

The Asia Pacific Cable Network

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The Asia Pacific Cable Network (APCN) is a regional undersea telecommunications network that will begin carrying traffic in the fourth quarter of 1996. APCN interconnects Japan, Korea, Taiwan, Hong Kong, Singapore, Indonesia, Malaysia, Thailand, and the Philippines with an 11,500 km trunk and branch undersea cable system. APCN is owned by a consortium of telecommunication carriers who have contracted with AT&T Submarine Systems Inc., Alcatel Submarine Networks, and KDD Submarine Cable Systems to build the network at a cost of \$540 million.

Figure 1 shows the geographical route of APCN. The nine landing sites are connected by undersea cables and branching units (BUs). The network topology consists of 13 digital line segments that provide fiber pair transmission paths between Japan and Korea, Japan and Taiwan, Korea and Hong Kong, Taiwan and Hong Kong, Taiwan and the Philippines, Taiwan and Singapore, the Philippines and Hong Kong, Hong Kong

Once operational in late 1996, the Asia Pacific Cable Network will interconnect countries in a region of the world that is experiencing rapid growth in demand for telecommunication services.

and Malaysia, Singapore and Indonesia, Singapore and Malaysia, Singapore and Thailand, Indonesia and Malaysia, and Malaysia and Thailand.

In this article, the technologies that make up this network are described, including the unique powering arrangement and a description of the equipment that provides for restoration, network monitoring, and control.

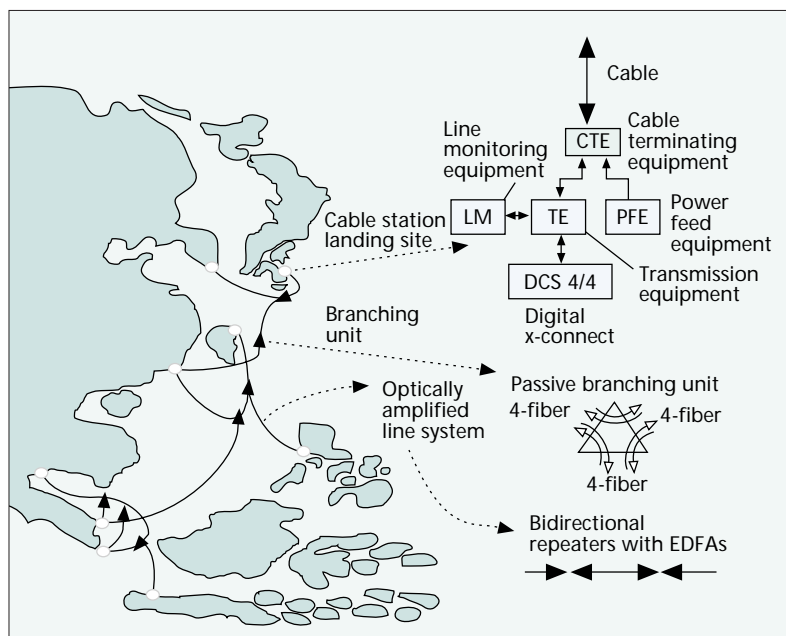
APCN CABLE STATION EQUIPMENT

Figure 2 shows an overview of the terminal transmission equipment and power feed equipment (PFE) located at each cable landing station. Two fiber pairs in the undersea cable terminate at 5 Gb/s line terminal equipment (LTE). Each LTE transmits and receives the 5 Gb/s optical line signals, composed of two bit-interleaved STM-16 (2.5 Gb/s) signals. The LTE also includes forward error correction (FEC) encoding and decoding to enhance the network's transmission performance. On the low-speed side of the LTE, two STM-16 signals arrive from two STM-1/STM-16 multiplexes. Digital crossconnect equipment provides STM-1 electrical and optical interfaces to the low-speed side of the STM-1/STM-16 multiplexes. The PFE provides a DC current to the undersea cable in order to power the undersea repeaters. All equipment shown in Fig. 2 is redundant, so the overall network outage due to cable station equipment faults is near zero. The network's powering arrangement and restoration capabilities are unique to APCN and will be discussed in a separate section.

