INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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SECOND WORKSHOP ON TELEMATICS

6 - 24 November 1989

Wide Band Network

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KTA International, Seoul, Korea

1. Introduction

Definition: Any network that carries wider Bandwidth than 64 KBPS or 4 KHz.

Examples of wideband network

* By Services
  - Voice or Audio Signals
    - Inter-office Trunks
    - Stereo Broadcasting Signals
  - Data Signals
    - Local Area Network
    - Metropolitan Area Network
    - PSDN
  - Video Signals
    - CATV
    - Television Broadcasting
    - DBS
    - HDTV
  - Broad Band ISDN

* By transmission media
  - Copper wires
    - Pair wires (T1 & T2)
    - Coaxial Cables (L-carrier & CATV)
  - Open Air Media
    - Terrestrial Radio Wave (AM/FM, Microwave)
    - Satellite Communication
  - Fiber Optics

TREND OF TRANSMISSION NETWORK

- Servicewise
  - Voice (Audio) Service
  - Data Services
  - Video Services
  ⇒ BISDN

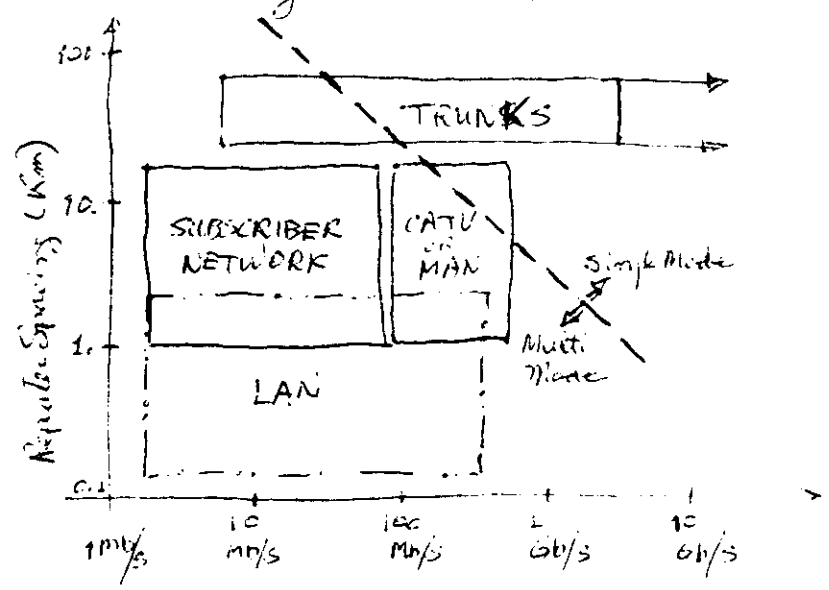
* Mediawise
  - Copper Wire
  - Open Air
  - Fiber Optics
  ⇒ Fiber Optics

Concentration of This Lecture:

Fiber Optics Network
and
Broad Band ISDN

- Fiber Optics Trunking Networks
  - Land Based
  - Submarine System
  - SONET
  - ATM
- Local Area Network
- Optical Cable Television (CATV)
- Optical Subscriber Network
  - Trends in Subscriber Area
  - ISDN
  - BISDN
- Future of Wide Band Network.

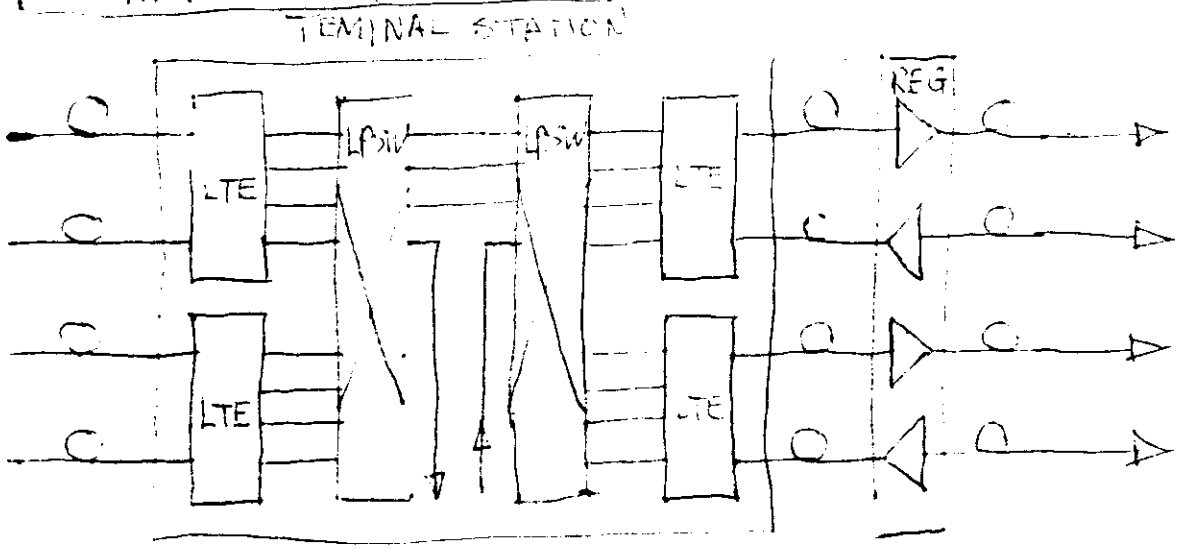
2. Trunking Networks



Practical Optical Transmission Bit Rate

6.3 MBPS → 1.6 GBPS.

2.1 REPEATED NETWORK



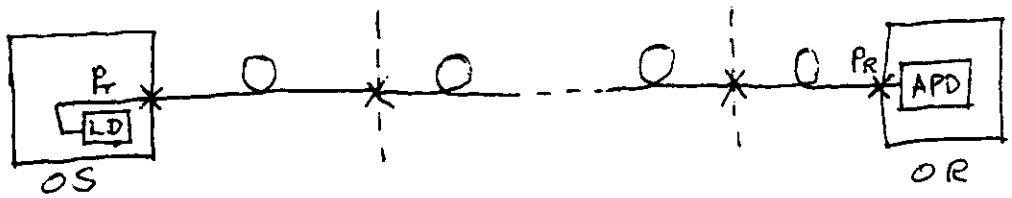
LTE: TERMINAL EQUIPMENT
REG: REGENERATOR
LFSW: CIRCUIT "CHANNEL" SWITCH

2.1.1 BLOCK DIAGRAM OF TYPICAL REPEATED TRUNK

2.1.2 RULES OF TRANSMISSION CODING

① Constant DC
② Narrower Bandwidth
③ Easy extraction of Timing information
④ Certain limitation of Continuous Mark or Space
⑤ TX/RX signal Ratio (The larger the better)
⑥ Monitoring and Control Signals can be inserted.
⑦ In-service Monitoring.
⑧ Simple conversion network.

2.1.3 DESIGN of Signal to Noise Ratio



—✕— : CONNECTOR

LD : LASER DIODE APD : AVALANCH PHOTO DIODE

OS : OPTICAL SENDER OR : OPTICAL RECEIVER

P_T : OPTICAL TRANSMITTING POWER LEVEL (PEAK) 1.0 DBm

P_R : OPTICAL RECEIVING POWER LEVEL (PEAK) −28.0 DBm

POWER PENALTY	0.9 DB	
CONNECTOR LOSS	2.4 DB	
SYSTEM MARGIN	3.0 DB	29 DB
FIBER LOSS ALLOWANCE	22.7 DB	

EXAMPLE OF LEVEL DISTRIBUTION

2.1.3.1 Estimation of Power Penalty

a). Penalty due to Band Width limitation of Fiber

Bandwidth for a fiber of L Km

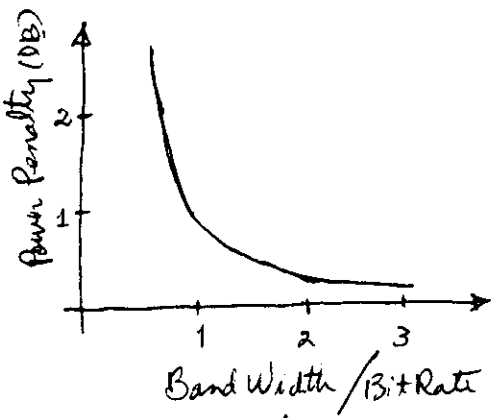
$$f_{cL}^{-2} = f_{mode-L}^{-2} + f_{chromatic}^{-2}$$

where $f_{mode-L} = \dfrac{f_{mode-1}}{L^{\gamma}}$

f_{mode-1} : BW of 1 Km fiber due to Mode dispersion

γ : 0.7 ~ 1.0

$f_{chromatic}$: BW due to Material dispersion



Power Penalty due to Band Width limitation

b). Power Penalty due to Modal Noise

- Light Source Output Variation
- Connector Loss Variation
- Output variation of Equalizer.
  - * Significant for Multimode System

c). Penalty due to Mode Distribution Noise

* Noise due to Single-mode ⇔ Multi mode LD

① Spectral Width of Source

② Spectral Jitter

③ Fiber's characteristics of wave length dispersion

④ Equalizer Method of Receiving Circuit.

* Pratical penalty range 2 ~ 3 db at max.

2.1.4 ~~2.4~~ Characteristics of Multi-repeater system

For a digital system of multi-repeater arrangement Two most important performance figures are Error Rate and Jitter.

2.1.4.1 ~~2.4.1~~) Error Rate (P_{ei})

Error ~~rate~~ of each repeater is independant of each other. Thus total error rate P_{ex} becomes:

$$P_{ex} = \sum_i P_{ei}.$$

In ~~gen~~. practice, the error rate of worst repeater dominates.

