Society of Cable
Telecommunications
Engineers

ENGINEERING COMMITTEE
Energy Management Subcommittee

SCTE STANDARD

SCTE 238 2017

Operational Practice for Measuring and Baselining Power Consumption in Outside Plant Equipment and Power Supplies

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140 Philips Road
Exton, PA 19341

Table of Contents

Title **Page Number**

List of Figures

List of Tables

1. Introduction

1.1. Executive Summary

This operational practice covers techniques for measuring the energy consumption of outside plant (OSP) equipment, including power supplies, fiber optic nodes, RF amplifiers and other active electronic devices in the outside plant. Methods apply to modern equipment with built-in metering and to un-metered legacy equipment, and some of the latter may be intrusive and service impacting.

This operational practice is to help cable operators determine the actual energy consumption of current and newer OSP devices as they are deployed in the field in order to 1) develop energy monitoring and management practices to improve energy efficiency in the OSP, and 2) to understand where improvements in next generation access network equipment are needed to achieve further improvements in energy efficiency.

1.2. Scope

ANSI/SCTE 211 2015 [3] describes energy metrics for access networks, and ANSI/SCTE 212 2015 [2] describes an overall framework for performing energy audits and establishing baseline energy consumption in cable access networks. However, even with the ANSI/SCTE 212 2015 [2] framework, portions of cable networks do not easily lend themselves to exact measurement and monitoring of energy consumption due to the lack throughout the network of certified utility metering and/or modern monitoring solutions built into the power supplies. This document thus provides specific operational practices in support of the ANSI/SCTE 212 2015 [2] standard for defining how cable operators can audit power consumption and accurately establish an energy baseline in access networks as they currently exist. This document is limited to the outside plant equipment and excludes any customer powered equipment. Inside plant, i.e. equipment located in critical facilities at the network edge, should be covered in a separate operational practice document.

1.3. Benefits

The immediate and long term benefits include:

- Developing an accurate model of actual energy consumption in the OSP for current and evolving network architectures
- Identifying near term opportunities for plant improvements or upgrades that can lead to substantial improvements in OSP energy efficiency
- Identifying opportunities for static/dynamic energy monitoring and management in the OSP

This document supports the Energy 2020 roadmap for improving energy efficiency in cable networks, especially in the access network where the majority of energy consumption occurs.

This document can be customized for your workforce/cable network specifics. Implement the practices, keeping track of key performance indicators (KPIs) both before and after the implementation to ensure it is meeting the business goals of the cable operator.

1.4. Intended Audience

The intended audience includes engineering and operations staff involved in planning to improve energy efficiency, outside plant technicians, field and installation technicians, training content developers, and those with an interest in energy consumption in outside plant equipment.

1.5. Areas for Further Investigation or to be Added in Future Versions

The *EMS-ANE* working group is currently developing a reference model for a separate document (*EMS*-033) and plans to include for example procedures for developing detailed models and examples of typical OSP architectures, lab testing/characterization of individual components as they are submitted for repair, and building a table of product by age to cross reference against a cable operator's network map, as well as other methods to accomplish the reference model with lab measurements method.

Also, further deas and suggestions for future investigation and development are presented throughout this document. See the final paragraphs in sections 6.3 and 6.4 for specific ideas.

2. Normative References

The following documents contain provisions, which, through reference in this text, constitute provisions of this document. At the time of Subcommittee approval, the editions indicated were valid. All documents are subject to revision; and while parties to any agreement based on this document are encouraged to investigate the possibility of applying the most recent editions of the documents listed below, they are reminded that newer editions of those documents might not be compatible with the referenced version.

2.1. SCTE References

- No normative references are applicable.

2.2. Standards from Other Organizations

- No normative references are applicable.

2.3. Published Materials

- No normative references are applicable.

3. Informative References

The following documents might provide valuable information to the reader but are not required when complying with this document.

3.1. SCTE References

- [1] R. Hughes, "FFTH: More savings than meets the EYE," paper and presentation at SCTE Cable-Tec Expo '15, New Orleans, LA, October 2015, available from www.scte.org.
- [2] ANSI/SCTE 212 2015 "Cable Operator Energy Audit Framework and Establishment of Energy Baseline," available from www.scte.org.
- [3] ANSI/SCTE 211 2015 "Energy Metrics for Cable Operator Access Networks," available from www.scte.org.
- [4] R. Spee, "Energy 2020 Baseline - Setting the Stage," paper and presentation at SCTE Cable-Tec Expo '15, New Orleans, LA, October 2015, available from www.scte.org.
- [5] SCTE Broadband Distribution Specialist (BDS) training course, available from www.scte.org.
- [6] ANSI/SCTE 210 2015 "Performance Metrics for Energy Efficiency & Functional Density of Cable Data Generation, Storage, Routing, and Transport Equipment" available from www.scte.org.

- [7] ANSI/SCTE 213 2015 “Edge and Core Facilities Energy Metrics” available from www.scte.org.
- [8] ANSI/SCTE 232 2016 “Key Performance Metrics: Energy Efficiency & Functional Density of CMTS, CCAP, and Time Server Equipment” available from www.scte.org.

3.2. Standards from Other Organizations

- No informative references are applicable.

3.3. Published Materials

- [9] 80 PLUS power supply efficiency voluntary certification, see for example https://en.wikipedia.org/wiki/80_Plus.
- [10] L. Vividino, “Power Factor, Harmonic Distortion; Causes, Effects and Considerations,” Telecommunications Energy Conference, 14th International INTELEC '92, 4-8 Oct 1992, pp.506-513.
- [11] P. Hiscocks, “Measuring AC Current and Power Factor,” Syscomp Electronic Design Ltd. application note, found on the web at http://www.syscompdesign.com/assets/Images/AppNotes/power-factor-measurement.pdf.
- [12] A. Skinner, “How to Accurately Measure Power Supply Efficiency,” TDK Lambda white paper, found on the web at http://tdk-lambda.ru/KB/How-to-Accurately-Measure-Power-Supply-Efficiency.pdf.
- [13] DOCSIS and Ethernet Status Monitor Data Sheet, available from www.alphatechnologies.com.
- [14] Cisco GS7000 1 GHz Node Data Sheet, available from www.cisco.com
- [15] STEFAN SVENSSON, "Power measurement techniques for non-sinusoidal conditions", Department of Electric Power Engineering , CHALMERS UNIVERSITY OF TECHNOLOGY, Göteborg, Sweden, 1999, found on the web at https://www.sp.se/en/index/services/DSWM/Documents/SvenssonStefanPhD.pdf
- [16] Peter Deierlein, "CATV SYSTEM POWERING CONSIDERATIONS", 1989 NCTA Technical Papers, found on the web at http://www.nctatechnicalpapers.com/Paper/1989/1989-catv-system-powering-considerations

