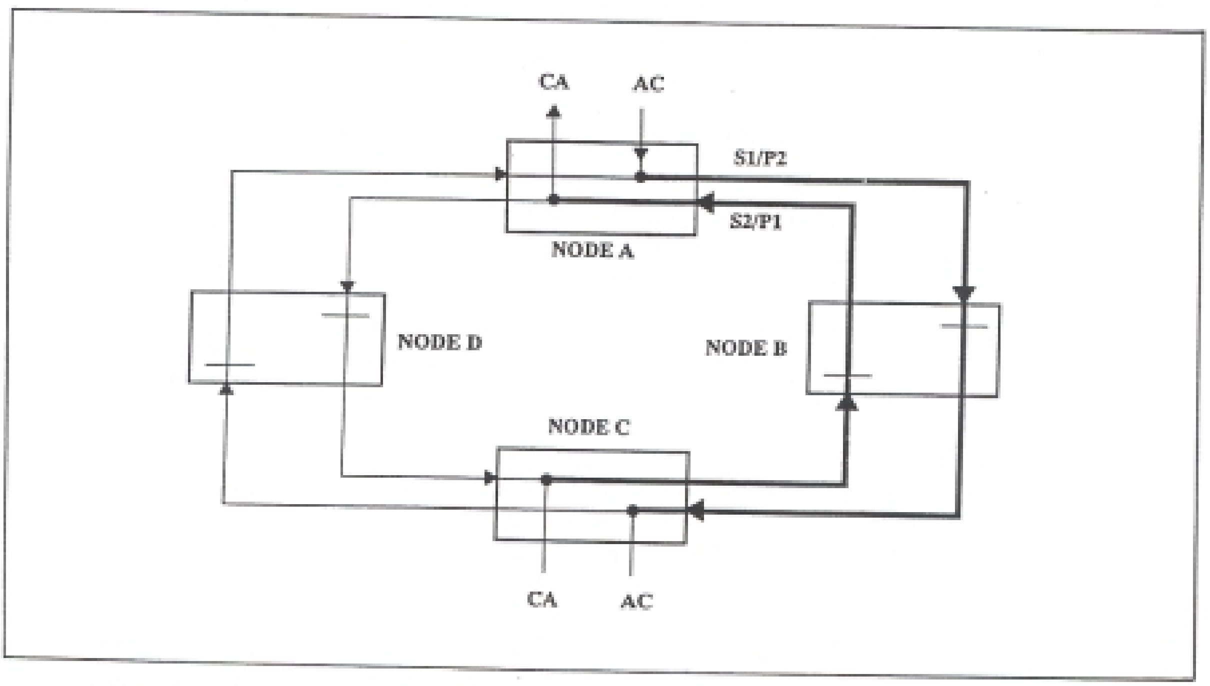


Figure 9. Normal traffic flow in two-fiber bidirectional line-switched ring

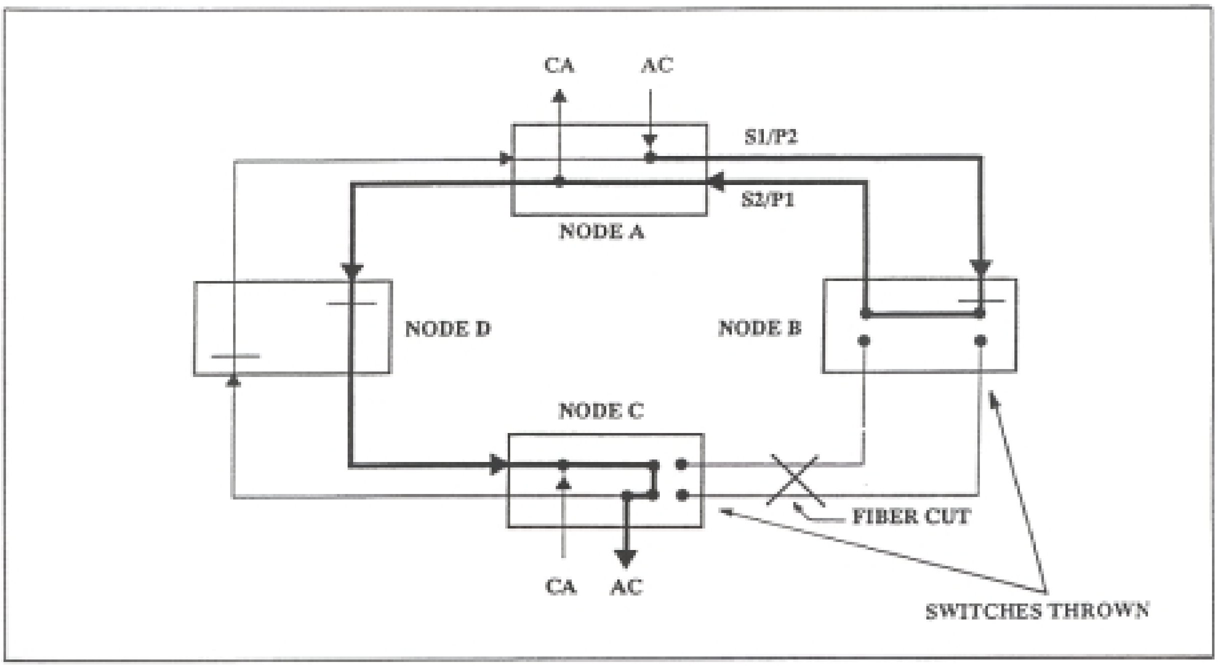


Figure 10. Protected traffic flow in two-fiber bidirectional line-switched ring

RELAYING ON SONET

While SONET offers many capabilities (including network management and self-healing rings), there are delay issues that must be considered when SONET traffic is re-routed due to breaks in the fiber or equipment failures. Like T1, timing characteristics vary from vendor to vendor. Some representative delay characteristics are as follows:

Description	Delay
Transfer Switch Time	< 60 ms
DS1 Synchronization Delay	< 100 μs
DS1 Through-Delay	< 50 μs
SONET Ring Delay (around the ring)	1 ms to 6 ms

In certain ring topologies, the received delays of the two terminal ends will be different, especially when the path is switched. While this is not a problem with transfer trip schemes, all electromechanical and most numeric current differential relays will not be able to handle this situation. Only numeric relays that can compensate for changing delays can be successfully applied.

CONCLUSIONS

Although digital networks have been in existence for many years, the use of teleprotection and digital relaying over these networks is relatively new. The overall advantages offered by these digital networks to the utilities in the area of reliability is tremendous. Teleprotection technology designed to take optimum advantage of these networks and the increased reliability exists today. However as with most things the upgrading of backbone communications systems is not tied to the upgrading of teleprotection systems so the issues discussed in this paper need to be considered.

