POWERING ISSUES IN AN OPTICAL FIBRE CUSTOMER ACCESS NETWORK

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ABSTRACT

This paper is a review of alternatives for powering equipment at the customer end of an optical Customer Access Network (CAN). The alternatives include: local, network, hybrid and optical powering. Comparisons are based on the following aspects; operation and maintenance costs, technological constraints, expected problems, safety and power requirements. Related issues, such as sizing of backup battery, are discussed. Finally, descriptions on a demonstration unit for local powering and optical CAN trials by Telecom Australia are given.

1. INTRODUCTION

Many telecommunication companies around the world, including Telecom Australia, are considering the extension of their optical fibre systems into (or near to) customers' homes. Advantages include improved noise immunity, savings in duct space and reduced operation and maintenance costs. Wider bandwidth is also available for future services, such as broadband integrated services digital network (B-ISDN) and Pay-TV.

In the present telephone network a metallic pair runs from the local exchange to the customer's premise and power is supplied to the telephone from the battery-backed supply in the exchange. In a CAN application the optical fibre cable may have a metallic wire for mechanical strength, however this single conductor would not be suitable for power provision. This raises a major issue of how to reliably power equipment at the customer end.

If optical fibre is installed right to the customer's home (Fibre To The Customers' Premises or FTTCP) a Customer Unit (CU) would be needed to interface a standard telephone to the optical fibre. It is estimated that the power requirement per Plain Ordinary Telephone Service (POTS) line is about 0.5 W for on-hook, 1.2 W for off-hook and 2.5 W to 4 W for ringing. For B-ISDN it is expected that more than 10 W per line will be required. There may be a dedicated optical fibre from the exchange to each customer or a single fibre may serve several customers and a passive splitter used to distribute the signals amongst nearby homes.

Another possible architecture is Fibre To The Curb (FTTC) in which a fibre is shared by several customers between the exchange and the curb and there is a short connection over a metallic pair between the curb and each customer's house. A Remote Unit (RU) would be needed in a pillar, cabinet or pit to interface optical and electronic circuits and to separate the signals for each individual customer.

Several powering alternatives, namely network, local, hybrid and optical are discussed in the following sections.

2. NETWORK POWERING

A separate metallic network can be used to transmit power from the local exchange to the CU/RU. The metallic network may be the existing one or a new network. This option offers the following advantages:

* It avoids having any battery in the external plant and hence the related costs of battery monitoring, maintenance and replacement.

* The CAN network is able to survive for as long as the exchange equipment during mains power outages.

* A power supply unit in the exchange is shared by many CU/RUs, hence lower capital cost.

2.1 Using the existing metallic network (dedicated wires)

The existing CAN has a pair of metallic wires from the exchange to each customer and this configuration (Figure 1) would suit FTTCP better than FTTC. This scheme would save a lot in wire installation cost when providing connections to existing customers.

If copper wire of 0.644 mm diameter (AWG#22, 109 Ω/loop km at 25 $^{\circ}$C) is used. The maximum available power at the end of the wire-pair is loop length and supply voltage dependent. Figure 2 shows the

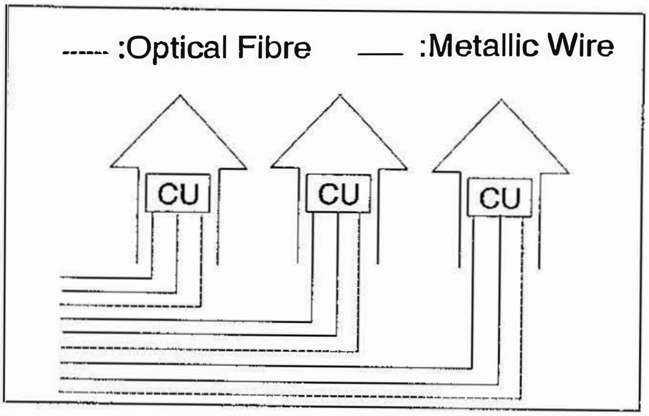

Fig. 1: Network powering of FTTCP using the existing metallic network (dedicated wires).

maximum available power at the end of the wire-pair versus loop length if the nominal 48 V supply voltage is still used. In Australia, the maximum loop length is 7 km; however, Telecom Australia would like to ensure that optical CAN equipment is not distance limited to less than 10 km. Hence, as shown on Figure 2, the available power by using existing metallic network should not be expected to be more than 600 mW for 48 V supply. This implies a higher supply voltage is needed. Figure 3 shows the required supply voltage versus the maximum available power for loop length of 10 km, which indicates that the minimum supply voltage for POTS (power of 2.5 W) would be 100 V, while that for ISDN service (power of 10 W) would be 200 V. The actual required voltages may well exceed these two values, as resistance within the exchange and temperature effect on wire resistance have not yet been taken into account. Furthermore, wires of smaller diameters (such as 0.4 mm, 0.51 mm) are quite common in metropolitan areas of Australian cities.