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shall not	This phrase means that the item is an absolute prohibition of this document.
forbidden	This word means the value specified shall never be used.
should	This word or the adjective "*recommended*" means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications should be understood and the case carefully weighted before choosing a different course.
should not	This phrase means that there may exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.
may	This word or the adjective "*optional*" means that this item is truly optional. One vendor may choose to include the item because a particular marketplace requires it or because it enhances the product, for example; another vendor may omit the same item.
deprecated	Use is permissible for legacy purposes only. Deprecated features may be removed from future versions of this document. Implementations should avoid use of deprecated features.

5. Abbreviations and Definitions

5.1. Abbreviations

AC	alternating current
ANE	access network efficiency (an SCTE/ISBE EMS working group)
AP	access point
BDS	broadband distribution specialist (an SCTE/ISBE certification)
CapEx	capital expenditures
CCAP	converged cable access platform
CMTS	cable modem termination system
DC	direct current
DPS	device power supply
EMS	element management system
EMS	the SCTE Energy Management Subcommittee
ETSI	European Telecommunications Standards Institute
GIS	geographical information systems
HFC	hybrid fiber coax
HHP	households passed
HMS	HFC management subcommittee (of the SCTE/ISBE)
I2R	I2R heating losses in a conductor, the current squared times the resistance
IoT	internet of things
ISBE	International Society of Broadband Experts
KPI	key performance indicator
kWh	kilo-Watt-hours
LGI	Liberty Global International
LPI	line power inserter

LPS	line power supply
MAC	media access control
MIB	management information base
MSO	multiple system operator
N+0	node plus zero (no amps after the node)
NFV	network functions virtualization
NOC	network operations center
OpEx	operational expenditures
OSP	outside plant
PHY	physical layer (of the open systems interconnection or OSI model)
PIN	package-in-line (a connector type)
PNM	proactive network maintenance
PON	passive optical network
QAM	quadrature amplitude modulation
RF	radio frequency
RMS	root-mean-squared
SCTE	Society of Cable Telecommunications Engineers
SDN	software defined network
SNMP	simple network management protocol
TB	terabytes
TB/s	terabytes per second
VAC	volts of alternating current
VDC	volts of direct current
VOM	volt-ohm meter

5.2. Definitions

metering	Use of certified devices recognized by the power company for billing purposes
monitoring	Use of non-certified measurements such as those available in OSP power supply add-on modules

6. Background

6.1. General considerations

With the outside plant (OSP) power consumption representing a major part of a cable operators' energy bill, there is increasing interest in improving the energy efficiency of the OSP equipment and evolving architectures. This is especially important since the following OSP technologies are expected to further increase the total power required for the OSP while increasing the total capacity of the OSP:

- Remote and/or distributed architectures such as remote PHY, remote MAC/PHY, remote CCAP and so on
- Higher RF upper frequencies for DOCSIS 3.1
- Greater intelligence/flexibility in the network from software defined network (SDN) and network functions virtualization (NFV) technology
- Increasing numbers of wireless devices on, and powered by the OSP (Wi-Fi access points and even newer cell backhaul devices)
- The addition/overbuilding of PON networks alongside existing HFC networks to produce a hybrid access network.

For the latter, while PON networks are more energy efficient [1], unfortunately when they are deployed alongside existing HFC networks, the total power consumed by the OSP still goes up overall. And due to limited fiber counts in some areas, PON architectures that include active devices in the OSP in order to extend the reach of the technology are used, which also increases the energy consumption of the OSP.

ANSI/SCTE 212 2015 [2] provides an audit framework for establishment of an energy baseline for the outside plant. Quoting from this document:

> "For metered power supplies, the utility billing information should provide power supply input power (kWh and days in bill).
>
> Legacy status monitoring devices can be used to capture output voltage and output current. Be aware, status monitoring data is not accurate enough across the board to serve as more than an indicator for power supply output. Thus, for unmetered power supplies with legacy transponders, there is no utility grade measurement available. In systems with a mixed population (metered and unmetered), the metered accounts can be used to statistically estimate unmetered usage. This will provide an indication if the unmetered power supply population as a whole is billed correctly and can be used as a decision point for follow up work.
>
> Metered power supplies are generally billed as stand-alone accounts, i.e. one bill per power supply. Unmetered power supplies are often billed on summary bills (many sub accounts under one primary account number). Many unmetered accounts are legacy accounts, often carried across multiple acquisitions without account maintenance. In many cases, utility addresses are missing completely. In these cases, in depth negotiations with the utility are required to resolve billing issues.
>
> Overbillings are normally related to unmetered power supplies. Not only is the number of supplies billed often inflated, but kWh numbers charged are in excess of actual usage. In some cases, utilities charge based on nameplate rating of the unmetered power supplies."

As stated previously, there is a need to gather accurate data on actual power consumption in the cases where power supplies are unmetered, or where older status monitoring systems are in place that may not be accurate enough. Also, the data from the above approach is coarse in that it does not express the actual power consumption vs. architecture in the network, nor how power consumption varies from element to element in the network and how the elements in the above list of new OSP technologies will specifically affect power consumption and efficiency. In particular, the data from the ANSI/SCTE 212 2015 [2] approach cannot be used to determine power efficiency of the power supplies, and therefore determine if there is a significant opportunity in the cable industry to improve power efficiency in outside plant power supplies.

Ultimately cable operators are looking for ways to reduce costs, so it is also recommended to capture the actual billed cost (in dollars, euros, etc.) from both the metered supplies as well as the billed amount based on estimates to use along with the billed kWh. Currently, power supply accounts generally are not fitted with a demand meter to capture peak power demand although this may change in the future. Capture of actual billed costs allows tracking of demand increases due to higher temperatures and the associated higher I^2R losses, higher tariff rates, or peak demand charges. Since most consumption in the OSP is relatively stable, cost tracking would also permit detection of unusual variations across a portfolio of sites that might be a useful predictor of equipment malfunction in certain situations. Utility bill aggregators are available to perform the tracking.