REFERENCES

1. ANSI T1.105-1991, American National Standard For Telecommunications - Digital Hierarchy - Optical Interface Rates and Format Specifications (SONET); American National Standards Institute, New York NY, 1991.

2. Technical Advisory TA-NWT-001230, SONET Bidirectional Line-Switched Ring Equipment Generic Criteria; Bell Communications Research (Bellcore), April, 1993.

3. Technical Reference TR-NWT-000496, SONET Add-Drop Multiplex Equipment (SONET ADM) Generic Criteria; Bell Communications Research (Bellcore), May 1992.

4. New Communication Systems And Their Possible Impact On Protection Schemes; Phil Whitehead and Stephen Fabray - RFL Electronics (Europe), and Ken Fodero - RFL Electronics Inc.

NOTES

RFL Electronics Inc.
353 Powerville Road
Boonton Township, NJ 07005-0239
Phone: (201) 334-3100
Fax: (201) 334-3863

Publication No. TP 94-002
Printed In U.S.A.
Revised March 18, 1994

RFL Electronics Inc.

OPTICAL STANDARDS

North American Synchronous Optical Network - 1988+)

- SONET - Synchronous Optical Network**

Channel	Bit Rate	Composition
OC-48	2.48832 Gb/s	48 DS3 Equivalent Capacity
OC-36*	1.86624 Gb/s	36 DS3 Equivalent Capacity
OC-24	1244.06 Mb/s	24 DS3 Equivalent Capacity
OC-18*	933.12 Mb/s	18 DS3 Equivalent Capacity
OC-12	622.08 Mb/s	12 DS3 Equivalent Capacity
OC-9*	466.56 Mb/s	9 DS3 Equivalent Capacity
OC-3	155.52 Mb/s	3 DS3 Equivalent Capacity
OC-1*	51.84 Mb/s	1 DS3/STS-1 Equivalent Capacity
STS-N+	N (x) 51.84 Mb/s	N (x) DS3 Equivalent Capacity