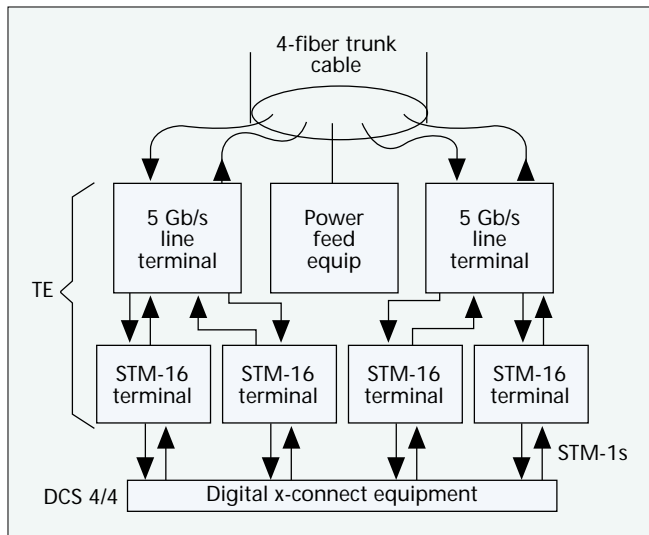
Another important function of the land-based equipment is to monitor the performance of the undersea plant. This is accomplished by using a line-monitoring (LM) feature, which directly modulates the transmitted 5 Gb/s line signal and processes the received signal. With LM, degradations as well as hard faults can be located.

APCN UNDERSEA TECHNOLOGY

Transmission of 5 Gb/s signals through APCN relies on state-of-the-art undersea fiber optic technology. Erbium doped fiber amplifiers



■ Figure 1. Asia Pacific Cable Network.



■ Figure 2. Terminal station equipment.

(EDFAs) are used in the undersea repeaters to compensate for the loss in the undersea fiber. Thorough engineering is required to control all the system aspects, including the characteristics of the dispersion-shifted fiber used in the undersea cable. The repeater design is aimed at performance, simplicity, and robustness, which will lead to a very high level of reliability for the undersea network.

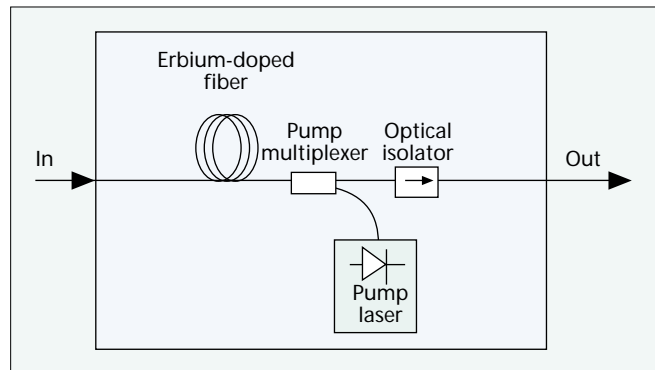
ERBIUM DOPED FIBER AMPLIFIER CHARACTERISTICS

EDFAs use the process of stimulated emission to amplify incoming light. The stimulated emission takes place in the core of a single-mode optical fiber that has been doped with Er^{3+} ions. Optical amplification is obtained through an injection of external energy known as “pumping.” Under the effect of the pumping, the stimulated emission is accompanied by a spontaneous emission, which is also amplified by the erbium doped fiber. This spontaneous emission results in optical noise and is called “amplified spontaneous emission” (ASE). The pumping process is achieved optically by coupling a powerful light flux at 1480 nm into the erbium doped fiber. Figure 3 illustrates a typical EDFA. The amplifier parameters are chosen for optimum operation at 1558 nm where the fiber attenuation is minimal. Therefore, optical amplifier systems are gain-selective around 1558 nm. Similarly, the very broad and flat noise spectrum for a single amplifier narrows with cascaded amplifiers (a phenomenon known as self-filtering), which limits the total noise power as shown in Fig. 4. The main merits of these amplifiers are that they are extremely simple to construct, offer virtually unlimited bandwidth, and feature low noise and excellent electrical/optical conversion efficiency.

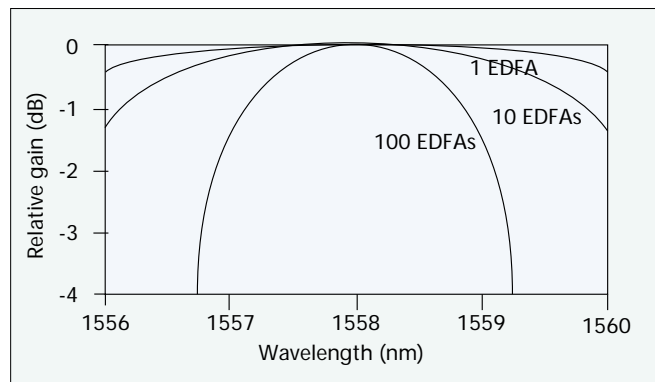
APCN LINE ENGINEERING

Various propagation-related factors affect the transmission over the long paths of APCN. To achieve error performance consistent with target quality specifications over the entire life of the network, the repeatered line design must ensure that the optical power input to the amplifiers is sufficient to obtain a high signal-to-noise ratio (SNR) for each amplifier and account for the accumulated noise at the end of each digital line segment.

Chromatic dispersion along the fiber paths needs to be



■ Figure 3. EDFA simplified diagram.