In the remaining subsections of this background discussion, we will discuss several aspects of the access network that affect power consumption, namely the power supply efficiencies, temperature variations, and power supply architecture.

6.2. Access network powering methods

ANSI/SCTE 211 2015 [3] describes access network powering methods in detail. A typical hybrid fiber-coax (HFC) network powering diagram is shown in Figure 1. The AN contains devices such as nodes, amplifiers and Wi-Fi access points (APs) that require electrical power to operate. The electrical power is provided to the AN by line power supplies (LPSs), which convert electrical power from the power grid to a quasi-square wave 60 volt (V) or 90 V alternating current (AC) voltage to power the AN equipment. The current from the LPS is conducted by the passive and active equipment in the AN across distances that can range from several feet to several miles. Because of the resistance of the conductors in the AN, there is a voltage drop and power dissipation in the conductors as the current traverses the path to the active components that utilize the power to produce useful work.

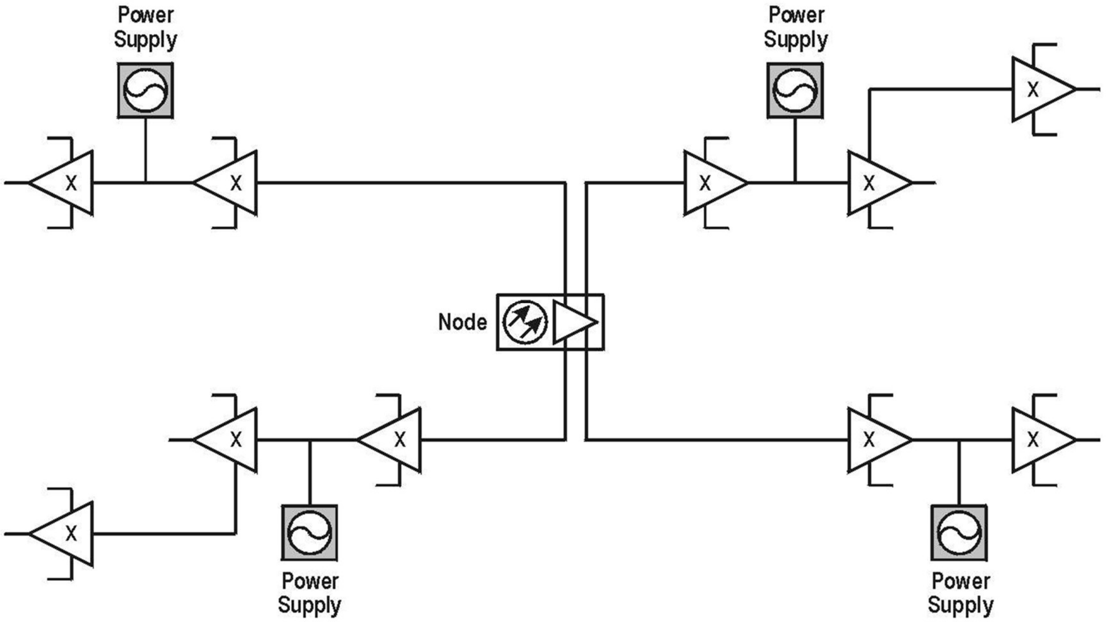


Figure 1 – Typical HFC Powering

Each active device in the AN contains a power supply to convert the AC voltage into useful direct current (DC) voltages for use inside the active device. To avoid confusion with the LPS, these power supplies inside the devices are called the device power supply (DPS).

Electrical power is consumed in the LPS as heat because of inefficiencies, in the cable and other passive conductors as heat because of resistance, in the DPS as heat because of inefficiencies and in the actives devices as heat because of inefficiencies and to produce useful work.

6.3. Power supply efficiencies

The efficiency of a power supply is the output power divided by the input power, and this efficiency typically varies with the load as a percentage of the total rated load on the supply. For example, the 80 PLUS voluntary certification, which is now part of the Energy Star computer specification, “certifies products that have more than 80% energy efficiency at 20%, 50% and 100% of rated load, and a power factor of 0.9 or greater at 100% load" [9]. An OSP power supply that is only 70% efficient and consumes 1 kW of mains power will waste 300 W of power as heat. If there are 10,000 such units in the outside plant, this represents a total energy waste of 3 MW in the OSP, which at a cost of 12 cents per kWh, represents a cost of $3.2 M per year. Fortunately, most modern OSP power supplies have an efficiency that is much higher. However, since it is still typically less than 99%, it remains of interest to characterize power supply efficiency as part of an overall effort to assess OSP energy efficiency.

As explained in section 6.2, there are two types of power supplies in the outside plant. Line power supplies (LPS) condition the incoming utility power for injection into the coaxial network. These power supplies convert the sinusoidal utility voltage into a quasi square wave to power the coaxial network and may also contain backup batteries to support the plant during utility outages. Device power supplies (DPS) are contained within the plant actives and convert the incoming ac quantities as required by the device - usually the transformation is into various dc levels. The DPS are nonlinear devices and generally function as rectified capacitive load. With a sinusoidal input voltage, the current into this type of load would be a spike occurring only during the peak of the voltage waveform. The application of quasi square wave voltage to power the OSP produces a current waveform which extends the current waveform over a bigger part of the half cycle and consequently lowers the peak current. This lowers the ohmic voltage drop across the coax, which in turn allows the LPS to reach further into the network than a sinusoidal power supply could.

Figure 2 illustrates typical waveforms at the input and output of an LPS.