* Rarely Used North American Optical Rates And Not Compatible With CCITT Standards

** A Single Mode Fiber At 1.3 - 1.5 Microns And The 1310 - 1550 Nm Spectral Window (Wavelengths)

GULF POWER

For the Gulf Power Application, RFL provided its 9001 Intelligent T-1 Multiplexer with 1300NM LED singlemode optical interface adapters for the communications backbone of the system. For the various voice and data requirements channel cards of the Model 9001 were used. RFL's Model 9720 Pilot Wire Interface, Model 9300 Charge Comparison System and Model 9700 Digital Protection Channel were used over a 56 KBS synchronous data channel of the Model 9001 for the current differential relay and DTT requirements respectively. DTT channels shown adjacent to pilot wire relays used the DTT channel available in the Model 9720 and Model 9300. The Model 9720 was used for all HCB Interfaces while the Model 9300 replaced a pair of CPD's.

Attached Drawing TMD-2000 depicts a block diagram of the system provided. The system is designed in correlation with the fiber route that was pre-defined by Gulf Power. Two units are required at Pace Boulevard to handle A DSO channel communication between the two units. Master timing will be handled by one T-1 string while the other T-1 string will be externally clocked to provide synchronization of all multiplexers. This will allow the channel to be passed between multiplexers at the DSO (56 KBS) data rate for current differential communications between Brentwood and Bayou Chico.

Channel delay for the current differential relays becomes a concern because of the fiber route which requires the equipment to transfer channels in-between multiplexer units. The signal delay of the 9001 from input of signal at one channel card to output of the correlating channel card at the other end is 450 microseconds. This includes the throughput delays of the multiplexers in which the channel cards are located as well as the delay of the interface channel cards themselves. This does not include the propagation delay of light through the fiber which is 8.2 microseconds per mile or the throughput delays of any additional multiplexers which is 25 microseconds per node. The following is channel delay calculations for the protected line which will have the largest channel delay due to this transferring of DSO's between multiplexers.

