ABSTRACT

The FTTdp (Fiber-to-the-Distribution Point) solution leverages growing fiber networks and existing distribution-side copper-wire infrastructure to more than double typical copper-based broadband service speeds. FTTdp accomplishes this by moving the optical fiber access point closer to the users. FTTdp supports triple-play broadband services including multiple HDTV channels over IP.

One of the issues with this architecture is the cost of installing the power-for-service unit deep in the network. An approach to overcome this is to provide reverse power from the subscriber (CPE) to the service unit, which avoids the expense of running power lines to the unit from the service provider.
1 Introduction

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Reliability of power source, overall efficiency, performance-monitoring and fair power sharing amongst each active user attached to DP is a major challenge, which is discussed in this report.

A reverse power feed transmission scheme allows operators to source suitably compliant equipment for inclusion in their networks. There are several twisted-pair copper technologies that may be considered for the FTTdp, that is, VDSL2, G.hn and G.fast.

At the DP, high voltage hot swap controllers are used for limiting inrush current and ultimately, power. These devices partially implement the function of power ORing controller with additional reverse blocking Schottky diodes. A low power microcontroller is used to monitor individual active CPEs and intelligently enable hot swap devices to ensure a fair power sharing scheme.

2 Abbreviations

- CO Central Office
- CPE Customer Premises Equipment
- DP Distribution Point
- DSL Digital Subscriber Line
- FTTx Fibre To The x (where x could be cabinet, premises, DP and so forth)
- GPON Gigabit-Capable Passive Optical Network
- NTE Network Termination Equipment
- NTU Network Terminating Unit
- ONU Optical Network Unit
- POTS Plain-Old-Telephone Service
- SELV Safety or Separation Extra-Low Voltage (AC < 50 Vrms, DC < 120 V)
- SG Service Gateway
- SU Service Unit
- VDSL Very High-Speed Digital Subscriber Line
- VoIP Voice-Over-Internet Protocol
3 Reverse Power Feed System Overview

Figure 1 shows power being injected at the NTE from a local power source (located within the home/building) which traverses the local loop to power a fiber-fed remote node (located at the DP). Apart from a cable to transmit and receive data between the CPE and DP, there is second copper-pair usually available, which can be used for power transfer.

![Functional Block Diagram of Reverse Power Feed System](image)

An issue with reverse powered fiber-fed nodes is that, who and what is responsible for the powering of common circuitry contained within the DP. It is easy to envisage that an individual user could be responsible for powering the remote line terminating/driver electronics corresponding to their particular circuit (see NOTE). However, it is not so easy to determine who or what is responsible for powering say, the ONU that terminates the fiber link.

**NOTE:** In practice, even this may not be easy to implement since DSL chipsets may be of an octal channel design; therefore, all eight channels are required to be powered in order to operate a single channel.

Also, the amount of power transferred by CPE has limitations due to safety concerns for technicians or any person that may come in contact with the conductors.

In the proposed solution, power sharing is done in time domain by enabling power from one active user at a time in sequential order. Duration for which power is derived from an active user will depend upon the amount of data bandwidth occupied by that particular user. Sending electrical power discretely in the time domain also improves personal safety of the technician.

There may be occasions where only a single user is active and providing power to the remote node, hence it is important to design the local power feed equipment with sufficient power capability, keeping in mind losses that will occur along the lines and SMPS sections.
Figure 2 and Figure 3 depict the system architecture of a typical network with the reverse power feed requirement. The ONU or remote DSL unit is located distant from the CO. The FTTdp equipment is common to N customers and is powered via a power combining interface attached to N copper lines (pairs) attached to N users.

At the CPE, the copper local loop is powered by a DC source.

Figure 2. Reference Model for DP

Figure 3. Reference Model for CPE
Plain-Old-Telephone System (POTS) Infrastructure

To utilize the existing copper infrastructure for triple-play services and reverse power, it is important to consider following:

- Bandwidth usage of the cables: to ensure intelligibility of the signals
- Impedance: for proper matching and to avoid reflections
- Signal levels: for protection of individual circuits in the system
- Current carrying capacity: to keep losses at the minimum level

Telephone line in POTS consists of one wire pair for each user, which carries full duplex audio and the operating current for the telephone. The telephone connected to the line is powered from current-limited 48-V power source, so phones on-hook measure around 48 volts DC.