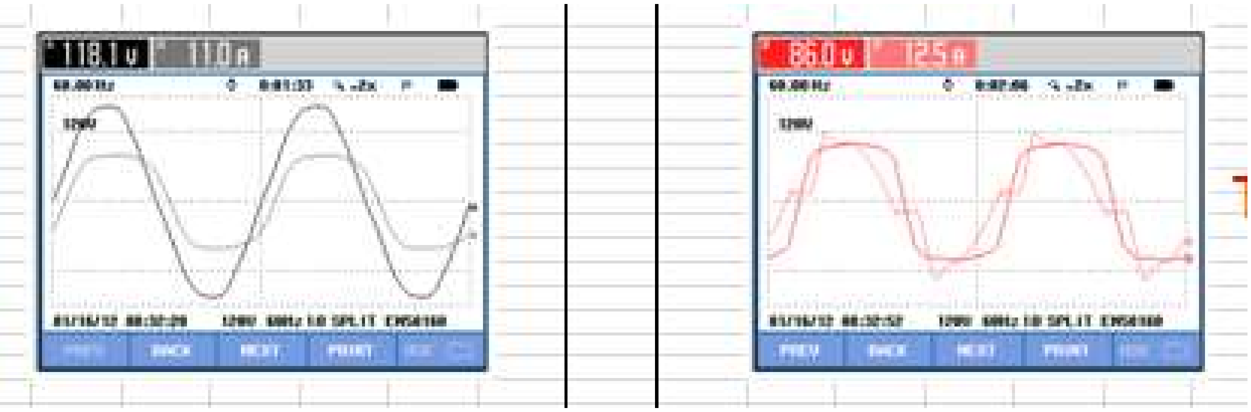


Figure 2 – LPS Input (left) and Output (right) Voltages

In order to establish power supply efficiency, we need to determine input and output power, then the efficiency is determined as

$$\eta = P_{out} / P_{in} \qquad (1)$$

Generically, active or mean power is calculated as

$$P = \frac{1}{T}\int_T v(t)i(t)\,dt \qquad (2)$$

where v(t) and i(t) are instantaneous voltage and current and T is the period for periodic waveforms.

For periodic sinusoidal quantities (see left picture in Figure A), this becomes the familiar equation

$$P = V\,I\cos\theta \qquad (3)$$

where V and I are the root mean square values of v(t) and i(t) and ɵ is the phase angle between voltage and current.

For non sinusoidal situations (e.g. the right picture in Figure A), it is best to utilize a power analyzer, which essentially solves equation (1) in either time or frequency domain. For LPS output waveforms as shown in Figure A, in addition to active or mean power P, we also encounter reactive (zero average) components [11]:

> (a) Displacement reactive power due to the phase angle between fundamental components of voltage and current, and
>
> (b) Distortion reactive power due to the harmonics contained in voltages and currents.

In a coaxial cable network, displacement reactive power is for example caused by the requirements of the transmission line characteristics of the coax, while distortion power is due to the harmonic requirements at the input of the DPS. Note that while reactive power quantities average zero over a cycle, the associated currents flowing still cause real losses in the system infrastructure.

Currents in the coax lead to voltage drops, which reduce and distort the voltage at the input to the actives and the associated DPS. The location of an active determines the source impedance going back to the LPS feeding the coax and impacts the DPS input voltage. This in turn affects DPS input current and thus input power factor and overall system efficiency. Consequently, the performance of a DPS is a function of its location relative to the powering LPS.

Thus, it is important to determine power supply performance in the application rather than solely in a laboratory environment. Another major criteria in determining the operating efficiency for LPS are the load factors they are operated under, as efficiency increases with load. This is shown in Figure 3 for a typical ferro-resonant power supply. As indicated in section 9, many LPS in operation are not loaded optimally, leaving room for improvement.

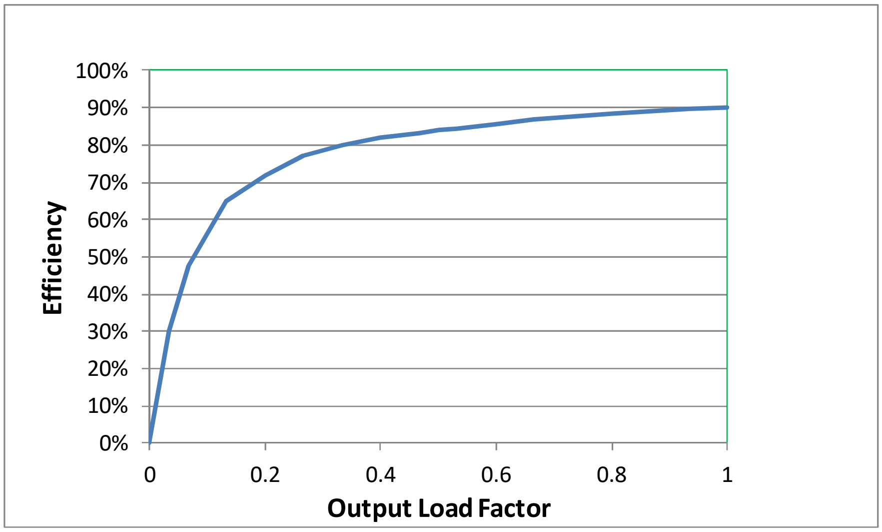


Figure 3 – Ferro-resonant Power Supply Efficiency as Function of Load

A detailed discussion of powering in non-sinusoidal situations is given in [15], while [16] provides a still timely discussion of DPS powering considerations for cable systems. A more complete discussion of different power factors is given in [10]. For a complete discussion of power factor measurement see the application note by Peter Hiscocks in reference [11], or the discussion by Skinner [12].

There is often a significant difference between the rated or ‘nameplate’ value of power consumption specified for a device and the actual value of power consumed by the device in operation. When baselining power consumption, at least a few spot checks should be made of actual power consumption, either in the lab or in the field, in order to either confirm the accuracy of the nameplate value, or to determine typical margins to offset the nameplate value for actual energy consumption.

This can be seen regarding loading of power supplies by noting that one cable operator recommends loading to 100% of nameplate value, assumedly to maximize the power efficiency, which typically drops as the loading is reduced.

In updates to this document, one could look at actual loading across cable operators to determine where the industry is as of now: some may be loading only to 85% per older recommendations in the cable industry, and according to audits of over 150,000 power supplies, the actual loading can be as low as 55-60%. Ideally, as a result of further activities in the working group, both loading in actual networks as well as power efficiency curves of deployed power supplies would be measured and/or characterized to determine the amount of energy wasted as heat in presently deployed network power supplies.

Other power efficiencies of interest in OSP equipment and architectures include the DC-RF power efficiency, which for an amplifier is defined as the sum of the RF forward power output and the RF reverse power output divided by the DC power input, and the I^2R losses in the coaxial cable itself.

6.4. Temperature variation in OSP energy consumption

There is a variation in power consumption in the OSP with temperature, in part due to the fact that coax power loss is temperature-dependent and will affect actual consumption in the field. Typical values are 1% change in copper resistance for every 3 °C, and for aluminum this figure is 1% for every 2 °C.