Protected Line Between Brentwood and Bayou Chico

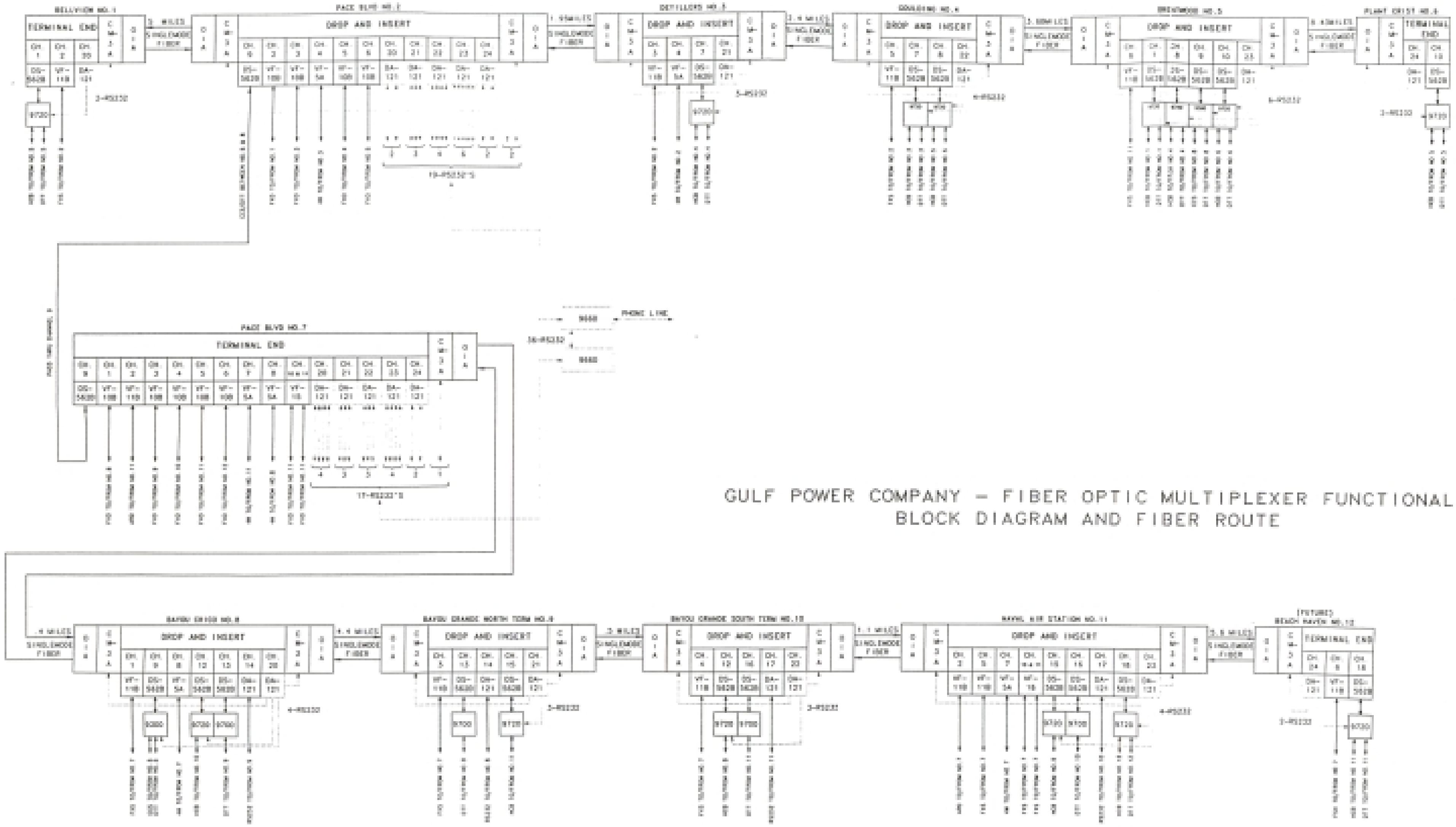
Multiplexer Signal Delay Brentwood to Pace	=	450 microseconds
Multiplexer Signal Pace to Bayou Chico	=	450 microseconds
Throughput Delay Goulding and Devilliers	=	50 microseconds
Propagation Delay (8.43 miles X 8.2)	=	69 microseconds
Total Channel Delay		1.019 milliseconds

Because of the Delay on that line section Gulf Power decided to use the Model 9300 Charge Comparison System. The Model 9300 can tolerate sudden changes in channel delay as much as 4 ms without affecting the tripping decision.

The 9300 automatically and continuously measure and correctly compensate for channel delay time, even if the channel delays in the outgoing and return directions are different.

For Networking RFL provided 7-port asynchronous data channels in conjunction with our Model 9660 which will allow the user to call into the Pace Boulevard location and have access to the whole network. This network is depicted on the attached drawing TMD-2000 as dotted lines.

GULF POWER COMPANY – FIBER OPTIC MULTIPLEXER FUNCTIONAL BLOCK DIAGRAM AND FIBER ROUTE



DOTTED LINES INDICATE NETWORK EQUIPMENT

CITY OF DANVILLE

The City of Danville project was divided into phases spread out over several years. Parts of the project have already been delivered while parts are presently being worked on and some yet to be delivered.

Attached drawing CD-39359 depicts a block diagram of the Danville System.