■ Figure 4. Self-filtering effect on gain bandwidth.

close to zero (slightly negative) for the 5 Gb/s pulses to be propagated with a minimum of distortion. As a result, the undersea optical cable uses dispersion-shifted fiber whose dispersion value is close to zero in the 1550 nm region and has a slight negative slope (-0.2 ps/nm/km). The digital line segments with lengths as long as 4000 km need to have a dispersion between -50 ps/nm and 0 ps/nm at 1558 nm at the end of that segment and must guarantee that the dispersion never goes positive. This type of design cannot be obtained simply by manufacture, so dispersion compensation is systematically introduced after approximately every 10 repeaters, by inserting into the cable a length of standard positive-dispersion fiber (about 8 km long). The standard fiber dispersion measures $+18$ ps/nm/km at 1550 nm. An adjusted length of standard fiber is also inserted at the receiving end terminal to optimize propagation compensation.

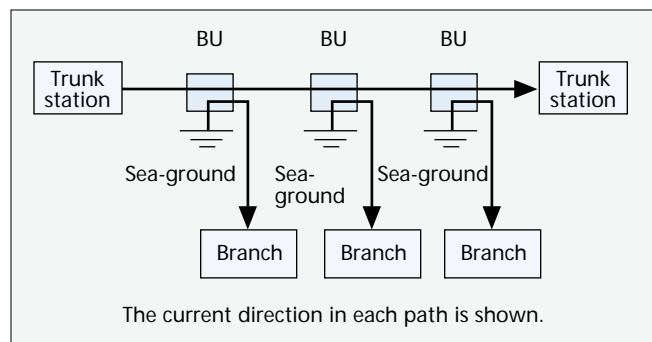
Propagation of the two light polarization modes in the fiber and the repeaters must be achieved with very similar characteristics (loss, group delay time, etc.) to minimize the degrading effects due to sensitivity of the system to polarization. Therefore, the fiber and the repeater components are designed to minimize the effect of polarization on propagation.

The optical power output from the amplifiers should not be too high in order to limit the nonlinear effects of the fiber (Kerr effect) from distorting the pulses. In the case of a 4000 km digital line segment, the output power is approximately $+4$ dBm. Given this power level and a fiber with an effective core area of approximately $50\mu\text{m}^2$, pulses show little distortion, but the optical spectrum spreads significantly from approximately 10 GHz at the transmitting end to 50 GHz at the end of a 4000 km line.

The transmitted spectrum needs to be very narrow and its wavelength settable and stable in order to simultaneously satisfy the requirements of optimum chromatic dispersion of the fiber and maximum gain in the optical amplifier system (self-

Section	Trunk stations		Branch stations		
Section 1	Japan	Hong Kong	Korea	Taiwan	
Section 2	Taiwan	Malaysia	Philippines	Hong Kong	Singapore
Section 3	Thailand	Indonesia	Malaysia	Singapore	

■ **Table 1.** Trunk and branch terminal stations in APCN.



■ **Figure 5.** APCN section powering with no system faults.

filtering wavelength). The quality of the transmitted signal is particularly important since it is propagated without regeneration along the transmission path.

The accumulation of noise and nonlinear effects necessitates a design that reduces the spacing between repeaters as the length of the digital line section increases. For APCN the nominal repeater spacing varies from approximately 73 km to 90 km according to the length of the digital line section.

In any amplified link between repeaters, the appearance of a significant loss between repeaters will be reflected in a slight reduction in the output level from the next amplifier. The output level will be restored to the normal level after the signal has passed through another three or four amplifiers. This will result in a slightly degraded SNR at the end of the digital line section. As the performance margins for amplified systems are taken from the overall SNR, this illustrates the inherent robustness of the EDFA technology.

REPEATERS

The main function of the repeater is to amplify the received 5 Gb/s optical signal without distortion, exactly compensating for losses encountered in the signal path after the last repeater. As mentioned above, the repeater is powered from a DC current flowing through the cable. Each fiber requires an amplifier; therefore, the repeaters in APCN contain four amplifiers.

For APCN, the repeater's characteristics for the longest 4000 km digital line sections will be:

Output power:	+ 4 dBm
Gain:	16 dB
Noise factor:	< 6.5 dB
Polarization gain sensitivity:	0.1 dB

The principle of providing the amplification in the optical domain considerably reduces the number of electronic components in the repeaters. For instance, no high-frequency electronics are required, and the limited number of low-frequency circuits used contribute to the high reliability of the repeaters.

The optical components shown in Fig. 3 have become key to the performance of the repeater. The characteristics

required of the main components are therefore important to the system.