Instead of the above constant voltage feeding (CVF), constant current feeding (CCF) may be used. Figure 4 shows that the required current for POTS should be around 50 mA, while that for ISDN service is about 100 mA at minimum supply voltage for loop length of 10 km. Using these two values of current sources, the actual supply voltages would always be less than (or at most equal to) those of the cases in CVF scheme, especially when the actual loop length is far less than the length limit, as shown in Figure 5. (It should be noted that the open circuit voltage in CCF is in fact no less than that in CVF if their distance limits are the same, unless a special protection circuit is installed.) Table 1, shows a comparison between these two kinds of power feeding methods. CCF has another advantage as well as lower voltage. Constant power can easily be obtained at lower loss with CCF and a DC-DC converter in the CU for large line length variation [1]. The higher cost in the power supply at the exchange end is offset by a simpler design in the DC-DC converter in the CU.

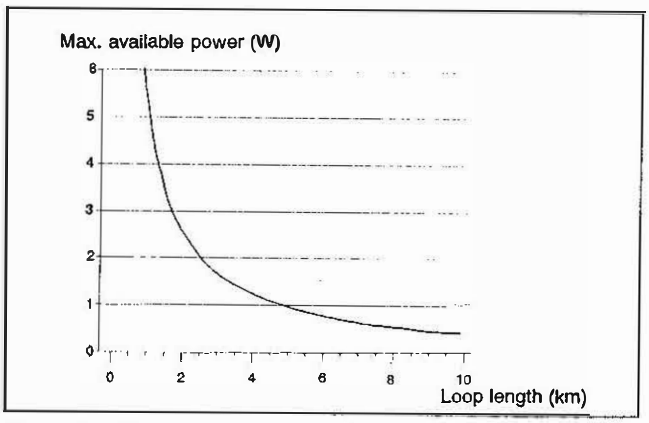

Fig. 2: Maximum available power across the ends of a pair of AWG#22 wires with 48 V supply voltage.

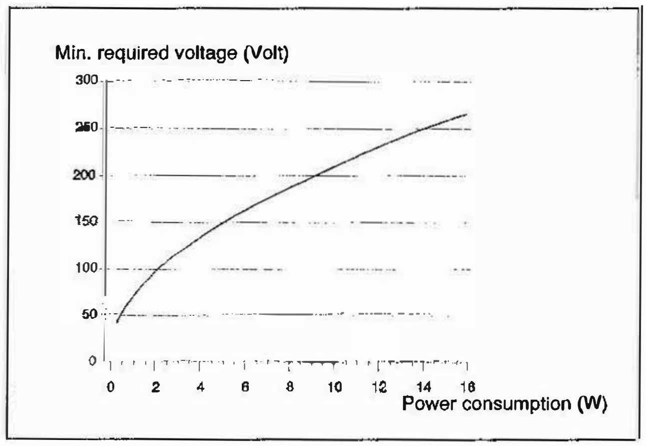

Fig. 3: Required supply voltage for 10 km loop length of AWG#22 wire (CVF).

	CVF	CCF
Voltage across the pair of wire	Higher	Lower
Power source in the exchange	Shared	Individual for each line
Voltage at the input of CU (at constant power)	Variable	Constant
Complexity of the DC-DC converter in CU	More complex	Simpler
Power loss in the DC-DC Converter of the CU	Higher	Lower
Protection required	Overcurrent	Overvoltage