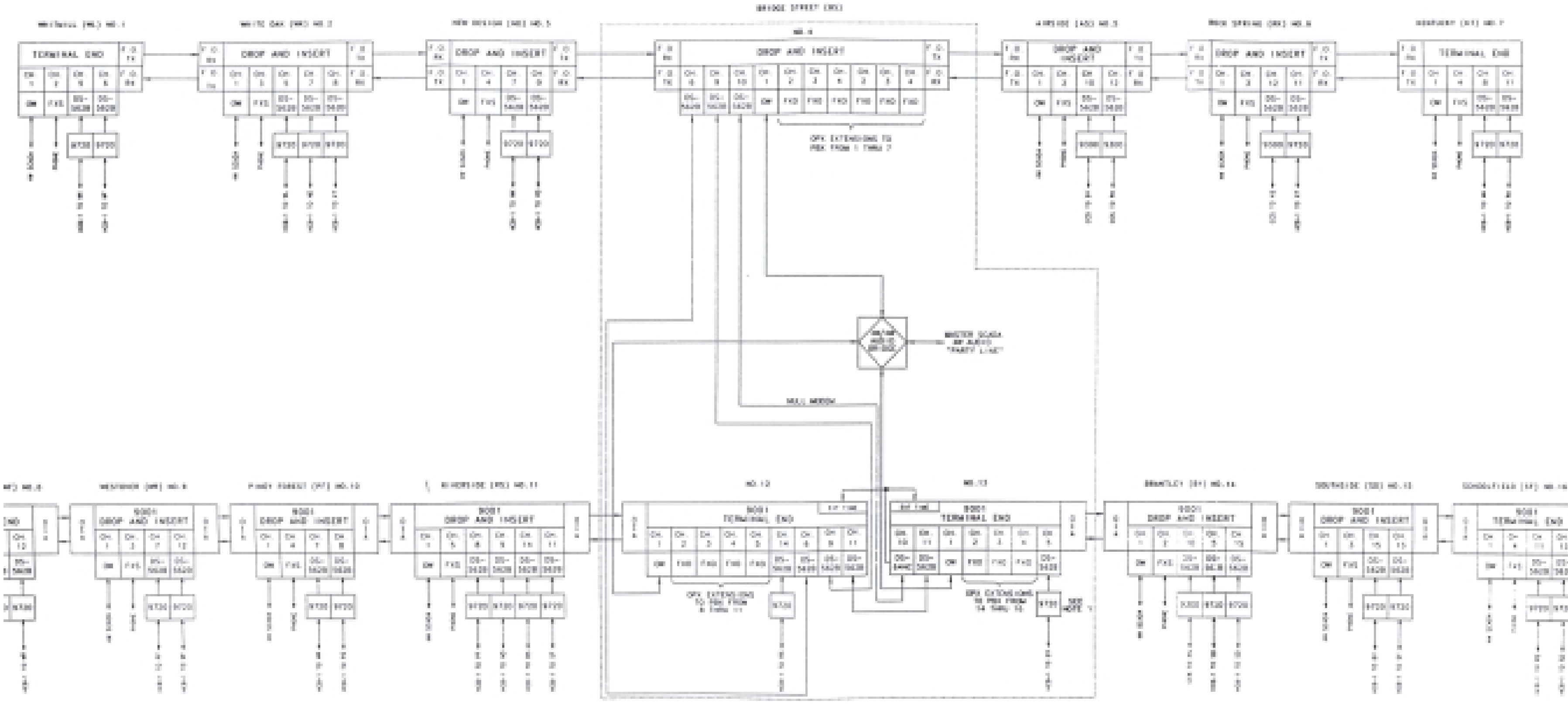
Danville's application was similar to Gulf Powers however they had two T-1 spurs off the Bridge Street Location. This required synchronization of all T-1 multiplexers by externally clocking the No. 12 and No. 13 units from the No. 4 unit at the Bridge Street location. This installation was also unique because it combined our first generation multiplexer (Model 9000 - units No. 1 through 7) with our second generation multiplexer (Model 9001 units No. 8 through 16).

The other main concern for this project was the delays incurred between current differential relays. The largest channel delay would be incurred between Whitmill No. 1 and West Fork No. 8. Using the same delay calculations as outlined in the Gulf Power description the following delays will be expected.

Protected line between Whitmill and West Fork

Multiplexer Signal Delay Whitmill (#1) to Bridge St. (#4)	=	450 microseconds
Throughput Delay of White Oak (#2) & New Design (#3)	=	50 microseconds
Multiplexer Signal Delay Bridge St (#12) to West Fork (#8)	=	450 microseconds
Throughput Delay of Westover (#9), Piney Forest (#10) & Riverside (#11)	=	75 microseconds
Propagation Delay (29 miles X 8.2)	=	238 microseconds
Total Channel Delay	=	1.263 milliseconds

Although this channel delay is excessive for older electromechanical current differential relays it does not exceed the maximum delay setting of the 9720 which is 2 milliseconds. Depending on the utility one might decide to go with the more reliable relay, Model 9300, as Gulf Power did in their application.



NOTES:
1. 9720 RELOCATED FROM ROCK SPRING.

CITY OF DANVILLE
DRAWING NO.2
FUNCTIONAL BLOCK DIAGRAM

DACS

On occasion a utility may be find a need to operate their multiplexer into a Digital Access and cross-connect system (DACS).