Table 1 is a sample of temperature variation measurements for deployed aerial plant in the Mid-Atlantic region of the United States located close to the coast. The “Power in watts” in row one is the average monthly billed power. Note in the table that monthly temperature data (calendar month average) and power data (billing cycle average) do not match up 100% since billing cycles do not follow calendar months. Nonetheless, a roughly +/- 2% power variation and a resistance variation of around +/-4% is seen from the data from an actual plant. This indicates that some of the plant has less temperature dependence than even copper does inherently, a point which will be further investigated. It also indicates that there do not appear to be extreme swings in amplifier power requirement, at least over the temperature ranges shown. But note that in some parts of the United States and around the world, temperatures have been reaching 110 °F or 43 °C, which could add another 3% increase in coax power loss. While a few percent is probably still a marginal amount, in the face of greater power consumption in the OSP from the technologies mentioned above, it does indicate additional attention should be given to the total power budget and effects of higher temperatures on OSP infrastructure.

Table 1 - Temperature Variations in Energy Consumption in an Actual HFC Network (Data Courtesy of Coppervale)

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Power in watts (from utility bill)	743	747	757	763	767	760	759	753	749	749	737	759
Mean Temperature (°F)	72	78	86	91	82	77	68	62	60	52	56	64
Mean Temperature (°C)	22	26	30	33	28	25	20	17	16	11	13	18
kWh deviation from annual average (%)	-1.4	-0.8	0.4	1.3	1.8	0.9	0.7	-0.1	-0.6	-0.6	-2.1	0.7
Copper resistivity deviation from average (%)	0.3	1.6	3.3	4.4	2.5	1.4	-0.6	-1.9	-2.3	-4.1	-3.2	-1.5

One future activity of this group may be to get a detailed readout from various vendors on how temperature may affect power consumption for their currently-deployed equipment and cabling, especially in extreme temperature zones. Data on currently-deployed equipment may be worse-case given the age of much of the equipment in the field, for example. A request to vendors to provide more detailed new product energy consumption vs. temperature may be generated by the group as well.

6.5. Centralized vs. distributed power supplies

Power consumption due to loss in the OSP also depends on whether the OSP powering architecture is centralized or distributed, as shown in Figure 4 and Figure 5. Generally, most new power supply deployments, especially those associated with fiber-deep build outs, are of the centralized power supply architecture type, and thus may have greater OSP coax power losses based on the longer runs of coax to get the power where it is needed.

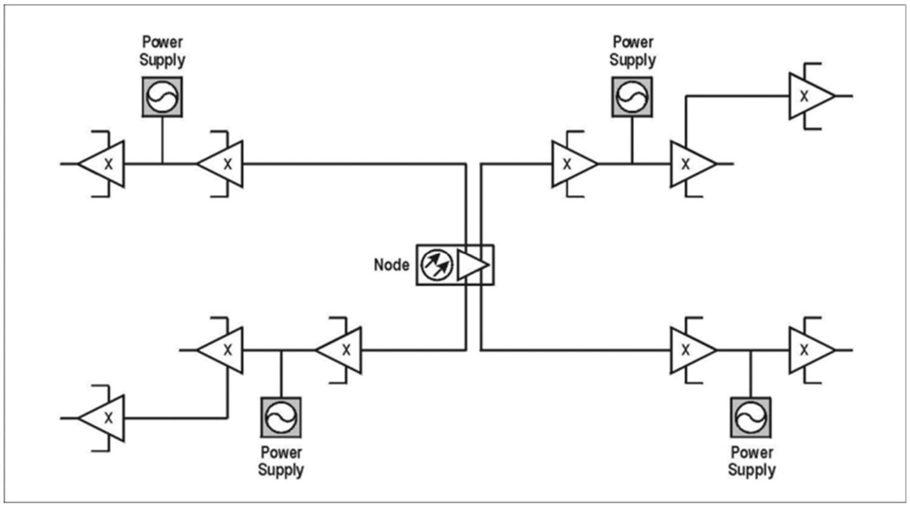


Figure 4 - Distributed Power Supply Architecture (from [5])

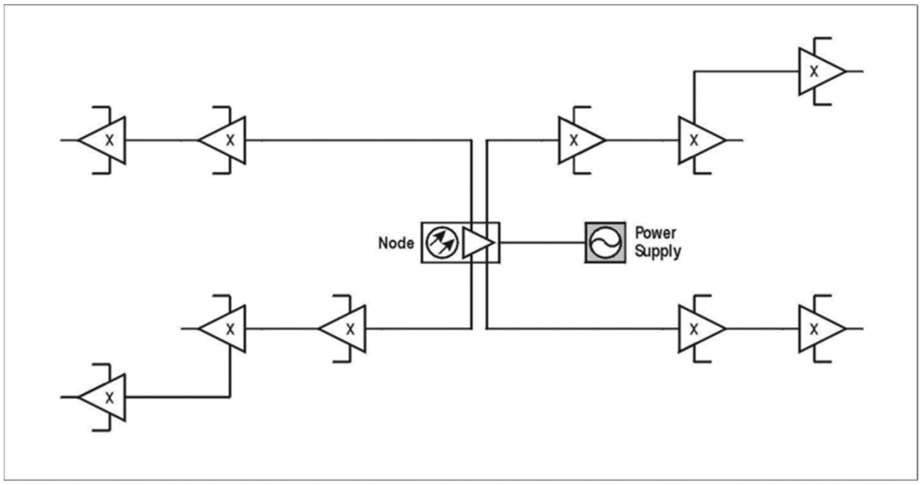


Figure 5 - Centralized Power Supply Architecture (from [5])

Consider a simple example that illustrates the voltage drops in a network as shown in Figure 6. Note that this is an extremely simplified example. For the purposes of this example it is assumed that the power supply is producing 90 volts. It is also assumed that each active device in the system draws 1 amp of current. In general, each active device will draw a different amount of current based on the input voltage, which drops as device distance from the power source increases. It is also assumed that the coaxial cable has a DC loop resistance of 1 ohm per 1000 feet.