The 1480 nm laser, used as the pump source, features high power and very high reliability. The erbium doped fiber is optimized in terms of doping and length to minimize its noise factor. The optical coupler couples the 1558 nm signal, and the pump into the erbium doped fiber has a low insertion loss at both wavelengths to maximize the optical efficiency of the repeater. The optical isolator has a high isolation factor to avoid spurious reflections in the amplifier. The other passive optical components are also designed to avoid reflections in the repeater. All the components of the repeater are qualified for undersea use. This means that, for each component, a series of analyses and tests have demonstrated that, given rigorous selection based on specific tests, its characteristics are consistent with its anticipated use. The reliability of these components is such that the 11,500-km-long APCN system shall experience less than one ship repair due to a component failure in the submersible plant over the 25-year design life.

NETWORK POWER AND INTERCONNECTIVITY CONSIDERATIONS FOR APCN

APCN is divided into three separate sections. Each section is powered independently, but traffic is multiply interconnected to the adjacent sections. Independent powering ensures that a powering failure in one section does not affect the operation of the other two sections, and the multiple transmission interconnection of the three sections provides a number of transmission paths for alternate routing in case of traffic congestion or faults.

SECTION POWERING

Each of the sections in APCN is an example of a trunk and branch transmission system. Powering of the trunk sections is shared by the end stations¹ under normal conditions, but a "single-end-feed" capability is provided at each trunk terminal for emergencies. Each branch section is powered to a sea-ground at its associated BU. However, power switching procedures are provided which make it possible to power between the cable stations that terminate the branch and cable stations which terminate the trunk, when cable or other failures make normal powering impossible. The powering configuration for a fault-free section² is given in Fig. 5. The trunk and branch stations in each section are as shown in Table 1.

PFE in the trunk stations is capable of producing several thousand volts to ensure that single-ended powering can be supported from either end of the section. Branch station PFE need only produce about 1000 V. These voltage levels are sufficient to accommodate earth potential variations as well.

Section powering and power reconfiguration activities are coordinated by a computer-based system called the "Power Control and Monitoring System" (PCMS), described below. This is very important because powering procedures must be carried out in a given order over an entire powering section to

¹ The voltages of the two trunk terminal stations are opposite in polarity.

² Section 2 has three branches, and the other sections have only two branches. Therefore, typical powering diagrams will be shown with three branches. Typical powering configurations for sections 1 and 3 can easily be deduced from the ones given.

ensure that a desired powering configuration is achieved. Any mistakes in a given powering procedure could cause the section to assume an undesired configuration.

All powering procedures within a cable station are performed by power control safety officers (PCSOs) as prompted by the PCMS. In addition, a power integration coordinator (PIC) is designated for each powering activity to coordinate the activities of the PCSOs in the various cable stations within a powering section. These individuals have received special training to qualify them for these functions. In general, section powering is accomplished by first ramping the voltage up at the trunk or end stations, establishing the trunk current path, and then ramping up the voltage³ at the various branch stations.

When a power failure occurs in any of the powering sections, each digital line segment of a powering section has at most one source of current (+ terminal voltage). All other terminals act as current sinks (- voltage). This helps ensure that the sections will “switch” to the desired powering configuration. In some cases, a “bias” voltage must be used to ensure that a desired powering configuration is achieved.

Power switching networks (PSNs) are located in the BUs, and each BU can achieve the following types of powering configurations as shown in Fig. 6.

- Powering from trunk to either branch A or branch B
- Powering from branch to branch

These two simple powering reconfigurations, when used separately or together, allow a powering section with a fault to be reconfigured, ensuring that all portions of the section which remain “intact” can continue to operate. These procedures will be described below.

The PSNs have been designed to activate or switch at low current levels to avoid “hot switching” during normal power switching activities. Once activated, they have also been designed to “latch” into a given configuration so that relay “chattering” is not a problem.

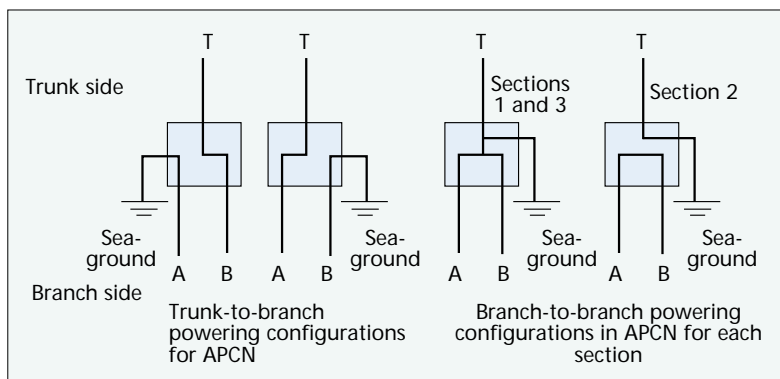
POWERING WITH SECTION FAULTS

Section powering faults generally fall into two categories: situations where the cable has parted (CP faults), and situations where the power conductor is exposed to the sea, forming a shunt fault, but the fibers are still intact (CS faults).