2.1.4.2 ~~2.4.2~~) Jitter

a). Jitter Transfer Function

Let $H(\omega)$ be freq. characteristics of timing circuit, then jitter transfer function, $G(\omega)$, of a repeater becomes

$$G(\omega) = \frac{1}{2}\{H(\omega_0 + \omega) + H^*(\omega_0 - \omega)\}$$

where ω_0 is timing freq.
H^* is conjugate of H

b). Accumulation of Jitter

- Accumulation of same phase jitter is most significant. For this case $\theta_0(\omega)$ from the first repeater input can be shown after n repeaters of same TF $G(\omega)$:

$$\theta_n(\omega) = \sum_i^n \theta_0(\omega) G^i(\omega) = \frac{G(\omega)\{1 - G^n(\omega)\}}{1 - G(\omega)} \cdot \theta_0($$

- For a single resonance circuit from above (a) $G(\omega)$ can be written

$$G(\omega) = \frac{1}{1 + j\frac{2Q\omega}{\omega_0}}.$$

Therefore

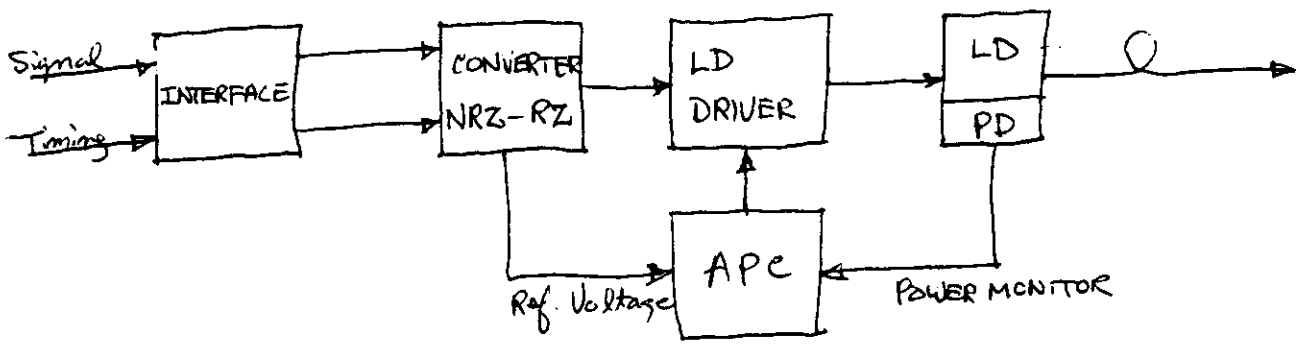
$$\theta_n(\omega) = \frac{1}{j\frac{2Q\omega}{\omega_0}}\left[1 - \left(\frac{1}{1 + j\frac{2Q\omega}{\omega_0}}\right)^n\right]\theta_0(\omega)$$

and power of jitter becomes:

$$\Phi_n(\omega) = \frac{1}{\left(\frac{2Q\omega}{\omega_0}\right)^2} \cdot \left| 1 - \left(\frac{1}{1 + j\frac{2Q\omega}{\omega_0}}\right)^n \right|^2 \Phi_i(\omega)$$

2.1.5 Design of Optical Transmitter and Receiver

2.1.5.1 Transmitter



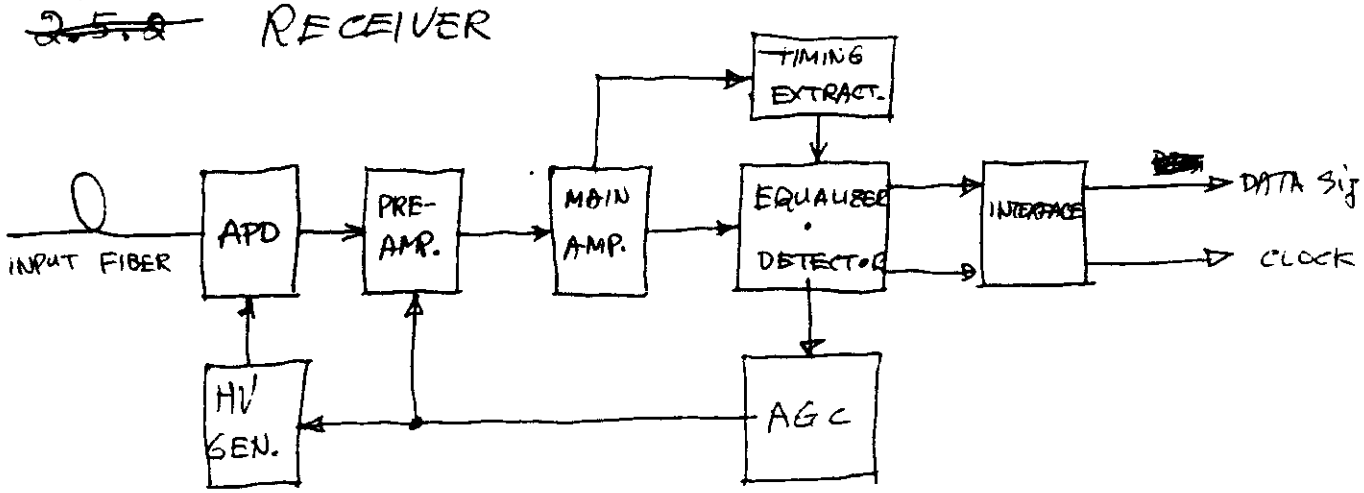
LD : LASER DIODE PD : Photo DIODE

APC: Auto Power Controller

AN EXAMPLE OF PHOTO TRANSMITTER.

2.1.5.2

~~2.5.2~~ RECEIVER



AGC: Automatic Gain Control

~~AGC~~

AN ~~EXAMPLE~~ OF PHOTO RECEIVER

2.2 Monitoring & Switching

2.2.1 Reliability of Repeated Transmission System

- Overall Evaluation Measure:

$$\frac{\text{COST}}{\text{PERFORMANCE}} = \frac{\text{ECONOMY (PRICE + OPERATING COST)}}{\text{PERFORMANCE (CHARACTERISTICS + RELIABILITY)}}$$

- To increase reliability, continuous monitoring and switching functions are essential.
- Switching of Transmission Path
  - ① System Switching (Use spare core in a same cable)
  - ② Route Switching
- Unavailability of system (W)

$$W = \frac{MTTR}{MTBF + MTTR}$$

MTTR : Mean time to repair
MTBF : Mean time between Failure

Since $MTTR \ll MTBM$

$$\fallingdotseq \frac{MTTR}{MTBF}$$

$$= fit \times MTTR$$

- For a given System $UA \propto MTTR$
- To reduce MTTR, switching failed system out and replacing it with a good system, then repairing the failed system

2.3.2 UNAVAILABILITY OF SWITCHED SYSTEM

(1) System Switching

$$W_s = \sum_{i=0}^{n} {}_nC_i W_o^i \cdot \sum_{k=n-i+1}^{m} ({}_mC_k W_o^k / m) + W_{r2}$$

m: Active systems per cable
n: Spare Systems per cable
W_o: Unavailability without switching
W_r: " due cut route

When $n=1$ (Spare core = 1),

$$W_s \fallingdotseq \frac{{}_mC_2 W_o^2 + {}_mC_1 W_o^2}{m} + W_{r2}$$

i.e. Failure in more than 1 system and route failure determine the unavailability of system.

(2) Route Switching

$$W = N \frac{(W_{r2}^2 - W_r \cdot W_s)}{2}$$

N: Number of Route
W_{r2}: Total route unavailability
W_s: Unavailability of system switching within each route

In general W_x, W_s are in the order of $10^{-3} \sim 10^{-4}$. Thus [redacted] route switching / Network with system switching greatly increases ~~[redacted]~~ reliability.

2.2.3 Circuit Monitoring

- Circuit Monitoring
- Equipment Monitoring
  - Special provision to monitor Bias current of LD.

2.3 Hierarchy of Interoffice Trunks

2.3.1 North American System

Primary Rate	1.544	MBPS
2nd "	6.3	MBPS
3rd "	45.	MBPS

Higher Rate multiples of 45 MBPS.
45 MBPS, 90 MBPS, 135 MBPS, 405/417 MBPS, 565 MBPS, 810 MBPS

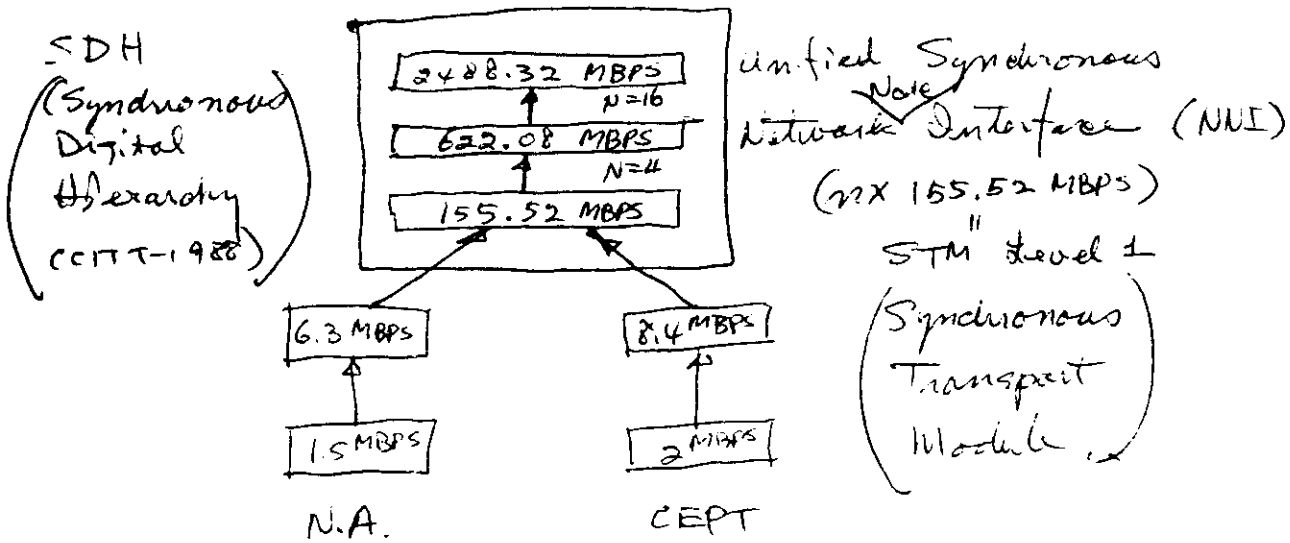
2.3.2. European System

Primary Rate		
2nd	"	8.4 MBPS
3rd	"	34. MBPS
4th	"	140. MBPS
5th	"	565. MBPS

2.3.3 Japanese System

Primary Rate		1.544 MBPS
2nd	"	6.312 "
3rd	"	32.064 "
4th	"	97.728 "
5th	"	397.200 "