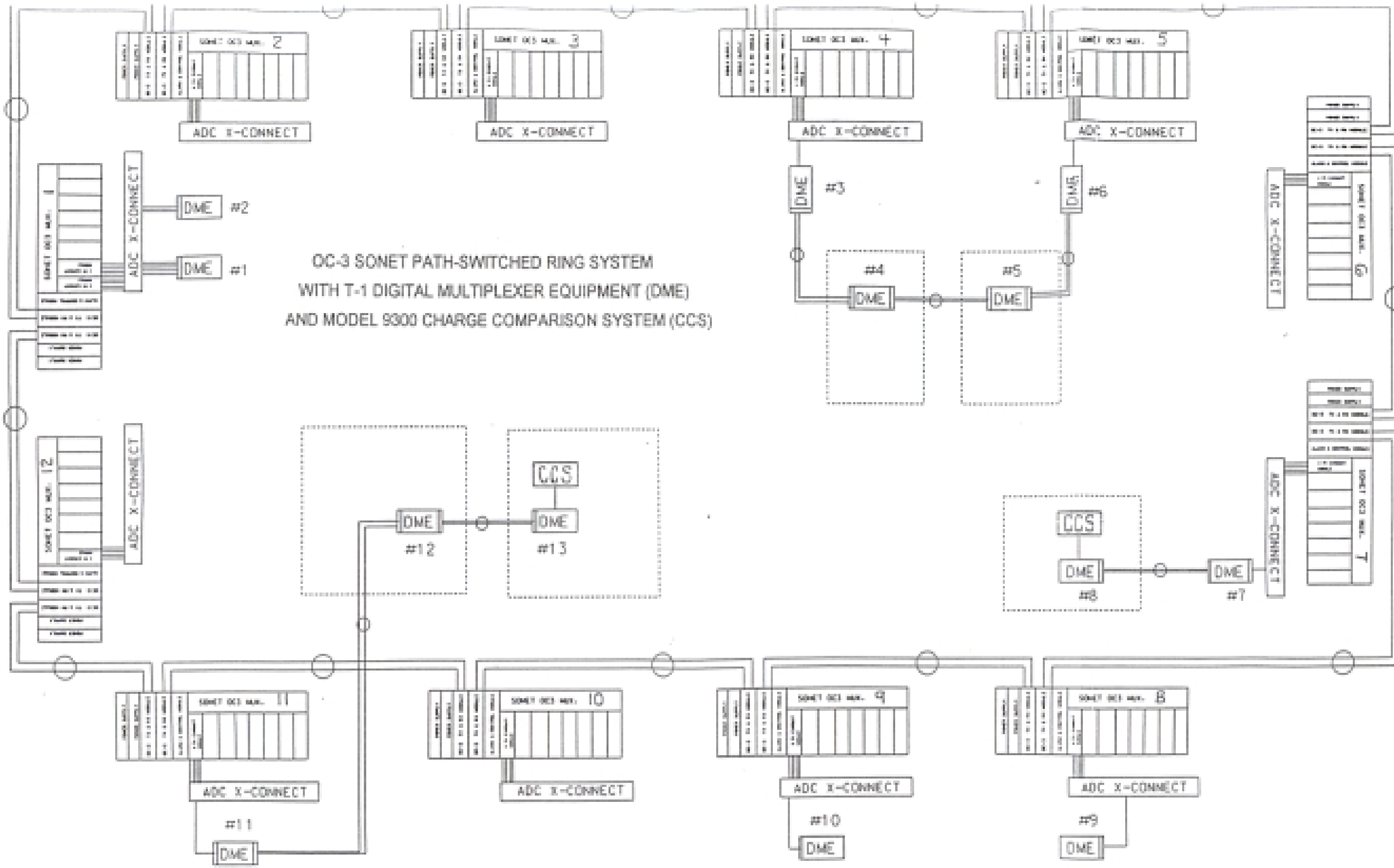
A DACS is an electronic replacement for gigantic wire frames and patch panels that provided DSO level access for central office testing and manual cross-connects using punched down wires and patch cords.

The DACS accepts multiple T-1 streams and can re-route the entire DS1 or individual DSO channels to a different output port. The DACS electronically extracts the information from one DSO time slot and place it into another, as defined by a pre-set switch plan.