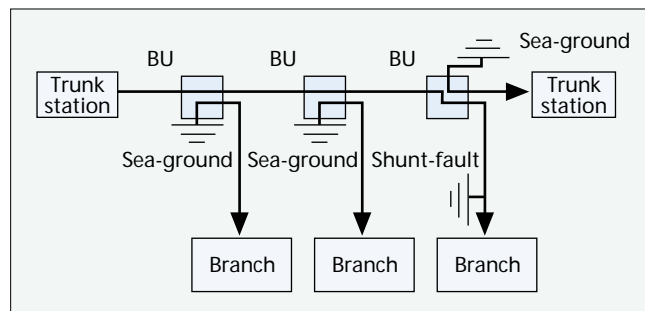
CS FAULTS

For CS faults, it is required that the net current flow into or out of the fault be as low as possible. This is accomplished by “balancing” the voltages applied at the ends of the powering section⁴ to produce a virtual ground at the site of the fault. This minimizes the effect that fault resistance has on fault-location procedures, which use cable resistance. It also reduces heat generation and electrolytic corrosion which can further damage the cable. This ensures that the damaged cable will remain in service and provides adequate time for repair activities to be organized.

Power reconfigurations for CS faults in the trunk sections



■ Figure 6. BU powering configurations used in APCN.



■ Figure 7. APCN section powering with a shunt fault in a branch but the fibers remaining intact.

are largely automatically accommodated by the PFE in the trunk stations. However, some additional manual power adjustment may be necessary to achieve an exact voltage balance at the fault location. If a CS fault occurs at some point in a branch section, the section powering must be reconfigured⁵ to provide powering between the trunk terminal station having the (+) positive polarity and the affected branch station, allowing the voltage to be balanced at the location of the fault. The rest of the trunk section is powered to the sea-ground at the effected BU, and the other branches would be powered in the normal manner. This is shown in Fig. 7. Thus, when a CS fault occurs either in a branch or at a trunk section, the entire powering section can be kept in operation while a repair operation is organized.

CP FAULTS

When a cable is parted, both transmission and powering connectivity is unavoidably lost. However, the portions of the section that remain intact can be kept in service. Furthermore, the out-of-service portions of a powering section are grounded at the associated⁶ BU(s). This facilitates repair activities and allows the portions of a section that remain intact to continue to operate during the repair.

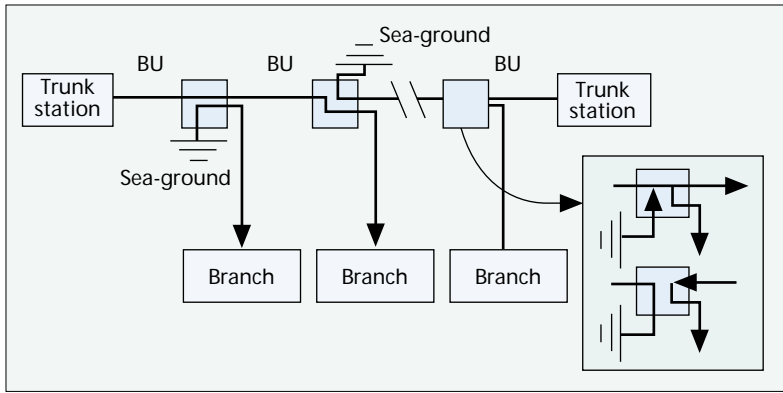
Specifically, if a CP-fault occurs in a branch segment of a powering section, service on that branch is unavoidably lost and no power reconfiguration is needed. If a CP fault occurs

³ Branch sections are powered from (-) sources to reduce the electrolytic corrosion of the sea-ground. Polarity inversions for short intervals to accommodate power switching pose no danger to the sea-ground.

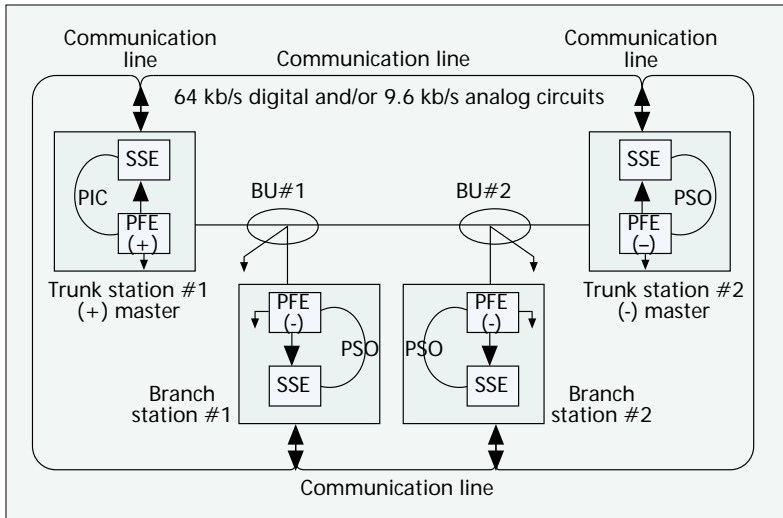
⁴ Balancing the voltage at a CS fault requires that the voltages at the cable ends be of opposite polarity.