Table 1 : Comparison between CVF and CCF methods

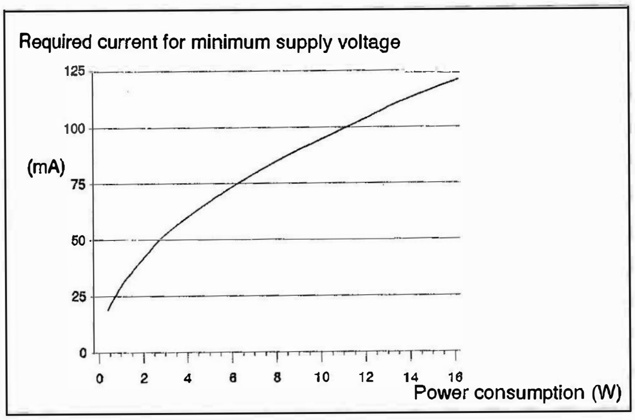

Fig. 4: Required supply current for 10 km loop length of AWG#22 wire (CCF).

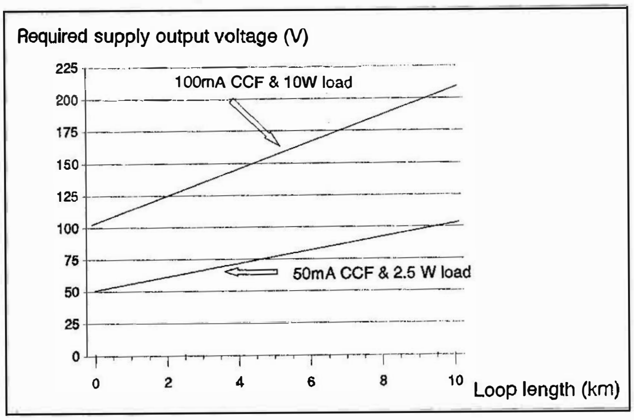

Fig. 5: Required supply voltage with CCF.

It is the authors' opinion that regardless of whether CVF or CCF is used, network powering with the existing metallic network can only be used at most for a "POTS-only" network. Unless the length limit is reduced dramatically, the operating voltage may be so high that special safety precautions and maintenance procedures may be necessary implying higher operating costs.

In addition to the high voltage problems this scheme has the following disadvantages, when compared with a new shared bus network scheme, which will be described in the next subsection.

* No saving in duct space from a reduction in metallic pairs.

* High energy losses in the network.

* High connection cost for new customers.

2.2 Installing a new metallic network (shared bus)

With greater flexibility in configuration and wire size, a shared bus configuration (Figure 6) with CVF would be preferred instead of a dedicated pair of wires per CU/RU. This will bring savings in wire cost and duct space by making use of the random nature of telephone traffic [2,3].

Consider a hypothetical FTTC system in which each RU supports 16 POTS lines. With ten RUs evenly spaced at 0.5 km interval, the last RU is 5 km away from the exchange. Assume that the base power of each RU is 8 W, power per off-hook line is 1.2 W, and the average traffic is 0.1 erlang per line.

If a dedicated pair of wires is used for each RU, then the wires have to be sized to carry 16.4 W to cater for 99.99% of the traffic condition (7 or less out of 16 are off-hook). To keep the supply voltage at a low value (75 V), copper wires of AWG#14 (diameter of 1.628 mm, resistance of 16.9 Ω/loop km, weight of 18.50 kg/km) have to be used. This implies 508.75 kg (=18.50 kg/km * (0.5 km + 1 km + ... + 5 km)) of copper weight.

If these ten RUs are connected by a shared power bus, then the size of the wires may be designed to carry just 45.2 W to cater for 99.99% of the traffic condition (31 or less out of 160 are off-hook). Copper wires of AWG#10 (diameter of 2.588 mm, resistance of 6.68 Ω/loop km, weight of 46.76 kg/km) are used to keep the supply voltage at similar value (78 V) as above. This implies 233.8 kg (=46.76 kg/km * 5 km) of copper weight, only 46% of the above value. Hence more than half of the copper and a lot of duct space are saved. Similar argument applies even if ringing power, non-POTS services and longer length limit are taken into account. The above calculations are based on unigauge power serving, similar analysis may be carried out when tapering is used in wire sizing.