2.3.4 Unification of Optical System Hierarchy



2.4 Submarine Cable Transmission

2.4.1 Characteristics of Optical Submarine Cable.

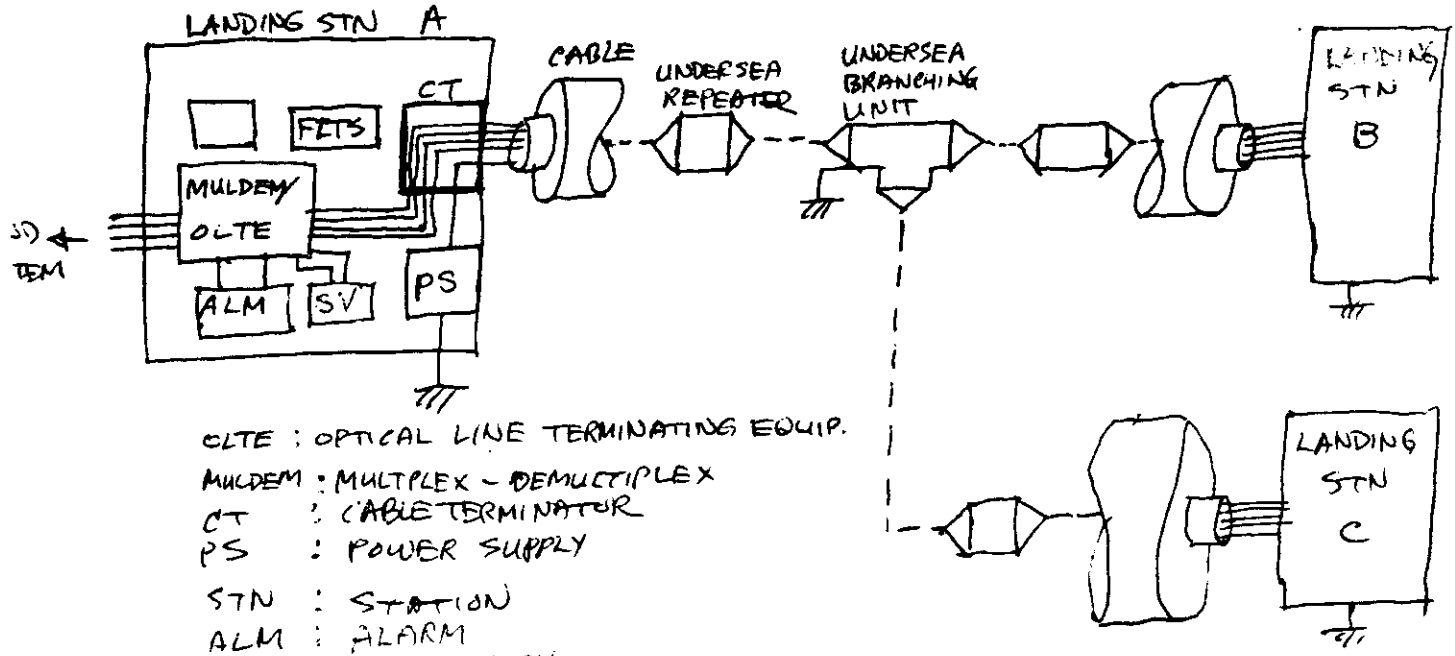
① Longer Repeater Spacing and High Speed Digital Transmission System → Good for ISDN

② Multi cored Optical Fiber Cable
- → Multi System Transmission
- → Space Division Multiplex is possible
- → Under Sea Branching is possible
- → Multiple Landing Site
- → Flexible Network Arrangement.

③ More Than 10 years of MTBF Required

④ Longer Repeater Spacing → Quicker and more accurate Monitoring System is required.

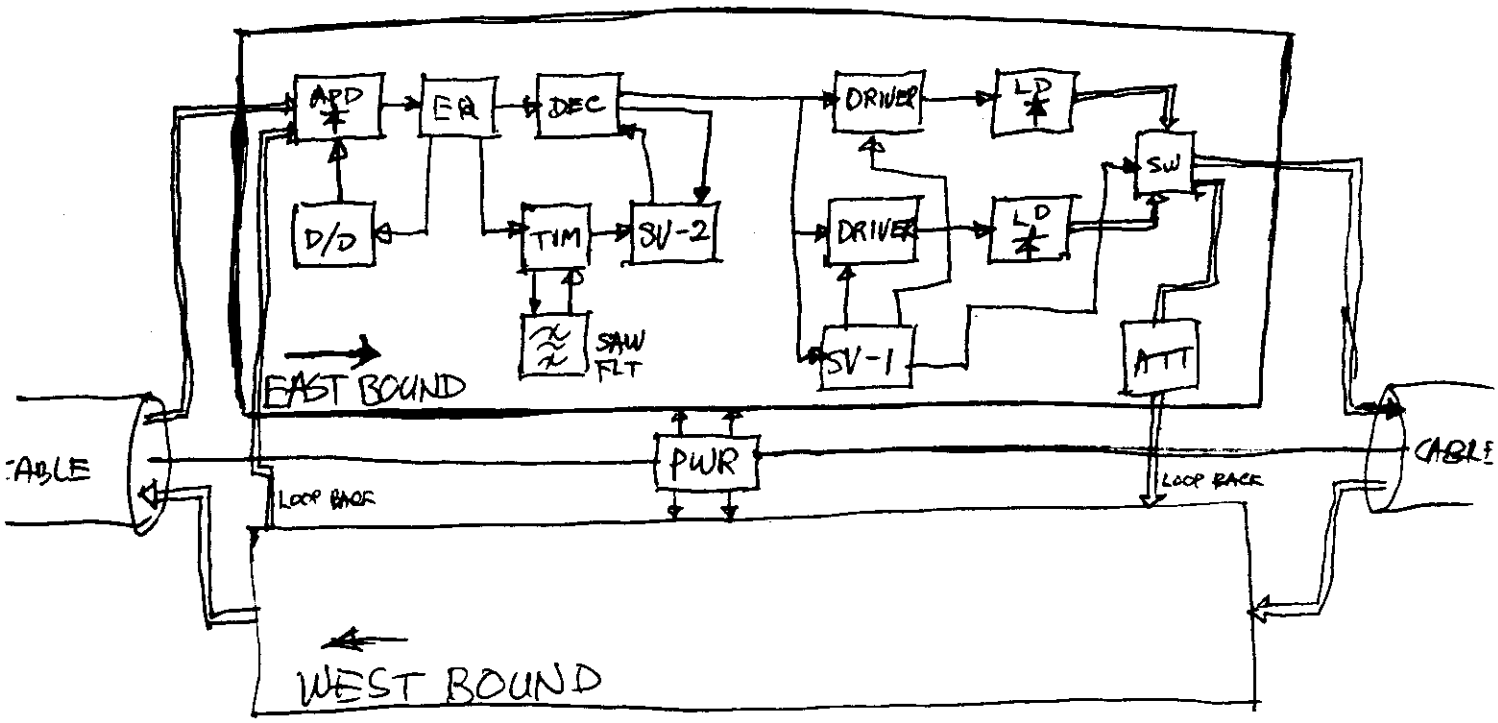
2.4.2 Submarine Cable System



OLTE : OPTICAL LINE TERMINATING EQUIP.
MULDEM : MULTIPLEX - DEMULTIPLEX
CT : CABLE TERMINATOR
PS : POWER SUPPLY
STN : STATION
ALM : ALARM
SV : SUPERVISORY

AN EXAMPLE OF SUBMARINE CABLE SYSTEM

2.4.3 Undersea Repeater



AN EXAMPLE OF UNDERSEA REPEATER

EQ: EQUALIZER
DEC: DECODER
TIM: TIMING
D/D: Diode Control
ATT: ATTENUATOR
SW: Optical Switch.
SV: Supervisory

Design Consideration

① Minimize No. of Active devices by using IC
② Cold Stand-by Laser Diode → TX Life extention
③ Super High Reliable Component
④ MTBF to 10 years.