⁵ This uses the trunk-to-branch power switching capability of the PSN in the BU, as shown in Fig. 2, and provides for terminal voltages of opposite polarity as required to “balance” the voltage at the site of the fault.

⁶ If the CP fault is in a shore segment, the failed segment is grounded at the terminal and the first BU.



■ Figure 8. APCN section powering with the cable parted between two branching units.



■ Figure 9. Power control and monitor system.

in a trunk section of a section between two BUs, both BUs must be reconfigured to allow the remaining portions of the section to continue to operate, as shown in Fig. 8. If a CP fault occurs in a shore section, only one BU reconfiguration is necessary, as can be seen from Fig. 8.

The type of reconfiguration required in a given BU when a fault occurs depends on whether the fault is on the “trunk” or “branch” side of a given BU. If the fault is on the “branch” side, a trunk-to-branch reconfiguration is needed; if on the “trunk” side, a branch-to-branch reconfiguration is needed, as shown in Fig. 8. Note also that the result of a branch-to-branch reconfiguration of a BU is slightly different for the two types of BUs used in APCN, but both provide the same level of service protection.

THE POWER CONTROL AND MONITORING SYSTEM (PCMS)

System surveillance equipment (SSE) is located in each cable station to monitor and control the various pieces of equipment⁷ needed to interconnect the terrestrial and under-sea networks. The PCMS function is provided by the SSE as one of the menu options. For PCMS functions, the SSEs in

⁷ The PFE and the SSE are interconnected through a “Q3” interface according to ITU specifications.

the various stations monitor the cable voltage and current through the PFE and make this information available to every other SSE within the powering section over the SSE communications network.

This SSE communications network is in a ring configuration for path redundancy and is implemented over 64 kb/s digital lines or, as an alternative, 9.6 kb/s analog lines. This network is robust enough that normal SSE communications, including e-mail activities, can be carried out during powering activities without interrupting PCMS communications. A typical arrangement for the SSE network is shown in Fig. 9.

PCMS functions include:

- Normal power-up/-down procedures
- Reconfigurations needed to protect service when an CS fault has occurred
- Reconfigurations needed to restore a trunk segment when a CP fault has occurred on the “trunk side” of the most distant BU in the segment
- Reconfigurations needed to restore a trunk segment when a CP fault has occurred on the “branch side” of the most distant BU in the segment

While the detailed powering procedures for each function are not presented, it has been conservatively estimated that reconfiguration times, in most cases, will be less than 30 minutes, due mainly to the coordinating function provided by the PCMS.

Before any PCMS activities are commenced, both the specific activity and the identity of the PIC will need to be agreed on among the various PCSOs of the powering section. The actual PCMS procedures will be as follows.

INITIAL SETTING

The PCSOs will verify the operation of the communication links of the SSE network, indicate the identity of the PIC to the SSE, and verify that PFE performance information for each cable station in the powering section. This information is provided by a PCMS display panel.

POWERING OPERATIONS

The PIC will then select the specific procedure to be carried out from the PCMS menu. If an erroneous procedure is selected, the PIC will be warned by the PCMS that this procedure is not consistent with the current powering configuration. When the correct procedure has been selected, the PIC will coordinate the activities according to the instructions from the PCMS.

Three different types of responses will be received by the PCMS from the PCSOs in the cable stations; these are Acknowledged, Executed, and Wait. These are displayed by the SSE at all stations in the segment simultaneously. The PCMS will not proceed until the execution of each step has been verified. This procedure is continued until the desired reconfiguration has been achieved. Figure 10 shows a flowchart of normal PCMS activities.

OTHER FUNCTIONS AND FEATURES

The PCMS software has been designed to provide a high level of security for system powering activities. This is done to ensure the safety of personnel and the integrity of powering procedures. These precautions include limiting PCMS control

functions to individuals having high-level passwords, checking proposed procedures against the current powering configuration, and keeping records on all powering activities, procedures, and the identities of the personnel involved.

Specific PCMS procedures are somewhat different for equipment provided by the different suppliers. However, the net function is identical, and all procedures will actually be carried out by PCSOs within each station as indicated.