From the CO, tens to hundreds of twisted pairs are carried to the central junction box in the building as shown in Figure 4. From this box, telephone lines (a single twisted pair) are routed to the individual user. Placement of the ONU close to or within this box can simplify the installation process.

Figure 4. Central Junction Box

A telephone line is a balanced voice path and like any electromagnetic transmission line, it has characteristic impedance. Twisted pair lines for telephone and LAN applications is typically fashioned from 22-AWG to 26-AWG stranded copper wire and will be in one of several categories defined by EIA/TIA-568A:

Table 1. Categories of Twisted Pair Cables

<table>
<thead>
<tr>
<th>Category</th>
<th>BWmax</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt; 1 MHz</td>
<td>Good only for analog voice communication, RS232, RS422 and ISDN, but not for data. Used in POTS.</td>
</tr>
<tr>
<td>2</td>
<td>&lt; 1 MHz</td>
<td>Used in telephone wiring</td>
</tr>
<tr>
<td>3</td>
<td>&lt; 16 MHz</td>
<td>Used for analog/digital voice, Ethernet 10Base-T and commercial customer premise wiring</td>
</tr>
<tr>
<td>4</td>
<td>&lt; 20 MHz</td>
<td>Similar to CAT5 with only one-fifth BW</td>
</tr>
<tr>
<td>5</td>
<td>&lt; 100 MHz</td>
<td>Used for fast Ethernet 100Base-T, 10Base-T, 22-AWG or 24-AWG wire pairs.</td>
</tr>
<tr>
<td>6</td>
<td>&lt; 350 MHz</td>
<td>Used for fast Ethernet 100Base-T</td>
</tr>
<tr>
<td>7</td>
<td>&lt; 600 MHz</td>
<td>Work is in progress</td>
</tr>
</tbody>
</table>
NOTE: DC to 4 kHz of frequency band is occupied by POTS. However, the upper limit for the cable can be tens of megahertz, which allows triple-play services over the same cables between the junction box and CPE.

Figure 5 represents variation in characteristic impedance of a typical twisted-pair cable against frequency. To get good transmission characteristics, impedance of analog front-end circuitry should match with the telephone line impedance at each end.

![Figure 5. Characteristic Impedance vs Frequency](image)

Table 2 shows some of the characteristics of these cables, which are important to consider while utilizing it for power transfer application.

**Table 2. Electrical Specifications for AWG Wire**

<table>
<thead>
<tr>
<th>AWG</th>
<th>Conductor diameter (mm²)</th>
<th>Ω/km</th>
<th>Max Ampere for Power Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>0.64516</td>
<td>52.94</td>
<td>0.92A</td>
</tr>
<tr>
<td>24</td>
<td>0.51054</td>
<td>84.2</td>
<td>0.577A</td>
</tr>
<tr>
<td>26</td>
<td>0.40386</td>
<td>133.87</td>
<td>0.361</td>
</tr>
</tbody>
</table>

Figure 6 shows that the average length of a drop-wire (in the UK) is approximately 30 m. Over such lengths, it is necessary to operate at high voltages and low current in order to reduce copper losses to an acceptable level. It is also important to operate within SELV safety levels in order to achieve a reasonably efficient reverse-powering scheme with personal safety.

![Figure 6. Drop Wire Lengths in Use (in the UK)](image)
5 Block-Wise Description of CPE

Figure 7 represents the connection diagram for various blocks in a CPE.

5.1 Isolated AC/DC Power Supply at CPE

This block is designed to deliver and meet peak power requirements at the DP. Efficiency of 75%, or better, can be easily achieved for this block. Overvoltage and overcurrent protection from the power feeding block are important features to integrate in the design, considering network safety.

To filter out switching noise or ripple at the output of AC/DC section, a common-mode choke (with least DC resistance and sufficient current rating) can be added at the power insertion point. It also helps to protect SMPS circuits of any transient voltage occurring on the lines.