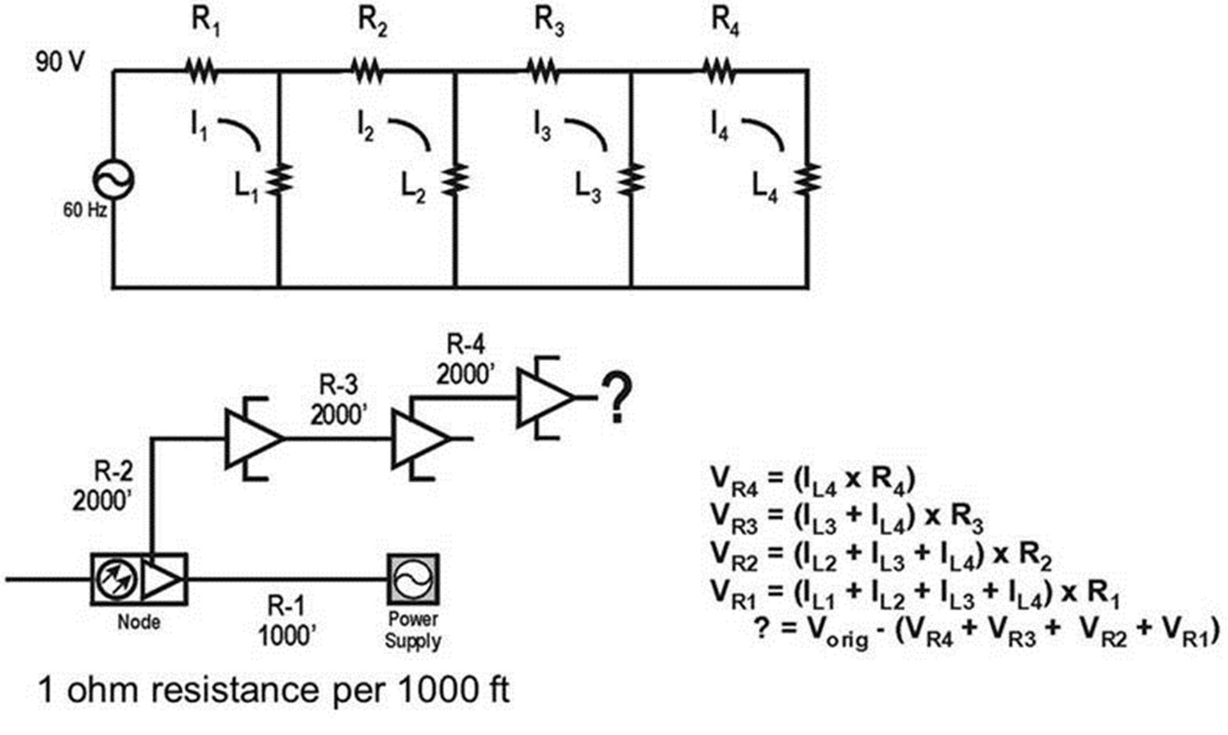


Figure 6 - Voltage Drop Calculation Example (from [5])

Based on the DC loop resistance, coaxial section R-1 has a DC loop resistance of 1 ohm, sections R-2, R-3 and R-4 each have a DC loop resistance of 2 ohms. Coaxial section R-4 must supply 1 amp of current for the last amplifier in the cascade and therefore has a voltage drop of 1 amp times 2 ohms which equals

2 volts. Coaxial section R-3 must carry 2 amps of current to supply the last two amplifiers in the cascade and consequently has a voltage drop of 2 amps times 2 ohms which equals 4 volts. Coaxial section R-2 must carry 3 amps of current to supply the last three amplifiers in the cascade and consequently has a voltage drop of 3 amps times 2 ohms which equals 6 volts. Finally, coaxial section R-1 must carry 3 amps of current to supply the last two amplifiers in the cascade and consequently has a voltage drop of 3 amps times 2 ohms which equals 6 volts. Coaxial section R-1 carries 4 amps to supply the node and the three amps and consequently has a voltage drop of 4 amps times 1 ohm which equals 4 volts.

The total voltage drop from the line power supply to L4 will be therefore be 2 + 4 + 6 + 4 volts which equals 16 volts. If the line power supply has an output of 90 volts, then the voltage at L4 will be 90 volts minus 16 volts or 74 volts.

Note that in general each active device will not draw the same current. The current required is dependent on the voltage and the voltage waveform ***at that device***. A detailed analysis considering the current draw of each active device as the voltage input changes is much more complex: the full analytical solution of the system problem requires solving for the roots of a high order polynomial. The analysis is further complicated by the fact that the current waveform at the device depends on the voltage waveform at the device. When device power supplies are not power factor corrected, the current waveform will also have higher peak currents. Thus, measurements and ultimately the ability to remotely monitor the voltage and power draw in the active devices themselves would be the best way to accurately monitor energy consumption of individual components in the network.

6.6. Other considerations

Another area of concern for cable operators is to determine what percentage of the plant is still running 60 V vs. 90 V power supplies. Since the I^2R losses are lower per unit length of coax with 90 V supplies, the latter have a longer reach at higher voltages. There are two ways to leverage an upgrade to 90 V: after replacing a number of 60 V supplies with 90 V supplies it can be possible to eliminate some power supplies since the newer 90 V supplies have a longer reach than the older 60 V supplies. Alternately, if the number of power supplies is kept the same, the total ohmic losses in the network are reduced and the network is more energy efficient. There are even situations where fewer 90 V power supplies are needed than in the existing 60 V plant, and additionally the lowest voltage in the plant is still higher than before the upgrade. Since this means the upgraded network is not utilizing the 90 V to its full extent, there is some current reduction and thus greater energy efficiency through reduced total I^2R losses. Power supply elimination is often primarily driven by CapEx and OpEx cost reductions, however it is still possible to save energy by having fewer power supplies at a higher load factor and thus higher efficiency.

Many of the legacy networks were designed how to handle circuit switched telephony deployments of the late ‘90s. With the decline in circuit switch telephony, many power supplies are running at much lower current levels than originally designed for which results in power supplies running at a much lower efficiency levels. A power supply has maximum efficiency while running near peak capacity, thus understanding the current draw on your network that is left/available is a key component while redesigning a network for new architectures, especially for remote PHY, remote MAC/PHY, remote CCAP, fiber deep and other advanced and/or hybrid access network architectures. Next generation networks should be designed to maximize power supply efficiency while also giving room to add future ancillary devices such as Wi-Fi radios, small cells, cameras, and future internet of things (IoT) devices.

7. Key Performance Metrics

This section includes the key performance metrics to be measured and provides a brief overview of the theory behind each one.

The main metrics to determine OSP network efficiencies fall into two categories, device level metrics and network metrics.