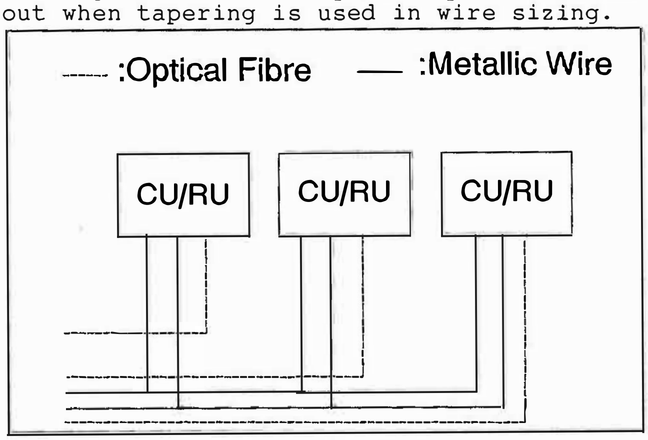

Fig. 6: Shared bus network powering for FTTCP/FTTC.

However, compared with local powering (which will be detailed in the next section), this option has these disadvantages:

* It requires monitoring, maintenance and testing of a separate power network in addition to the fibre network.

* Cost of wire installation will be very high, especially when one realises that the diameters of the wires and ducts have to be oversized to cater for higher power consumption of future services.

* Some of the potential merits of optical CAN such as high EMI immunity, lower susceptibility to lightning and savings in duct space may not be realised.

* The total power requirement of an optical CAN will be much higher than the present metallic CAN and this would mean more power equipment is need in the local exchange taking up floor space and increasing cooling loads.

3. LOCAL POWERING

In this option, power is distributed by the utility and connection is made in the street or at the customer's home. This avoids problems associated with an overlay metallic network and the power supply can be enlarged easily whenever additional boards are added into the CU/RU for new services. However it introduces a new problem - how to cover mains power outages. Batteries are the obvious solution but new range of issues have to be considered, these include cost, performance, lifetime and replacement of battery.

3.1 Dedicated local powering for FTTCP

For FTTCP, local power may be provided by the customer from a general purpose electric outlet (or fixed connection, Figure 7a) and the CU, which may be customer owned, could be installed indoors. All maintenance, backup battery replacement and electricity charges would be the responsibility of the customer. The telecommunication company would only be responsible for providing an optical fibre outlet in the house. If the customer rents the CU from the telecommunication company, then maintenance and battery replacement would be done by the company with the customer still paying the electricity charges. Installing the CU indoors would provide a favourable environment for the battery, particularly in regard to temperature extremes. A smaller battery could be used and it would have a longer life time than if mounted outdoors. (Battery sizing will be discussed later.)

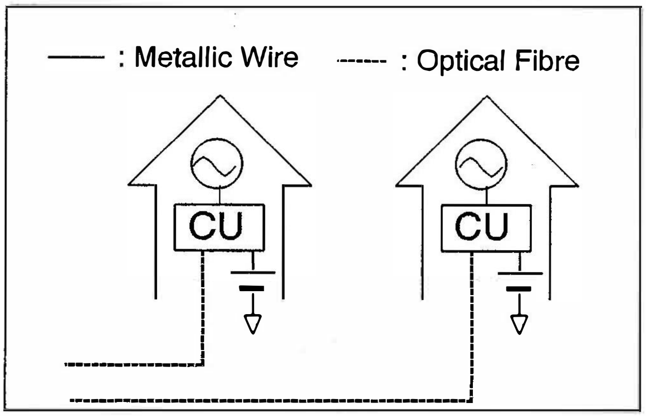

Fig. 7a: Local powering for FTTCP with supply from customers.

Some customers (especially business customers) may have their own uninterruptible power system (UPS) and they may not need separate backup supply for their phone or related services. The telecommunication company may also offer rental discount to such customers (if the customer is renting the CU).

However, a CU located indoors presents problems in regard to access for maintenance and battery replacement. Customers may also object to the local power option because they bear the electricity charges for the telephone and the capital cost or rental of the CU. This is a high price to pay if the customers only want POTS and are satisfied with the present telephone service. These factors may hinder the spread of the optical CAN [3].

The CU may be installed outdoors for easy access for maintenance and battery replacement. This would require a larger battery capacity to cater for the relatively hostile environment and the battery life would probably be shortened. To eliminate customer concerns on electricity charges, the power connection of the CU could be obtained directly from the utility side of the electricity meter with the telecommunication company paying for the electricity.