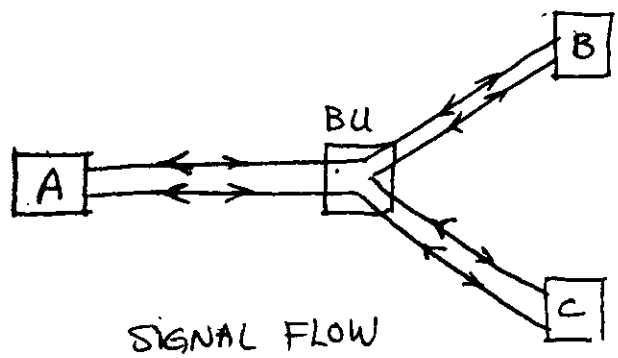
Monitoring And Testing

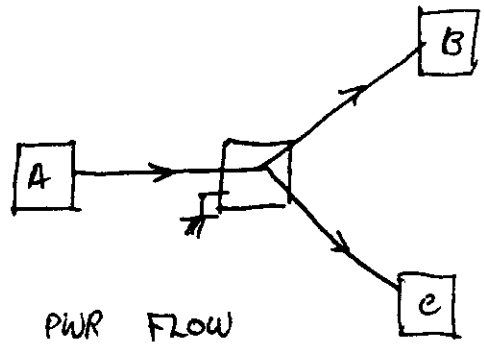
Out of Service Monitoring
- ① Loop Back Path is used to locate fault detection.
- ② Remote switching of Laser Diode
- ③ Bias voltage is read and sent back to Land site
- ④ Power level monitoring
- ⑤ Identification of Active LD (Spare or not)

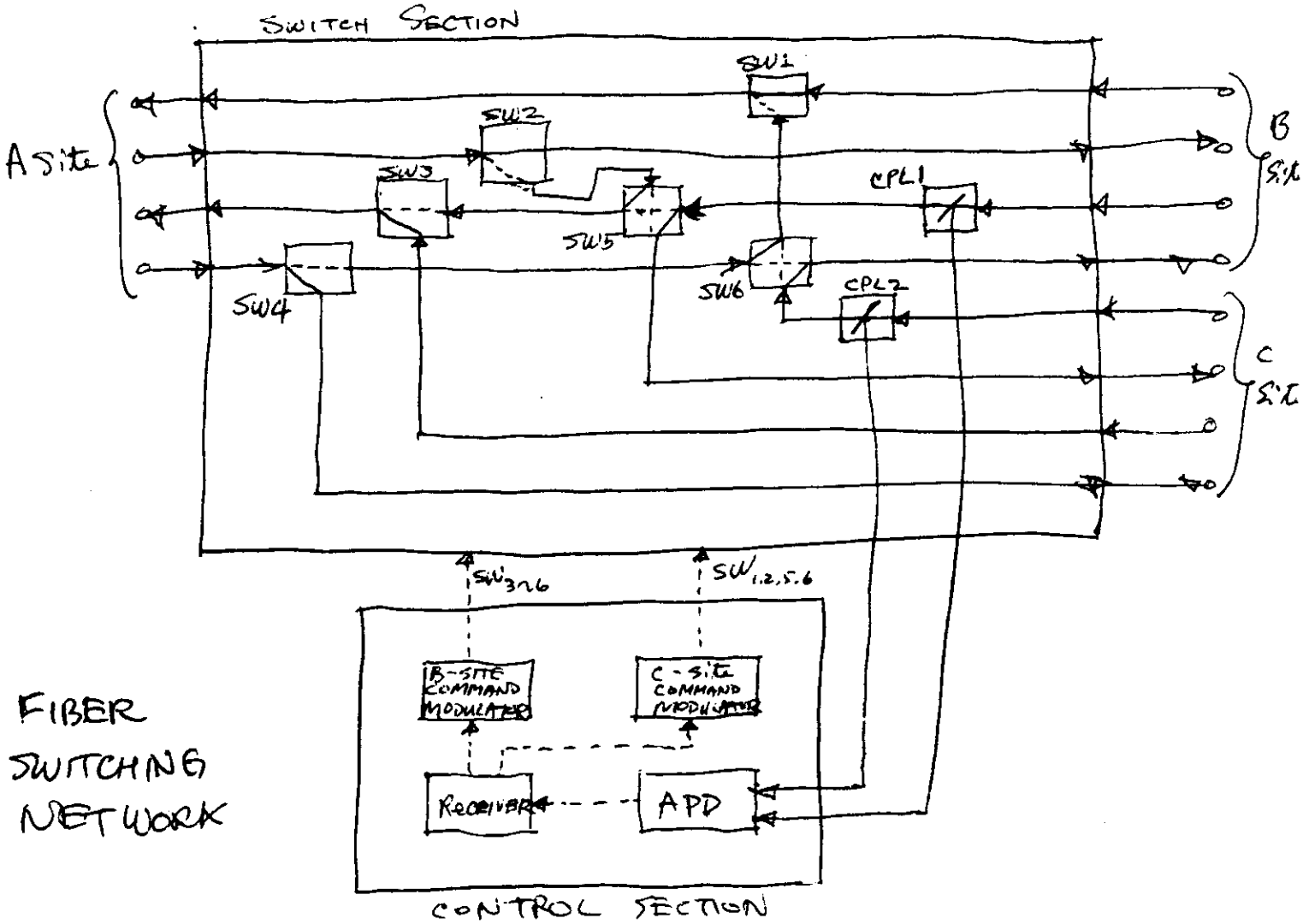
⊕ In Service Monitoring
- ① Code error monitoring
- ② 24 B 1P - Parity Violation
- ③ Parity error reported by phase modulation of clock signal to [redacted] base station.
- ④ Indentification of Faults

[redacted].

2.4.4. Undersea Branching Unit







FIBER SWITCHING NETWORK

5. Optical Subscriber Network

5.1. Application of Optical Transmission to Subscribers

5.1.1 Advantage of Subscriber Fiber Network
- Wider Bandwidth

Telephone + Low Speed Data Service

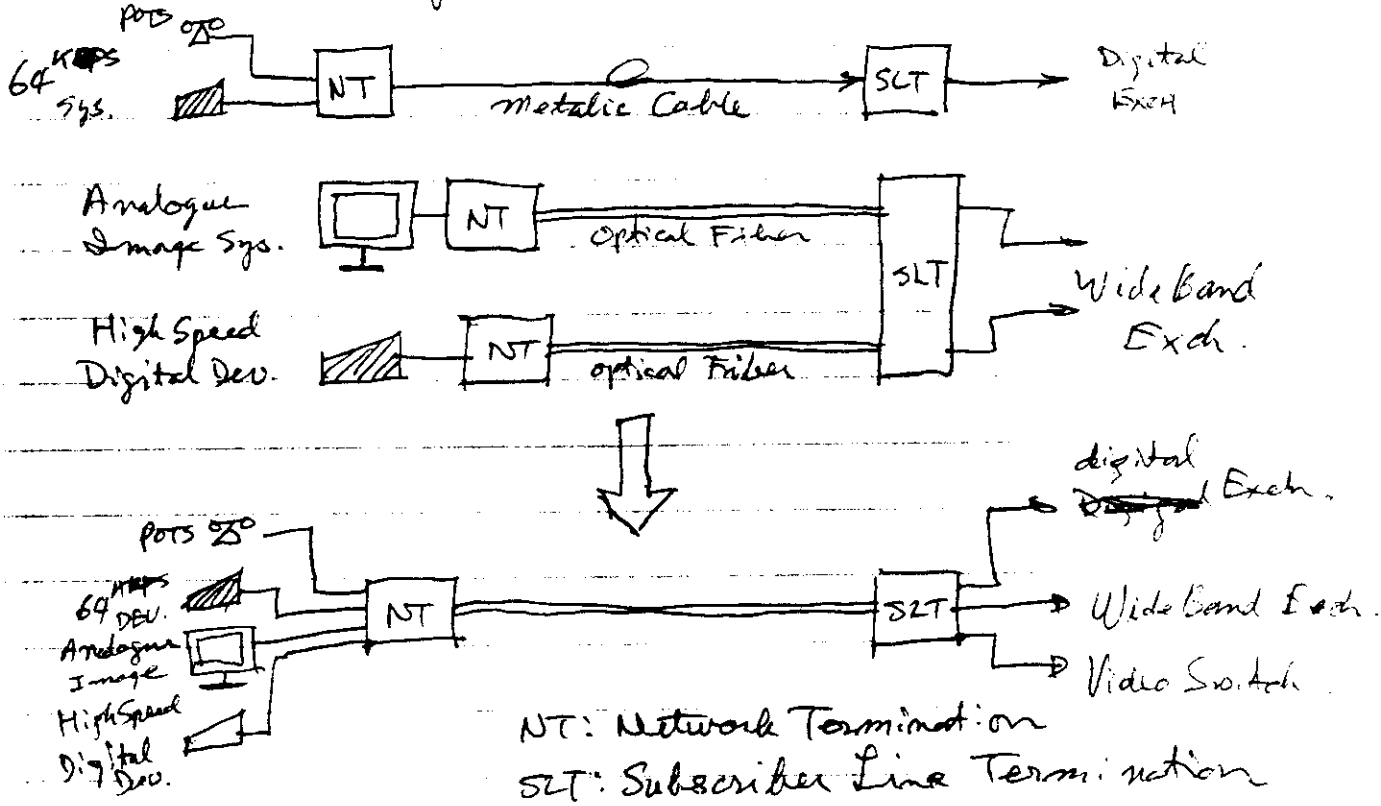
↓

High Speed FAX, Moving Image Transmission

↓

Build most important Infrastructure of Future Information Age

1.2 Examples of Optical Subscriber Lines.



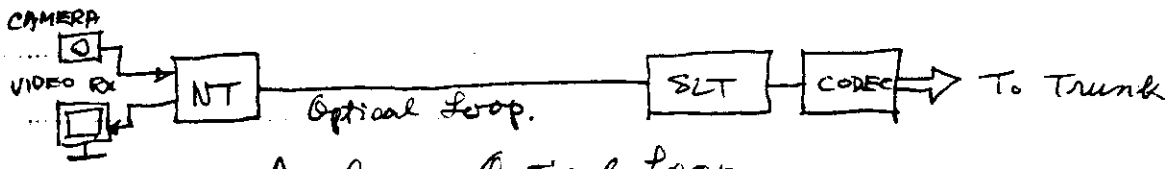
* OBJECTIVES OF OPTICAL TRIALS

- To answer to the growing needs of sophisticated telecomm. services.
- To develope and prove technical possibilities.
- To find a solution for economically feasible services
- To test user popularity of some new services.