5.2 Micro-Filter for Analog Telephone Lines

A micro-filter or DSL filter is a commonly used circuit to separate out analog telephone signals from DSL signals. The filter is used to avoid any kind of noise and interference that could be heard on the phone otherwise. It is extremely important to match the impedance of this circuit with line impedance (for audible signal range), which acts as line termination.
6 Block-Wise Description of DP

This section illustrates the following:
(a) Function of hot-swap controllers
(b) Housekeeping controller: logic for voltage sensing on individual lines, power sharing, OVP, and UVLO
(c) Power ORing and reverse current blocking
(d) Power scheme for Housekeeping controller

Figure 8 represents the connection diagram for various blocks in the proposed system at DP.
6.1 Control Logic Implementation Using MSP430 (Housekeeping)

General purpose input pins of the controller are used to sense the voltages on individual channels continuously using an internal ADC or comparator. General purpose output pins can be used to drive the EN signal of individual hot-swap controllers.

![Figure 9. Channel Voltage Sensing](image)

A low-power microcontroller should be used to minimize the operating current of the system.

![Figure 10. Controller Power Supply](image)
6.2 **Hot-Swap Controller**

For this particular application, the TPS2491, which is a positive high-voltage hot-swap power manager device, is suitable. The device ensures inrush current limiting, controlled load turn on, interfacing with downstream DC-to-DC (DC/DC) converter, power feed protection, operation of MOSFET within SOA, and auto-retry during fault condition.

*Figure 11* depicts the response of this device under various conditions for full load.

![Probe 1: Channel 1 hot-swap output → DC coupled](image1)

![Probe 2: Channel 2 hot-swap output → DC coupled](image2)

![Probe 3: Channel 1 Enable signal (EN1) → DC coupled](image3)

![Probe 4: Channel 2 Enable signal (EN2) → DC coupled](image4)

*Figure 11. Hot-Swap Response*
6.3 **Power ORing Circuit**

To provide uninterrupted power to isolated DC/DC sections of DP, discrete power packets need to be ORed. This is achieved by using Schottky diodes, which also block reverse current from one channel to the other.

![Power ORing Circuit Diagram](image)

**Figure 12. Power ORing Circuit: Example With 2 Channel**

**Figure 13** shows waveforms of transients at the output of power ORing circuit, when both the CPEs are active and hand-off occurs from one channel to another. The DC level of the output is about 52 V, which falls by 5 V, momentarily, during hand off. This is not much of a concern because variation in voltage is slow and isolated DC/DC converters can easily regulate the final load voltage at 12 V or 5 V.

![Transients Waveforms](image)

(a) Light-Load Condition  
(b) Full-Load Condition

Probe 1: Channel 1 Enable signal (EN1) → DC coupled  
Probe 2: Channel 2 Enable signal (EN2) → DC coupled  
Probe 3: Power ORing circuit output → AC coupled

**Figure 13. Transients at Power ORing Circuit Output**
6.4 **Need for Isolated DC/DC Converter**

The line and DP circuitry are inductively isolated. Hence, it is important to generate the isolated power with a separate ground. Note that, none of the wire of twisted pair cable acts as reference ground for the DP circuit. Not isolating the supply halves the amplitude of the differential signals on the line, and may also damage components of the DP circuitry.

7 **Conclusion**

Typically, in this type of system, more than 70% of the power gets delivered to the final load. Losses across cables and filters are negligibly small, due to small resistance and the low current flowing through them. However, major power loss occurs in isolated switching power supplies.

![Figure 14. Analysis of Power Losses in the System](image)

The suggested system is a basic working model for a reverse power feeding system; however, there are a number of parameters that need to be considered for an actual scenario. This includes:

1. Peak power requirement of the DP, which differs – based on hardware
2. Average cable drop lengths and impedance
3. Occasions where only a single user is providing power to the remote node but this may not be sufficient to power all of the remote node electronics for proper operation
4. Occasions where, for example, a GPON feed requests a response from the ONU located at the DP (for ranging or management purposes) when no users are currently connected and providing electrical power. Such situations result in the requirement for battery back-up devices and these may be located in the DP.
5. Provision can be made for compatibility with other architectures such as forward-powering of remote equipment from the CO or the provision of local main powering

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8 References

1. ETSI TR 102 629: Access, Terminals, Transmission and Multiplexing (ATTM); Reverse Power Feed for Remote Nodes
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