NETWORK TRANSMISSION INTERCONNECTIVITY CAPABILITY AND MANAGEMENT

All network transmission conforms to SDH standards, and each fiber pair accommodates two standard STM-16 signals. As mentioned above, these are multiplexed together to form a 5 Gb/s signal. Each of the undersea cables contains two fiber pairs, (Fig. 11), and the STM-16 terminal equipment in the stations provides direct access to all 32 individual STM-1 signals that are handled by each fiber pair.

As seen in Fig. 11, four of the nine stations in the network have double cable landings. This creates two separate "ring" configurations within APCN. Each of the single-landing stations connects to two other stations, and the double-landing stations connect to four other stations. This provides a large number of options for alternate routing. All APCN network traffic in each cable station is terminated at a DACS V-2000 (4/4) cross-connect switch which is used to manage network connectivity as well as local network access.

The DACS V-2000 allows network connectivity to be altered as a function of traffic need or section availability. The two ring networks provide great flexibility for such reconfigurations. If section failures resulting from cable cuts or equipment failures occur within one of the rings, traffic can quickly be rerouted back around the ring while a repair is being made. Flexibility also exists for portions of a section which are outside of the central rings. For example, if the branch in Section 1 to Taiwan is out of service (Fig. 11), traffic from Japan can still reach Taiwan through Korea and Hong Kong. At the Hong Kong station, the traffic is transferred to Section 2, reaching Taiwan either directly or indirectly through the

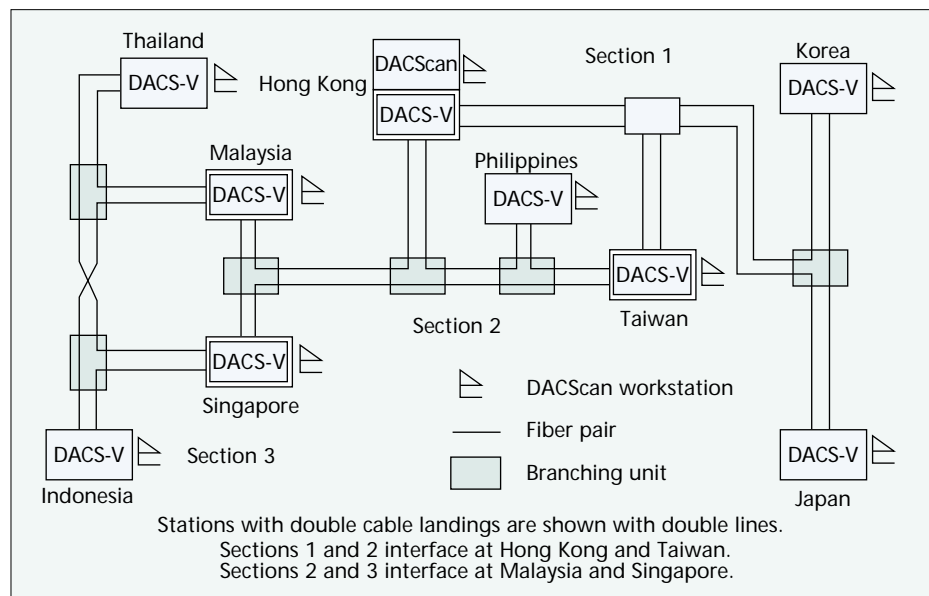


Figure 11. Fiber paths in the APCN network placement of DACS V-2000 and DACScan-2000 and the interconnection of the three sections are shown.