The connections can be altered manually, by an operator, or automatically by a stored program. The DACS is typically software controlled and provides some level of diagnostics.

Attached is a block diagram illustrating the DSO grooming.

The main concern a utility needs to be aware of is the channel delay through a DACS. Typical throughput delays of a DACS unit is anywhere from 2 to 3 frames or 250 microseconds to 375 microseconds. This delay may become prohibitive if there is any Current Differential or Blocking applications they may communicate through a DACS.



PATH SWITCHED RING PRIMARY CLOCKWISE COMMUNICATIONS PATH CHANNEL DELAYS

Channel Delay CCS/DME #8 to CCS/DME #13

DME signal delay of DME #8 and DME #13	= 450 microseconds
Throughput delay of DME #7, 11 and 12 (3 x 25us)	= 75 microseconds
DS1 throughput delay of SONET #7, 8, 9, 10, and 11 (5 x 50us)	= 250 microseconds
SONET DS1 synchronization delay	= 100 microseconds
Propagation delay (10 miles x 8.2us/mile)	= 82 microseconds
TOTAL	= 957 microseconds

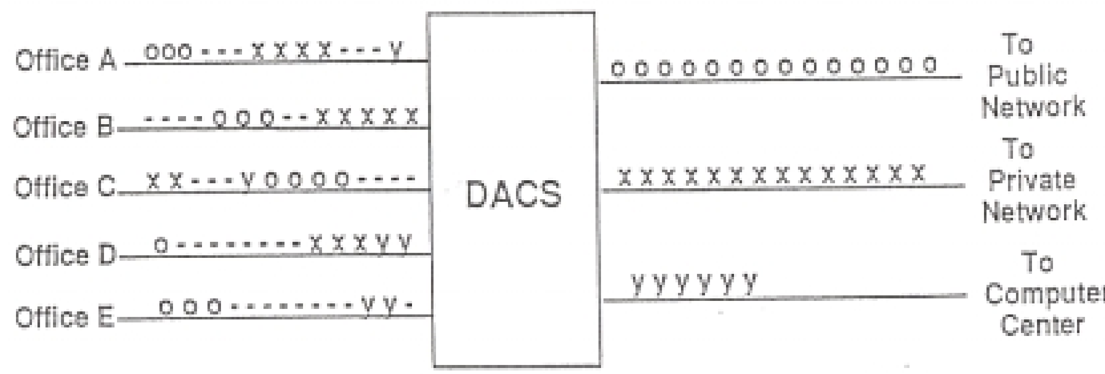
Channel Delay CCS/DME #13 to CCS/DME #8

DME signal delay of DME #13 and DME #8	= 450 microseconds
Throughput delay of DME #12, 11 and 7 (3 x 25us)	= 75 microseconds
DS1 throughput delay of SONET #11, 12, 1 thru 7 (9 x 50us)	= 450 microseconds
SONET DS1 synchronization delay	= 100 microseconds
Propagation delay (15 miles x 8.2us/mile)	= 123 microseconds
TOTAL	= 1,198 microseconds

TMD-2001

RFL Electronics Inc.

DIGITAL ACCESS CROSS-CONNECT SYSTEMS
Illustration of DACS Grooming



SONET

Attached drawing TMD-2001 depicts a block diagram of an OC-3 SONET path-switched ring system consisting of 12 OC-3 units. Communicating through the SONET ring system are T-1 Digital Multiplexers which enter the SONET system via a 4 T-1 circuit module integral to the SONET system itself.

The OC-3 SONET system No. 1 is the central office location where voice communications from all T-1 multiplexers are communicated. A DACS is required at this location to handle all the DS0 grooming needed to separate the voice from the data information.

Among other things, current differential relaying is handled by the model 9300 Charge Comparison System (CCS). The model 9300 is ideal for this application because it can handle unequal transmit and receive channel delays that can be a result of using a path-switched ring SONET solution. To demonstrate this, channel delays are calculated to show the different delays incurred when operating the T-1 Digital Multiplexer Equipment (DME) in the clockwise direction around the ring between DME #8 and DME #13.

Obviously there is much more that would be communicated on a SONET system of this nature but we simplified this application just to give you an understanding of the types of considerations that must be addressed in order to insure a reliable system.