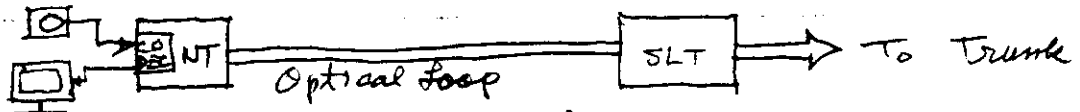
* Some Fiber Optic Subscriber Loop Test Projects.

- Canadian Elie Project (1981)
  160 Users, TV, FM Broadcasting, POTS and Data Service
- British Miltonkeynes System (1982)
  18 Users, TV, FM, Videotex, etc
- French Biarritz Project (1983)
  1,500 Users, POTS, TV, Picture Phone, FM, etc.
- West German Bigfon Project (1983)
  320 Users, POTS, Picture Phone, TV, FM. etc.
- Japanese INS Model Project (1983)
  300 Users, POTS, Picture Phone, High Speed Data Service
  etc.

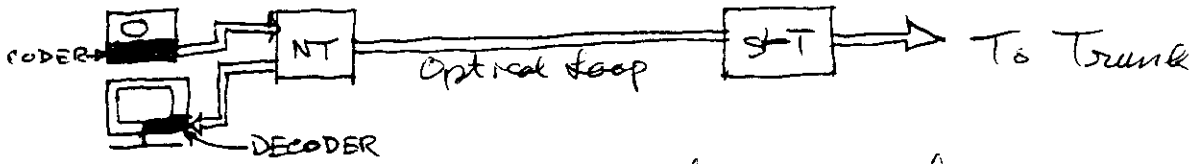
5.1.3 Evolution toward Digital Loop (Video Signals)



Analogue Optical Loop



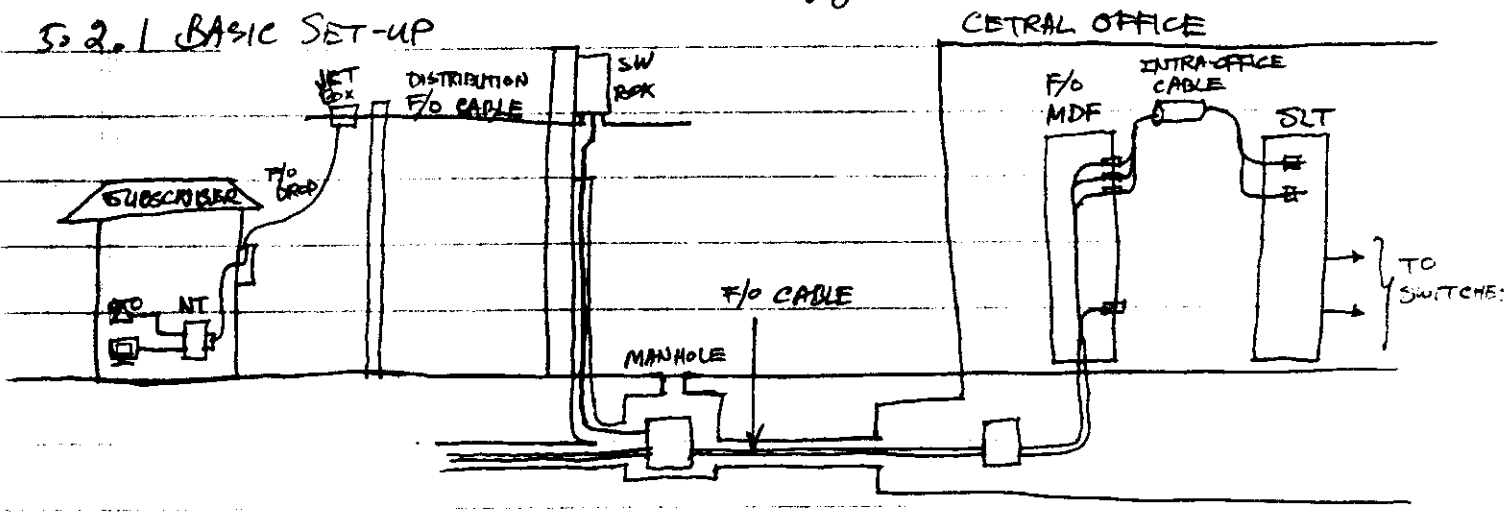
Digital Optical Loop.



Fully Digital Optical Loop.

5.2. Optical Transmission Technology in Subscriber Network.

5.2.1 BASIC SET-UP



OPTICAL SUBSCRIBER SYSTEM

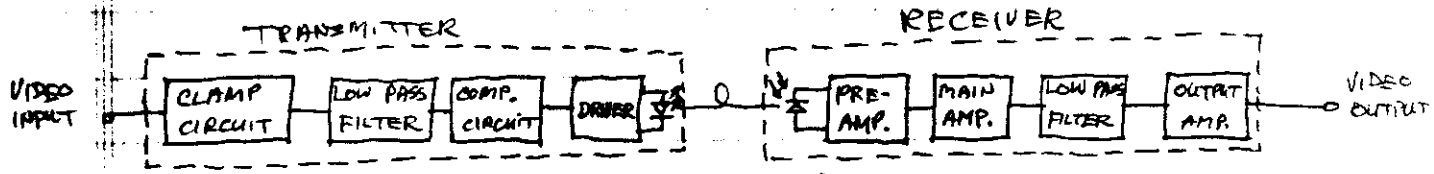
NT: • Network Termination
- Interface to Network
- Supplies power to telephone set
- Unified connection to Network

SLT: • Subscriber Line Termination
- Subscriber code conversion to match CO code.
- Interface for CO Equipment.
- Fault monitoring of Subscriber Lines
- Identification and separation of Fault.

5.2.2 Optical Transmission

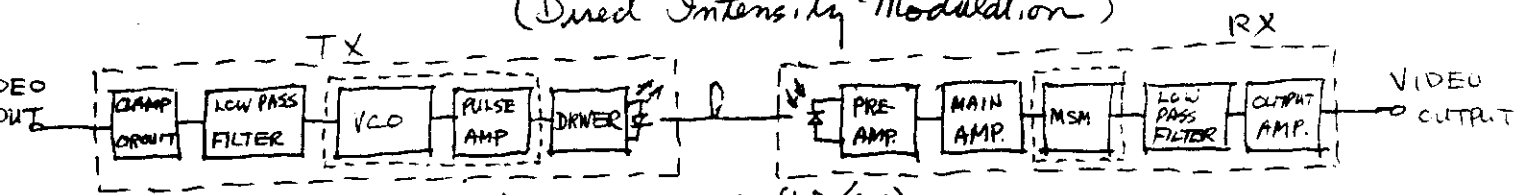
2.2.1 Optical Modulation

a). Analogue Intensity Modulation



Analog D-IM (LED/GI)

(Direct Intensity Modulation)



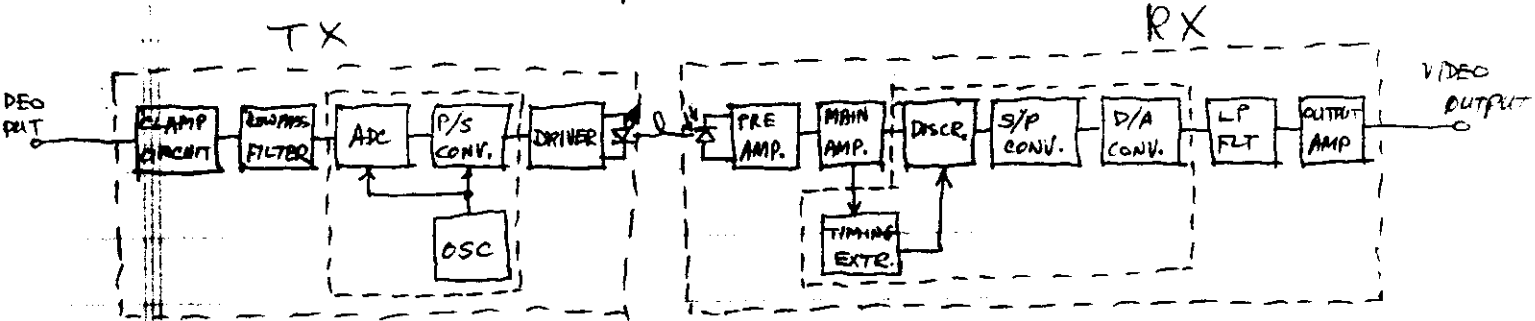
Analog PFM-IM (LD/SM)

(Phase Freq. Modulation)