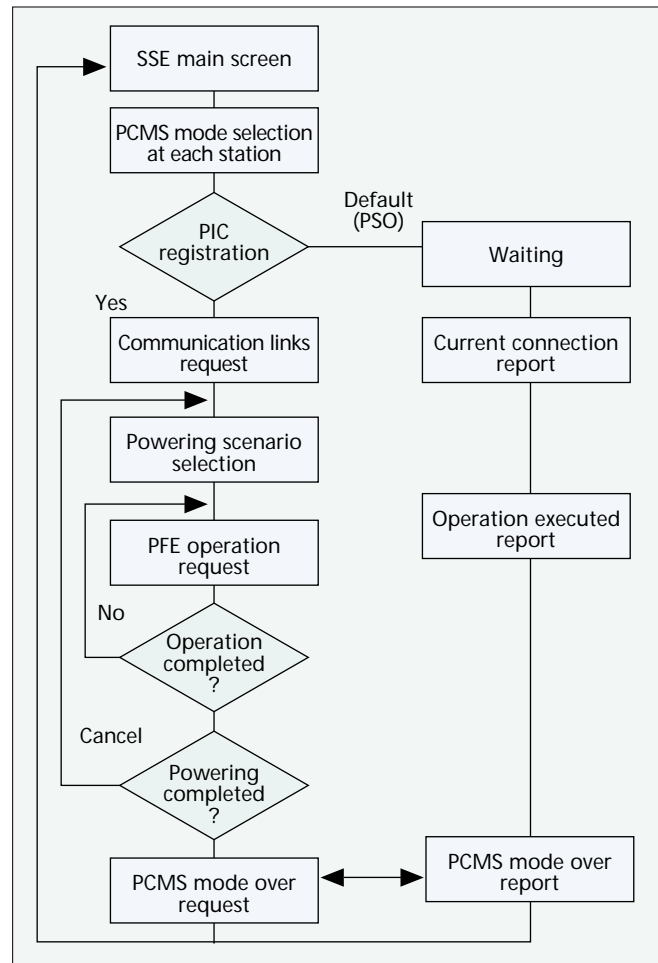


Figure 10. PCMS sequence flow chart.

Philippines. Similar reconfigurations could be made for other types of failure conditions.

The STM-1 signals transferred out of APCN for local network use are routed to a fully redundant DACS V1-2000⁸ (4/3/1) cross connect switch. DACS V1-2000 either grooms⁹ these STM-1 signals as needed for local use or passes them on unchanged to the local network.

All network traffic reconfigurations for APCN are coordinated through a computer-based networking tool called DACScan, which is located at the Hong Kong station, as shown in Fig. 11. The DACScan-2000 host stores various reconfigurations or alternate network maps so that, under the direc-

⁸ DACS VI-2000 cross-connect switches are owned and operated by the local landing parties and are not considered to be part of APCN.

⁹ In addition to the STM-I format, DACS VI-2000 supports conversion between the STM-I format and CEPT-4, DS3, E1, and various synchronous optical network (SONET) formats.

tion of the staff, it can reconfigure the DACS V-2000 switches in the various network stations. This allows APCN to respond to varying traffic level needs as well as various network failure conditions. Each station within the network also has a DACScan-2000 workstation, which provides access to information stored at the host for the various monitoring and control functions of DACScan-2000. These functions include:

- Network performance monitoring for each link in the network according to International Telecommunications Union (ITU) standards
- Point-and click traffic provisioning for the entire network
- Visual display of the current network map at a nodal level
- Automatic synchronization of the databases of the DACS V-2000s in the network, the DACScan-2000 databases stored at the host, and centralized management of the available DACS V-2000 resources available in the network

The DACScan 2000 host communicates with the DACS V-2000 cross-connect switches in the network stations over redundant, diversely routed X.25 private line networks having a modified star configuration. This network uses 64 kb/s digital lines. The host communicates with the DACScan workstations over an Ethernet network with a modified ring configuration. The ring configuration provides multiple path access to each workstation and uses analog lines operating at 9.6 kb/s.

SUMMARY

We have described the equipment and general operation of the Asia Pacific Cable Network. Because of its uniqueness to APCN, additional detail regarding the powering system and its restoration have been supplied.

Once operational in late 1996, APCN will interconnect countries in a region of the world that is experiencing rapid growth in demand for telecommunication services. With trans-

APCN will not only serve as a regional network, but as a feeder network to other interregional networks, providing connectivity to other parts of the world.

Pacific and other interregional networks such as the TPC-5 Cable Network and the FLAG network going into service in 1996 and 1997, APCN will not only serve as a regional network, but as a feeder network to these networks, providing connectivity to other parts of the world. APCN will play an important role as another network in the ever growing global undersea communications network.

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BIOGRAPHIES

DAVID R. GUNDERSON is responsible for providing technical support to the purchasers of APCN. He is a Distinguished Member of Technical Staff at AT&T Bell Laboratories in Holmdel, New Jersey, where he has worked for 26 years on the design of microwave, satellite, and undersea communication systems. His work on optical systems began with the Optican-1 System in the Canary Islands that was carried out as part of the development of TAT-8. He holds a Ph.D. in microwaves and physical electronics.

ANTOINE LECROART was born in Paris, France, in 1957. In 1980, he graduated from a French engineering school where he specialized in mechanical and electronic design. He joined Alcatel in 1982. After a few years of engineering of mediation devices for terrestrial transport systems he got involved with submarine activities through line terminal design. He was involved in APCN as technical bidding engineer for Alcatel Submarcom. Since November 1995, he has been responsible for product marketing within Alcatel Submarine Networks.

KOICHI TATEKURA received the B.E., M.E., and Ph.D. degrees, all in electronics engineering, from Hokkaido University, Japan. In 1980 he joined KDD's Research and Development Laboratories, where he was a member of the research group that developed the first transoceanic submarine cable systems using optical fiber technology. In 1983 he moved to KDD's Submarine Cable Systems Department and since then has been involved in system development, marine engineering, cable maintenance, and international submarine cable planning.