3.2 Shared local powering for FTTCP

Another local power option for FTTCP would be to have a small power supply on or under a utility pole which distributes low-voltage DC power to a group of nearby CUs via short wires (say < 500 m, Figure 7b). There will be losses in these wires but since the power supply is shared by a number of CUs the cost will be reduced. The random nature of telephone traffic also helps because the power supply need not be sized to power all CUs simultaneously at their maximum loads. A backup battery could be placed in either the power supply or in each of the CUs. The former results in a lesser number of batteries and smaller total Amp-hr requirement, while the latter gives greater service reliability and a longer battery life because of a relatively favourable environment in the CU.

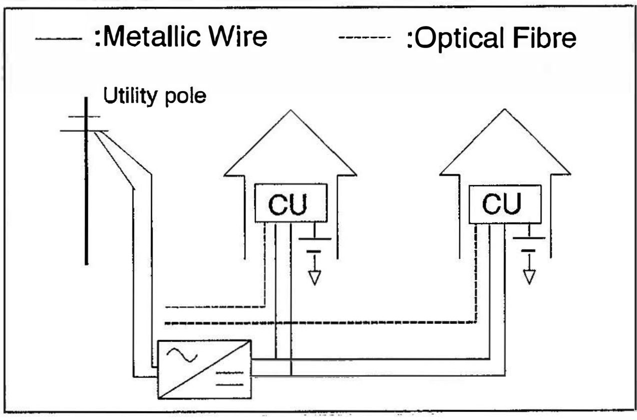

Fig. 7b: Local powering for FTTCP with supply from utility poles.

3.3 Local powering from the pole for FTTC

For FTTC, an RU situated at the street corner could be locally powered by a dedicated drop from the utility pole (Figure 8a). In this case, the introduction of optical CAN will be transparent to customers because connection to the home would still be over a metallic pair. The backup battery would be in the RU and would experience wide temperature variations which imply lower useable capacity and shorter life.

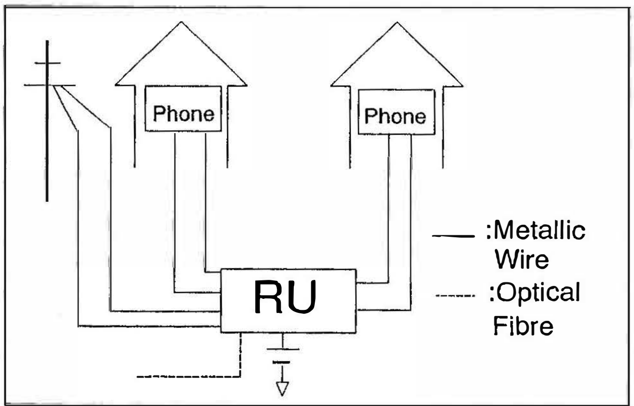

Fig. 8a: Local powering for FTTC with supply from utility poles.

3.4 Backfeed local powering for FTTC

Another option would be to backfeed DC power from customers' premises to the RU via the same metallic pairs as used for communication (Figure 8b). To ensure high reliability, power would need to be backfed from more than one customer with the backup battery being either in the RU, with the customers or both. Agreements between the telecommunication company and power-providing customers would have to be made to cover electricity costs.

3.5 Backup battery issues

To achieve similar service standard as the existing metallic CAN, the availability performance of the optical CAN should be maintained at or above 99.99% [4]. This means that the down time of the CAN must be kept below 53 minutes per year. This down time includes component failures, line failures, power outages, etc. Table 2 shows the power outage statistics for Australia.

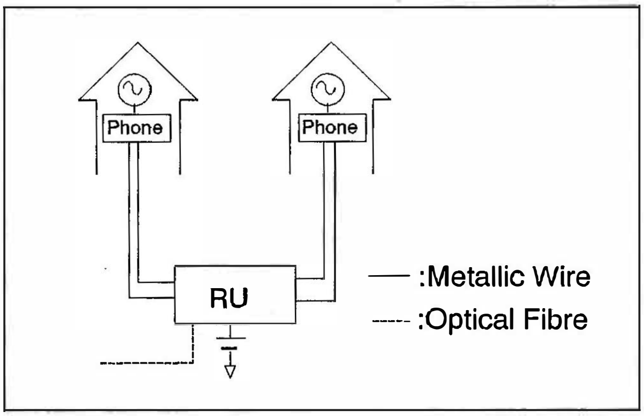

Fig. 8b: Local powering for FTTC with supply backfed from customers.