VCO: Voltage Controlled Oscillator

MSM: Mono Stable Multivibrater

b. Digital Intensity Modulation



ADC: Analogue to Digital Converter

P/S: Parallel to Serial, S/P: Serial to Parallel

DISCR: Discriminator

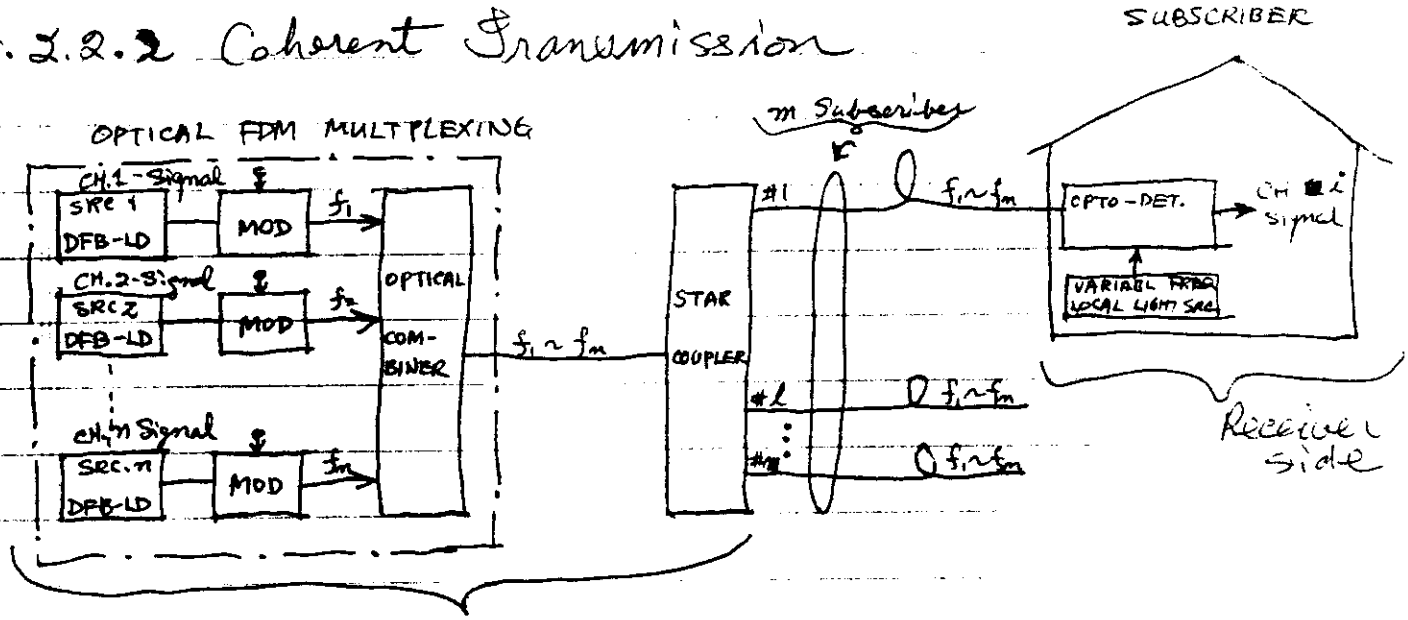
EXTR: Extraction

* Bit Sequence Independency (BSI)
  - Timing Extraction from Received Signal
  - When a long continuous sequence of zeros shows, sync can be lost

* Method of Transmission Sequence Coding

- Scrambled Binary
  $2^n - 1$ maximum periodic sequence
- Block Code - mBnB
  m Bit Binary sequence is made to n Bit ($n > m$) sequence that probability of Mark be $\frac{1}{2}$.
- Pulse Insert Code - mB1C
  m Bit binary sequence is added by 1 bit which is complementary to last bit.
- Biphase Codes : (Need 2 times Bandwidth)
  Coded Mark Inversion (CMI), Differencial Mode Inversion (DMI
  Manchester Code.

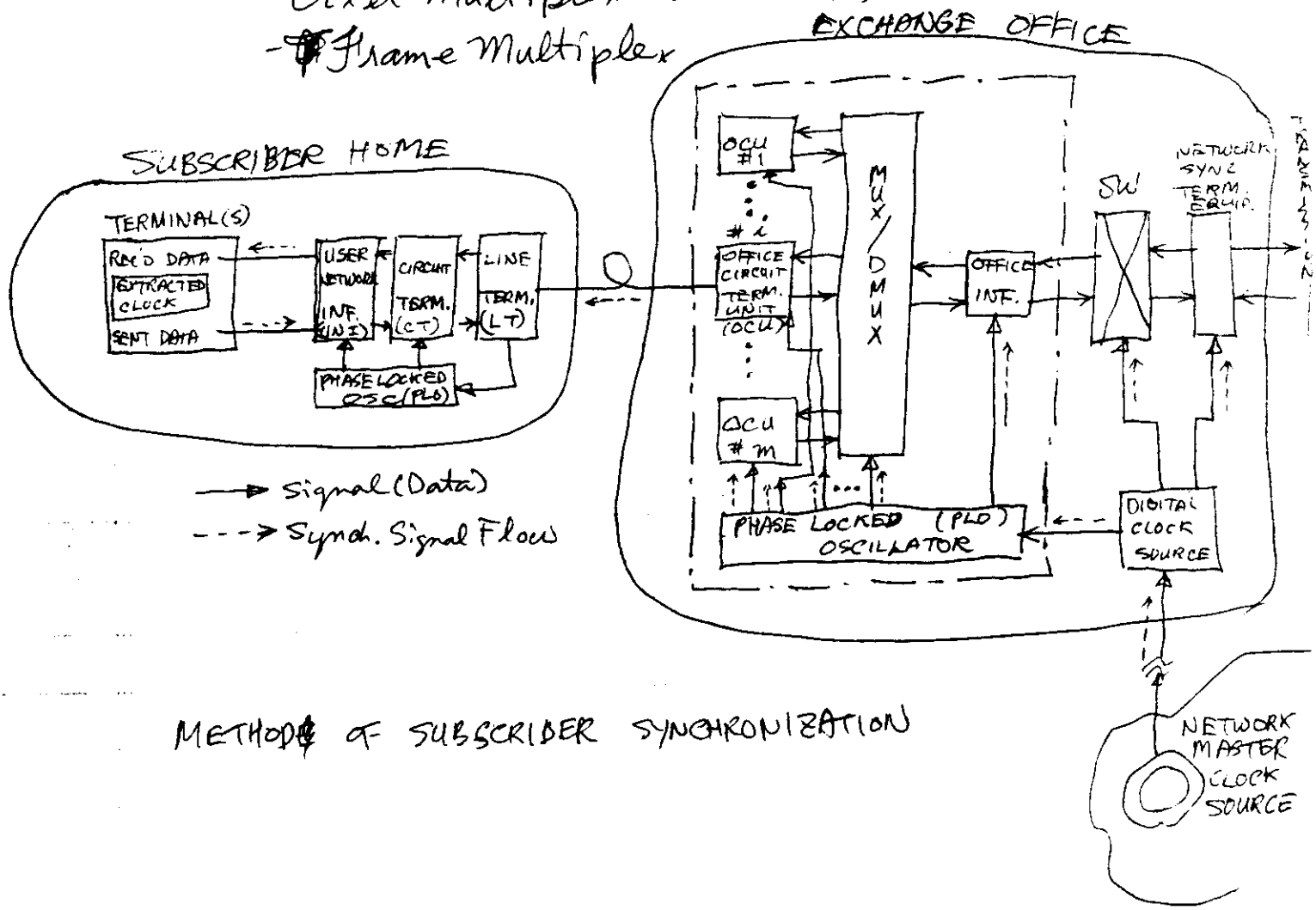
5.2.2.2 Coherent Transmission



AN EXAMPLE OF COHERENT LIGHT SUBSCRIBER NETWORK

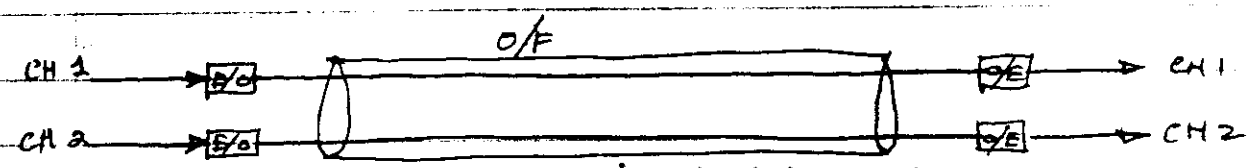
5.2.2.3 Synchronization Signal Multiplexing

- Optical Subscriber (OS) must extract sync signal from Network or received ~~signal~~ data. (NT's responsibility)
- Terminal Equip. (receives) sends signal ~~out~~ in asynch. with NT's synch. signal.
- For simultaneous services, NT or SLT must multiplex many signals, for this synch. info. is essential.
- Methods commonly used are
  - Bit Multiplex
  - Octet Multiplex (ISDN STO)
  - ~~F~~ Frame Multiplex