Device level metrics include:

- Line power supply (LPS) efficiencies (power out / power in)
- Device power supply (DPS) efficiencies (power out / power in)
- Network interaction (power factor) effect on efficiency
- Cable efficiencies (cable resistance and lengths)

Network level metrics include

- Watts per household passed (W/HHP)
- W/meter or mile
- kWh per TB

7.1. Device level metrics

To date, SCTE Energy 2020 has dealt with device level metrics as part of the *EMS*-004 standards development. *EMS*-004 focuses on energy efficiency metrics for common equipment items deployed in cable operator networks. The intent is to provide defined metrics and testing structures for suppliers to use in detailing energy efficiency and functional density for their devices. Operators can then use published metric data to make comparisons of devices to be deployed in the network based on defined standards.

EMS-004 work initially focused on devices in facilities, i.e. servers, cable modem termination systems (CMTSs), quadrature amplitude modulators (QAMs), etc. One standard has been developed (ANSI/SCTE 210 2015 [6]), and the Phase 2 standard (*EMS*-004 Phase 2, Key Performance Metrics: Energy Efficiency, & Functional Density of CMTS, Edge-QAM, and CCAP Equipment) is currently under development.

Recently it was decided to extend *EMS*-004 to include in future metrics for access network devices (i.e. OSP power supplies, nodes, amplifiers, etc.). Work on the document (currently called *EMS*-004-4 for access network equipment) is currently in process.

Additionally, with respect to device level energy metrics, in 2014, the European Telecommunications Standards Institute (ETSI) completed both a standard (ETSI 205 200-2-4) and a Technical Recommendation (TR 105 174-6) related to energy metrics in access networks. Although the TR itself is just a recommendation, and carries no weight of a standard, TR 105 174-6 specifically makes mention of potential device level metrics which might be used to compare device level performance. These include:

- For OSP power supplies, power supply efficiency (Section 7.2 of document)
- For fiber nodes, watts/wavelength (Section 7.3 of document)
- For amplifiers, watts/dBmV output (Section 7.4 of document)

ANSI/SCTE 232 2016 [8] provides definition around key equipment and device level metrics for access networks. Development of ANSI/SCTE 232 2016 [8] builds on the starting point provided for device level metrics in ETSI TR 105 174-6, with the ultimate intent to produce the full complement of metrics that operators can use to compare access network field devices with respect to energy efficiency. Please download and refer to the latest version of ANSI/SCTE 232 2016 [8] for headend device-specific metrics impacting access network power consumption.

7.2. Network level metrics

SCTE 211 2015 "Energy Metrics for Cable Operator Access Networks" defines calculation of the energy intensity metric, kWh/TB for operators to use in assessing the productivity of access networks with respect to energy usage. ETSI in its 205 200-2-4 standard defines a similar productivity metric for access networks as well.

As measurement of bits consumed in smaller subsets of network can sometimes be difficult, ETSI TR 105174-6, Section 8.2 defines watts/km of plant as a potential benchmarking network level metric. Additionally, section 5.2 of the R. Spee paper [4] details use of watts/home passed to make access network comparisons. If homes passed and/or linear miles of coaxial plant is known and/or easier to find for a particular piece of network, these metrics are options for assessing and comparing access network energy performance.

7.3. Supplemental metrics

A recent paper by R. Spee [4] , provides the additional metrics of interest for the access network shown in Table 2:

Table 2 - Supplemental Metrics

Metric	Discussion
Power supply load distribution and average load per power supply	Correlates usage to installed capacity for power supply efficiency analysis and load growth investigations
Comparison of power supply averages for metered and unmetered accounts	Identifies possible overbillings on the unmetered sites
Correlation with aspects of plant infrastructure	This can be used to evaluate plant segments with different characteristics (e.g. voltage, fiber penetration, coax impedance)

7.4. Other metrics

Other metrics of potential interest include histograms of the previously listed metrics that can be plotted for all OSP devices or versus various parameters such as plant age, plant repair activity, temporal history, construction nearby, and so on so that long term trends in energy consumption and efficiency can be identified in the future and addressed to improve energy efficiency.

Also, metrics that relate to the workforce or effectiveness of measurements during maintenance windows can be collected. These may include metrics such as:

- Mean duration of plant outage during maintenance/measurement;
- Number of equipment failures or other trouble-tickets associated with measurements

These latter measures would be important in determining if a service impacting measurement is viable, even if the costs of such measurements are not considered.

8. Required Equipment

8.1. Built in Metering

It is now possible to use existing metering/transponder devices in modern OSP power supplies to monitor and characterize power consumption in the OSP. This is the preferred method since these devices are already in use in the network and the only additional cost is the back office software, integration with geographical information systems (GIS), and training of the workforce to use the or these remote monitoring technology and capabilities.

SCTE's Energy Management Subcommittee working group on access network efficiency (*EMS-ANE*) is aware of the following commercially-manufactured power supply status monitoring equipment as some examples of how remote monitoring and/or measurements can be implemented:

- AlphaNet^{TM} DSMDS3.0M
- Continuity
- Cheetah XD Element Management Systems
- Other "DOCSIS" Ethernet status monitor (ESM) products

The reader is urged to contact manufacturers of power supplies that they use for additional information.

The following information is not intended to be an endorsement of the manufacturers or their products by SCTE or members of *EMS-ANE*, nor is it intended to be an exhaustive list; it is merely given as an example of equipment that can be used to perform the operational practice.

The latest generation of power supplies and status monitoring platforms provide a wealth of information when analyzing a network and looking into potential cost savings associated with upgrades, see Table 3. In a matter of minutes, an operator is able to understand their percent of 60 V versus 90 V plant, the average current draw on their power supplies, and also look at how much power is being utilized at the meter.

Table 3 - Example TPower Supply Status Monitering Parameters

Major alarm	Logical (OR) of: test fail, battery fail, line isolation alarm, output overload, inverter over temperature, N+1 active, fuse fail
Minor alarm	Logical (OR) of: temperature probe error, AC line loss, N+1 error
Input line voltage	90-270 VAC 50/60Hz measured value
Output voltage	60/90 VAC measured value
Output current 1	0 to 25 A measured value
Output current 2,3,4	0 to 25A measured value (if optional ports installed)
Output power	Calculated, reported in AC Watts
UPS status	AC line, Standby, Test in-process, Test Alarm
Enclosure door	Open/Closed
Battery voltage	6V or 12V batteries, up to 16 batteries; Individual battery voltages measured reported to ±100mv resolution
Battery temperature	Battery Temperature: Measured, reported in Celsius
Remote test control	Remote Test Control: Start/Stop XM2 self-test cycle

Modern status monitoring systems are continually able to pull more information out of the power supply helping an operator to understand how efficient the power supplies are running, the expected runtime of a power supply in stand-by, estimated remaining life of the batteries, along with stand-by times of power supplies during an outage to simplify generator deployments.