It can be seen from Table 2, without battery backup, the down time figure will be exceeded due to unplanned power outages alone. Therefore backup battery is a must for all local powering schemes. It is, in fact, the main disadvantage of local powering. Since an enormous number of batteries would be deployed, selection of battery size and technology is critical. Every effort should be made to reduce the required battery size and hence the overall cost of the system. The required battery size depends on reserve time, temperature and power consumption and these will be discussed in the following paragraphs.

3.5.1 Battery reserve time

Table 2 indicates that a battery reserve time of 3 hours is able to cope with more than 90% of the unplanned outages, but less than half of the planned outages. From other data collected, planned outages are very rarely longer than 8 hours. Therefore, battery reserve time of 8 hours is a reasonable choice. However, it is the authors' view that reserve time of 3 hours may be used in case of FTTCP architecture with individual backup battery in each CU, provided that the CUs are designed such that primary batteries could be installed to replace the usual rechargeable batteries in the event of extended mains outage. This is because reserve time of longer than 3 hours is mainly to cover planned outages which have the following three characteristics:

* they are much less frequent than unplanned outages (Table 2);

Average number of unplanned power outages per year per customer:	2.22
Average duration of unplanned outages:	1 hr. 17 mins.
Percentage of unplanned outages with duration under 3 hours:	93.6%
Average number of planned outages per year per customer:	0.56
Average duration of planned outages:	3 hrs. 13 mins
Percentage of planned outages with duration under 3 hours:	43.6%

Table 2 : Statistics on power outages of Australia

* they are usually arranged to occur in non-busy hours by power companies (during the day on weekdays for residential areas and during weekends for business areas); and

* the customers and the telecommunication companies are informed well in advance.

When notifying customers of a long planned outage the power company could suggest to either minimise the use of the telephone or to purchase some primary batteries for the CU. Customers would experience only minimal inconvenience as statistics show that this would occur only about once every four years.

3.5.2 Effect of temperature on battery

The capacity of battery has to be derated at low temperatures. Figure 9 shows the derated curve for commonly used sealed lead-acid batteries. Prolonged operation at high temperatures shortens the lifetime of battery as shown on Figure 10. Temperature also has effects on the required charging voltage and rate of self discharge. Therefore proper housing and environment for battery is essential if the required battery size is to be minimised and battery replacement cost reduced.

3.5.3 Power consumption

No matter which powering option is used, power consumption of CU/RU is critical to the overall cost of the system, since size of wire, size of backup battery, ventilation requirement of the CU/RU, capacity of power supply (and hence the cost of associated cooling equipment), energy cost and size of CUs and RUs all depend on the power consumption. Therefore low power devices should be used in CU/RU design wherever possible and the CU/RU should revert to a "power down" mode when all the lines of the CU/RU are in an on-hook condition. Total duration of all calls in a day is usually less than 1 hour for residential customers and 2.25 hours for business customers as shown by the call statistics of Telecom Australia (Table 3). These figures highlight the value of a power down mode.

To conserve the battery energy, only POTS could be supported during power outages. In fact, there is no point retaining the wide-band services because they usually have to be supported by other AC powered equipment in the customers' premises such as TVs and terminals.

3.5.4 Other battery related issues

To conserve battery energy, some form of warning signal should be given out to the customer(s) from the RU/CU automatically when the RU/CU is being powered by the battery and the line is in the off-hook condition. This can be in the form of a low level audio signal injected into the telephone line. Customers would then be aware that battery power is being used and may keep their conversation time short.

Furthermore, the CU/RU designer may also consider incorporating a "battery low" warning signal, so the customers are aware of low battery voltage and may conclude their current conversation as soon as possible. A more sophisticated battery lifetime monitor is being developed at the Telecom Research Laboratories (TRL) of Telecom Australia. This unit tracks battery charge and discharge cycles, and provides alarms on battery conditions and end of battery life. Some of these signals would be sent to the local exchange to initiate remedial action.