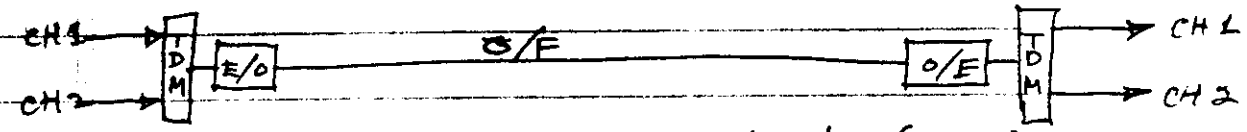


METHOD OF SUBSCRIBER SYNCHRONIZATION

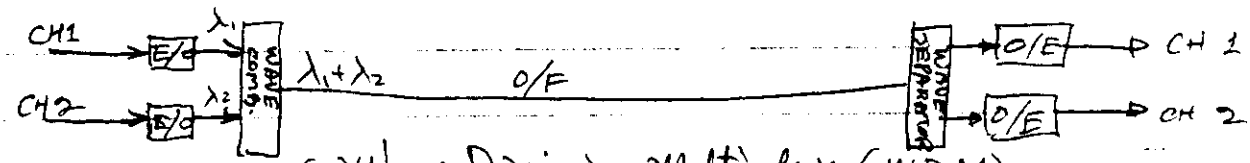
5.2.3 MULTIPLEXING TECHNICS



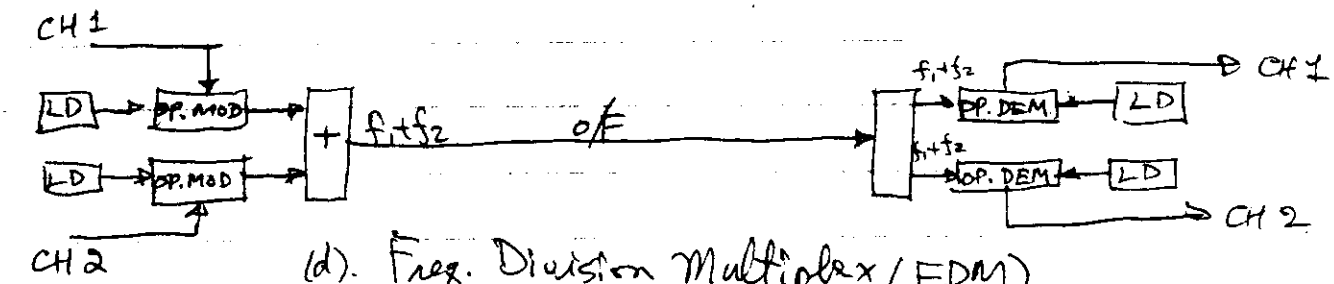
(a) Space Division Multiplex (SDM)



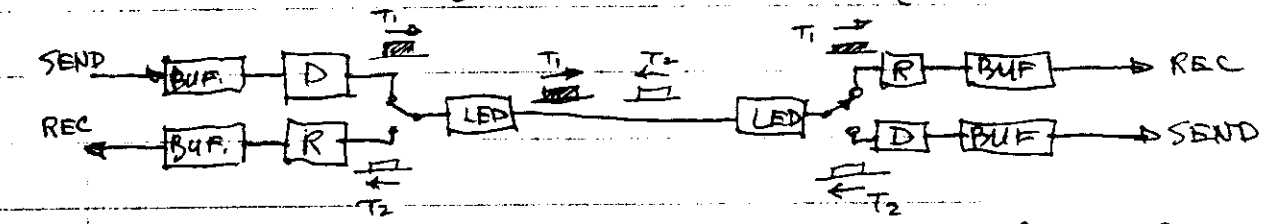
(b) Time Division Multiplex (TDM)



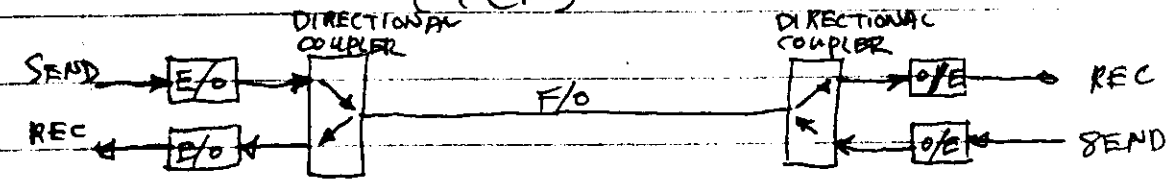
(c) Wave Division Multiplex (WDM)



(d). Freq. Division Multiplex (FDM)



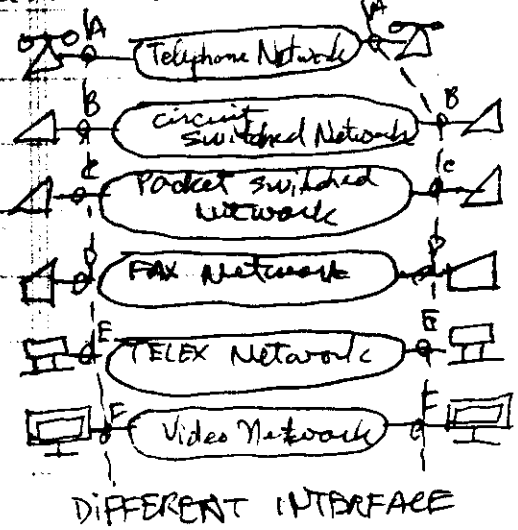
(e) Time Compressed Multiplex (Ping Pong Method) (TCM)

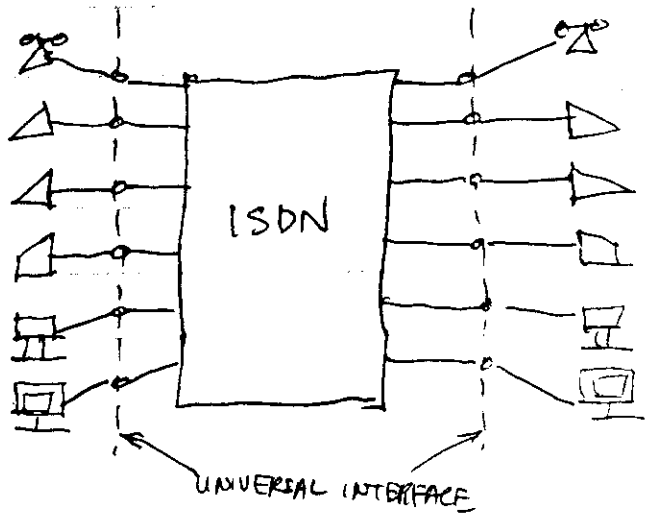


(f) Direction Division Multiplex (DDM)

5.2.3 ISDN

2.3.1 CONCEPT OF ISDN





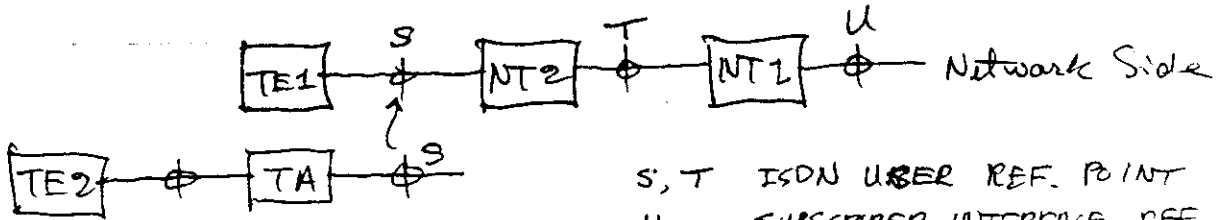
CONCEPT OF ISDN

5.2.3.2 ISDN Services

Bearer Service : Network supplies 64 KBPS circuit or packet switched functions.
i.e. Layer 1~3 functions of OSI

Teleservice : Terminal to Terminal, Total system Service : Videotex, Telete-
i.e. Layer 1~7 functions.

5.2.3.3 CCITT Recommendations



S, T ISDN USER REF. POINT
U SUBSCRIBER INTERFACE REF. POINT
NT1 : NETWORK TERMINATION (LAYER 1) TE1: ISDN STD TERMINAL
NT2 ; NETWORK TERMINATION (LAYER 1&2) TE2: NON STD TERMINAL
TA: TERMINAL ADAPTER

ISDN USER ⇔ NETWORK INTERFACE REF. POINT

*CCITT Recommendations (I-Series)

I.100	BASIC CONCEPTS
I.200	DEF. of ISDN SERVICES
I.300	OVERALL NETWORK RELATED
I.400	USER ↔ NETWORK INTERFACE
I.500	NETWORK ↔ NETWORK INTERFACE
I.600	MAINTENANCE

5.2.3.4 Direction of Broadband ISDN Services

Broadband Services

a) Communication Services

- Dialog Style Services
  - ◦ Image (Video) Service
    - TV telephone, Conference
    - TV Monitoring, Channel Distribution, News
  - ◦ Data Services
    - High Speed data Transmission
    - File Transport, CAD/CAM
    - Real Time Control & Telemetry
    - Inter LAN or MAN
  - ◦ Document Services
    - High Speed FAX
    - Text, Graph, & Image
- Message Services
  - ◦ Image
  - ◦ Document

  } via Electronic Mail
- Retrieval Services
  - ◦ Image
    - Wide Band Videotex
    - Video Retrieval (Movie)
  - ◦ Text, Graphics, Image
    - High Resolution & Still Picture
    - Document Retrieval
    - Sound Retrieval

b). Distribution Services

- Broadcasting Services
  - Video Service
    - TV Broadcasting
    - Pay TV
    - High Definition TV
  - Audio Service
    - High Fidelity Audio Services
  - Document & Data
    - Data Distribution Services
    - Electronic Publishing
    - Electronic News Paper

- User Defined Services
  - Text, Image, Graphics
    - Cable Text Broadcasting

5.2.3.5 Broad Band ISDN

- H_2, H_4 Channels under discussion for interfacing User to Network for BISDN.

① H_2 channel for Standard Video Signal for Use of ~~High~~ Efficiency Coding.

H_{21} : ≈ 32.768 MBPS , H_{22} : ≈ 43 ~ 45 MBPS

② H_4 Channel for ~~High~~ Definition Image

H_4 : 132 ~ 138.24 MBPS

- CCITT Agreed on two H_1 different rates.
- Good possibility that H_2 can have two rates.
- H_4 : CCITT Agrees to have one unified rate but at what freq. is not yet decided.
- Multiplexing method → Byte (Octet) Multiplexing Method
- Proposed BISDN

  Bell Core : SONET (Synchronous Optical Network

  AT&T : UIS (Universal Information Servic

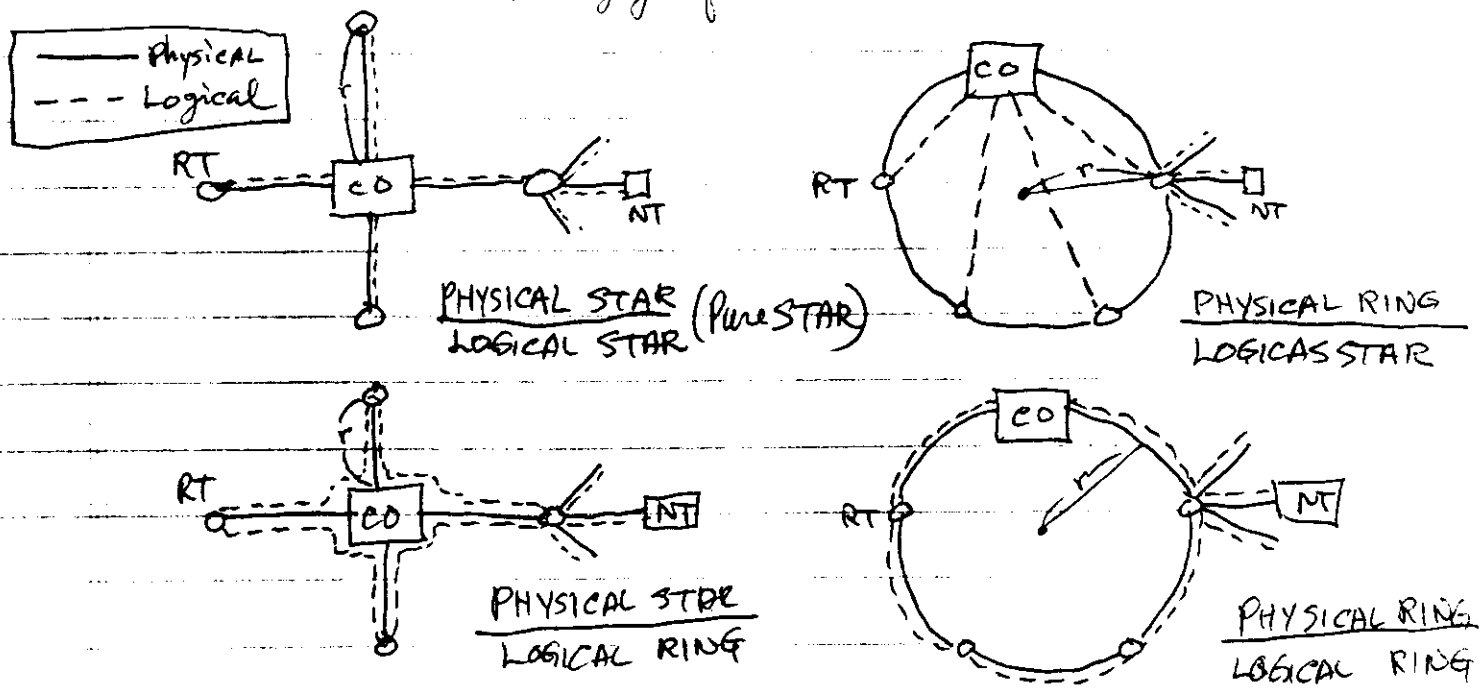
To make BISDN possible following ~~area~~ technical areas must be improved:

- LSI Technology
- Opto-Electronic Technology
- Network Construction Technology
- Software Technology to make use of the Bandwidth

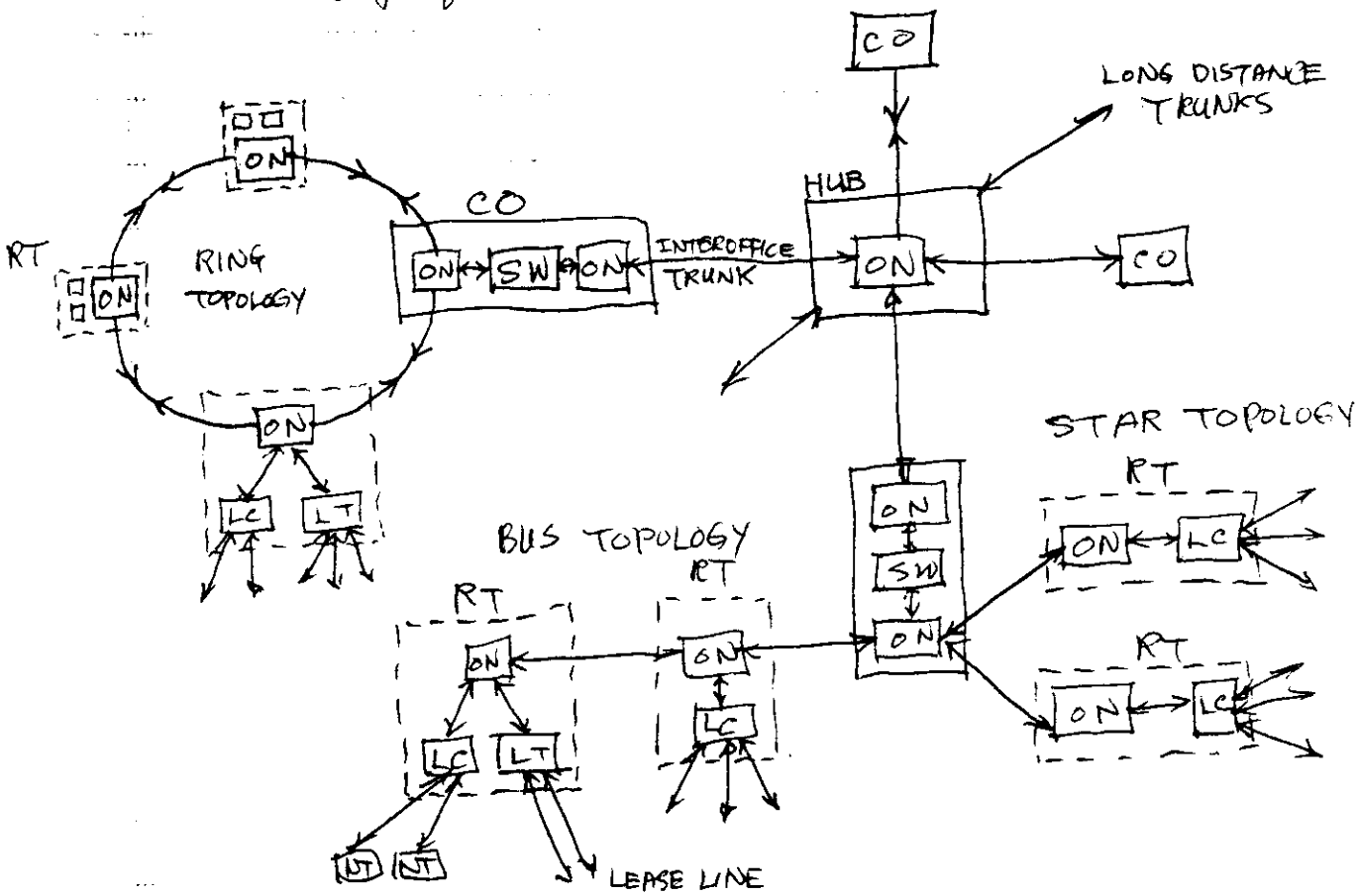
3.2.3.5 Proposition for an Optical Subscriber Network

- Consideration Point
  1. Flexibility to user's needs
  2. Stimulate Demands with economic feasibility
  3. Flexible Network Configuration to adopt to ~~potato~~ potential Demand.

- Possible Topology of Network



* Judging from the cost of Optical Cable; Physical STAR / Logical STAR is the most economical topology for subscriber network.



CO : Central Office
RT : Remote Terminal Office
LC : Line Concentrator
ON : Optical Network Node

SW : Switching System
NT : Network Termination
HUB : Regional Center

6. Future of Wide Band Network

6.1 Areas of Current Investigation

6.1.1 Search of Low Loss Fiber

- Limitation of Glass fiber
  Rayleigh Scattering & Power Absorption
  of Infra-Red light region.
  (1.5μ and Longer)
- Freon Compound Glass (ZrF, BaF, AlF etc)
  Theoretical Loss Minimum 0.001 DB/Km
- Halogen Compound Crystall (KCl)
  Theoretical Loss Minimum 0.0001 DB/Km.

* Possible Realization of 10,000 Km Unrepeated system.

6.1.2 Coherent Light Transmission

- Direct modulation of light intensity. masses use of:
  - Superwide Bandwidth of Light
  - High Speed of Light
- Problems:
  - Stable Light Source
  - Single Spectrum - Purity.
  - Elimination of Polarization change in Fiber due to local temperature changes, mechanica vibration, or stresses.
  - At receiving end control of polarization of light to cause interference.

6.1.3 Generation of Extremely Short Pulses.

- Gain Switching
  - Short Electric Current Pulse
    - few PS ~ few 10 ps
- Loss Switching
  - Component hard to manufacture } ⇒ few ps.
  - Control is difficult.
- Mode Synch.
  - Coherent Pulse & External Resonator are required.
  - Close to Theoretical Limit, Sub-ps.

6.1.4 Optical Soliton Wave Transmission

- Uses difference of light velocity in fiber to generate very short pulse ∋ $ps^3/Km \cdot nm$ order.

6.2 Future of Wide Band Network

- Possibility of repeaterless intercontinental network.
- Unlimited Band Width
- True multimedia Services to Subscriber are possible
- Coherent Systems and Light Amplifier can create End to End Optical systems.
- Full optical computers will change the method of communications for human.
- Optical Computers linked by optical network can create tremendous processing power for Human beings.