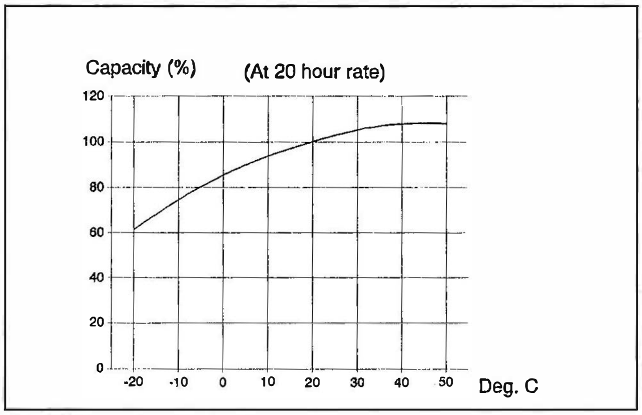

Fig. 9: Effect of temperature on battery capacity.

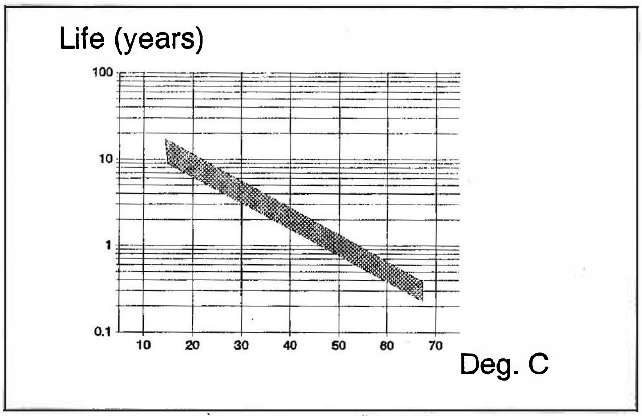

Fig. 10: Effect of temperature on battery float life.

90% of residential telephone calls are shorter than:	15 minutes
Average number of telephone calls per day per residential line:	3.52
90% of business telephone calls are shorter than:	6.5 minutes
Average number of telephone calls per day per business line:	20.77

Table 3: Statistics on telephone calls of Telecom Australia

4. HYBRID POWERING

Different combinations of local and network powering can be selected to suit the local conditions. An interesting one is: local powering for normal operation and network powering during power outages. If only POTS is supported during power outages, the existing metallic network may be used without raising the supply voltage to a high value. This combination has both the advantages of local and network powering, except no saving in duct spacing. This option is best suited to FTTCP connections to existing customers (hence no extra wire installation cost) and in an area where saving duct space is not a concern. In this case, monitoring circuits should be incorporated in the system to check wire continuity and hence repair work can be done (if necessary) to ensure satisfactory operation during power outages.

5. OPTICAL POWERING

An elegant solution to the power problem would be to deliver optical power down the fibres and have photovoltaic cells at the customer end to convert the optical energy to electrical energy. Most communication optical fibres are of small diameter (around 10 μm) single mode type for minimisation of distortion. These fibres do not allow a significant amount (say, >100 mW) of optical power to be transmitted continuously without sustaining damage. However, multimode fibres of larger diameter (> 50 μm) are suitable for optical power transmission. A multimode fibre could be included in a fibre cable along with a number of single mode communications fibres at small additional cost.

A demonstration optical power delivery system, using a 100 μm multimode fibre, was set up in TRL (Figure 11). In the initial experiment more than 0.5 W of power was obtained at the output of a non-optimised photovoltaic cell which is placed at end of a fibre of 200 meters. Better optical alignment and an optimised photovoltaic cell are expected to improve the performance two fold in the next phase of this project.

Although this approach is marginally viable in terms of technology, its cost is high and it has low overall efficiency, less than 10%. More importantly, there is a great concern about the safety, since the laser power density in the fibres may go beyond 1 MW/cm^2. Moreover, if non-POTS services are provided or FTTC is adopted, then the power requirement will well exceed 10 W per CU/RU which is no longer feasible to be transmitted down the fibre at the present state of technology [5]. In a passive optical CAN where signals in one communication fibre are split between customers by a passive splitter, the energy in the power fibre would also be divided proportionately between customers. Therefore it is the authors' view that optical powering is not yet practical, even for a POTS only network.

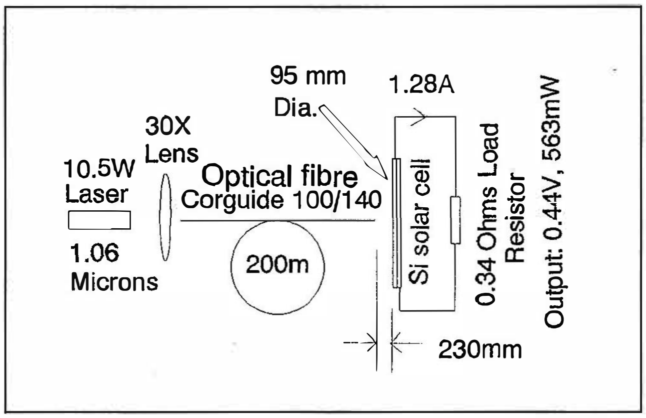

Fig. 11: An optical power delivery demonstration system in TRL.

6. A DEMONSTRATION UNIT FOR LOCAL POWERING

TRL is currently developing a demonstration unit of local powering and Figure 12 shows the block diagram of the unit. Connection is to the ordinary metallic CAN, but power consumption of a POTS line and a CU are simulated. Battery cycling is also monitored. The purposes of the demonstration unit are to provide a tool to analyse the power consumption of a POTS line and a CU, and to develop a battery lifetime monitor and a suitable charging algorithm for the back-up battery.

To simulate the interface with an optical fibre, optical couplers are used to provide electrical isolation between the incoming line and the telephone. A DC-AC inverter has been built for generation of the ringing signal. A single chip microprocessor is used to monitor the power consumption, the voltages, currents and temperature on the battery and to control the battery charger.

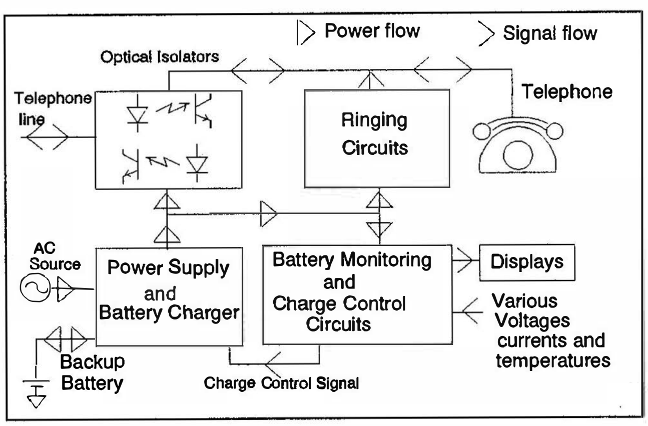

Fig. 12: Block diagram of the local powering demonstration unit in TRL.

7. OPTICAL CAN TRIALS BY TELECOM AUSTRALIA

Optical CAN trails have been running in Melbourne and Sydney since late 1989 with about 80 customers at each location. The architecture is FTTCP with a dedicated fibre to each customer and local powering is used. Both audio and video signals are carried over the optical fibre network. Equipment from a number of vendors is being used and different problems have been encountered with equipment from the various vendors. As far as powering is concerned, the following are some of the practical problems:

* Battery replacement is difficult in some manufacturers' CUs because of awkward access.

* Some CUs draw power from the backup batteries during ringing (especially when the CU is connected to a traditional phone with electro-magnetic ringer). These frequent shallow discharges shorten the life of the backup battery.

* Simple or improper charging methods are used and the battery life is not as long as expected in some CUs.

* Temperature effects on batteries are not easily seen in these trials because batteries are located indoors and both cities have mild climates.

* Despite a low frequency of power outages, some battery failures have been experienced within the first two years.

It is too early to give any conclusive results but TRL is continuing to keep a close watch on these trials. Telecom Australia is now planning for another phase of trials based on both FTTCP & FTTC with local powering.

8. CONCLUSIONS

Optical fibre deployment in the CAN won't achieve high penetration unless a cost-effective and reliable solution to the power provisioning problem is found. Any solution should not degrade the high availability of the present telephone system. Among the alternatives discussed, optical powering and network powering using existing metallic network are not promising, while network powering using a new metallic network and various options of local powering each has its own merits and demerits. The hybrid power option is an attractive one when local conditions are suitable. When selecting a powering option, the following aspects have to be considered: the architecture of the optical CAN, actual power consumption per CU/RU, cost structure of the option, battery reserve requirement, government legislation on the customer/network interface location, telecommunication power distributi,on and provision of non-POTS service (such as Pay-TV). TRL is carrying out further analysis on these aspects and is also developing hardware for power consumption investigations and backup battery monitoring and charging. Currently Telecom Australia is running and planning trials based on both FTTCP & FTTC architecture with local powering.

9. ACKNOWLEDGMENTS

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