The latest generation of power supplies has available an even greater spectrum of information than standard HMS MIBs which are communicated to a NOC or headend via SNMP and can be displayed through an EMS. The use of DOCSIS 3.1 transponders in next generation power supplies would also provide a valuable point of presence for much more capable proactive network maintenance (PNM) network health monitoring. As networks become re-architected for fiber deep or remote-PHY, or any of the other power-consuming OSP evolutionary steps described earlier, information generated by an advanced status monitoring system will provide a valuable power consumption baseline to ensure the next generation network is adequately and efficiently powered.

8.2. Supplemental Test Equipment

Another way to perform the measurements is via traditional power measurement and monitoring equipment, which can be used to identify and characterize the power levels, consumption, and efficiencies in the network and associated equipment. Such measuring and monitoring equipment includes:

- Volt-amp meter/AC voltmeter
- Power meter
- Amp clamp, capable of measuring up to 20 A and preferably one that has a waveform output connection in order to measure power factor (may need larger, some are rated at 22 A, depends on where measurement is made). The meters should be ‘true’ RMS type.
- Power analyzer to measure power factor, such as those from Valhalla Scientific, found at http://valhallascientific.com/instruments/wattmeters-power-analyzers or those from Xitron, found at http://www.xitrontech.com/products/general-purpose-power-analyzers.
- Oscilloscope
- Spectrum analyzer or QAM analyzer

Note that these are merely examples that are offered and are not intended to be an endorsement of the manufacturers or their products by SCTE or members of *EMS-ANE* working group, nor is it intended to be an exhaustive list.

9. Procedures

9.1. Overview

Given the goal of improving energy efficiency in the outside plant and the variation seen in modern network powering as implemented, it is therefore desired to have an operational practice for measuring power efficiencies and consumption of OSP equipment. Such measurements will allow the development of better models for OSP energy consumption as well as drive improvements in energy efficiency of OSP equipment and even architectures moving forward. In particular, a reference is desired to compare the different options available for reducing the power consumption per TB/s on the network.

The methods of characterizing energy consumption and power efficiencies are defined in the following sections.

9.1.1. Ubiquitous metering and monitoring

Deployment of certified meters on every power supply to measure input power consumed and to be billed only for power actually consumed, as well as accurate status monitoring solutions built into the OSP power supplies to report output power and thus determine power efficiency. This option is the most accurate but also the most expensive to deploy. Note that ‘metering’ refers to certified devices recognized by the power company for billing purposes, while ‘monitoring’ refers to non-certified measurements such as those available in OSP power supply add-on modules.

9.1.2. Partial metering and ubiquitous modern monitoring

Partial deployment of certified meters and ubiquitous deployment of modern monitoring solutions so that accurate estimates of power consumption and power efficiencies can be developed from the metered power supplies and applied to the portions of the network that are not metered via modeling. Note that it is not yet clear that the utility companies will accept the results of monitoring solutions unless the accuracy of them can be proven, perhaps via deployment of a few new certified meters on selected power supplies to validate the data.

If the cable operator is currently able to determine exact power consumption and efficiency via modern power supply status monitoring transponders, this solution is not only much less costly than installing certified meters on all power supplies, but an operator should also be able to do a desktop analysis to get a reasonable understanding of the network load and how it varies with the as-built network configuration. With this information and an accurate network map, it is reasonable to assume that power loss of individual elements can be figured out by working backwards. This information may also be validated by comparison with power billing information from the local utility provider, using the method outlined in ANSI/SCTE 212 2015 [2]. However, it may require upgrading some power supplies to support the more modern monitoring solutions, unless an add-on that is compatible with all currently deployed units is available.

9.1.3. Partial metering and partial monitoring, including legacy monitors

This case represents many of the current cable networks. In this case, very accurate models of power efficiencies vs. load of the power supplies, power loss on the coax network, power consumption of individual active components, and field measurements to validate the models would be required in order to 1) calibrate the legacy power supply monitoring solution and 2) apply the results to the remaining unmetered and unmonitored portions of the network.

As part of this method, it would be necessary to characterize each type of active component in a network, account for any variation due to age, and then cross reference the power supply load against miles of plant, position and thus voltage of the actives on the plant, and even the number and position of passives to get a good cross reference of plant load. With this cross-reference, it should be possible to develop an accurate model of the actual plant layout that permits validation of the monitoring solution, both legacy and modern, and finally validate against meter data where available.

Further, it might be required to take actual readings of each active device, or representative types of equipment in the field with measurement equipment such as amp clamps, power meters, perhaps even opening the outer lid of equipment, removing fuses and measuring power consumption directly, and so on. While this method is relatively straightforward, it may not be practical based on truck rolls, person-hours and the potential for plant outages. Note that for measuring RF actives, even though one can pull the fuse and measure values directly, it only gives the actual consumption in that particular device at the voltage it sees for its location in the network; other RF actives may see different voltages and thus consume different power levels, so a way to translate power consumption of actives vs. position on the network is also required.

Note that a way to avoid some of the labor involved in field measurements would be to characterize network equipment in a lab setting and/or during repair as a non-intrusive method. This method is particularly useful to perform historical and trend analysis to determine if aging alters the power efficiency/consumption of equipment in the field. It also leads to the final method described next.

9.1.4. Reference model with lab measurements

Many operators have relatively standard architectures (N+3, e.g.). Thus, one could take 1000 nodes and develop an 'average tree and branch layout' in the lab and fully characterize it in the lab. Then spot measurements could be made in the field to validate the lab measurements. One could then use a lab cascade to alter the architecture to represent either other types of cascades (and possibly do more spot checks to validate) or to explore new architectures, e.g. N+0, to see the impact.

9.1.5. Summary and analysis of options

Regarding the above options, it is noted that some of them are very labor intensive, potentially customer-impacting, and may not even be necessary if other means of accurately estimating or obtaining the data are available. The recommended approach of this is that such labor-intensive activities only be performed if outliers are seen from current or easily obtained data. For example, a histogram of power consumption for each metered power supply can be developed, an example of which is shown in Figure 7.

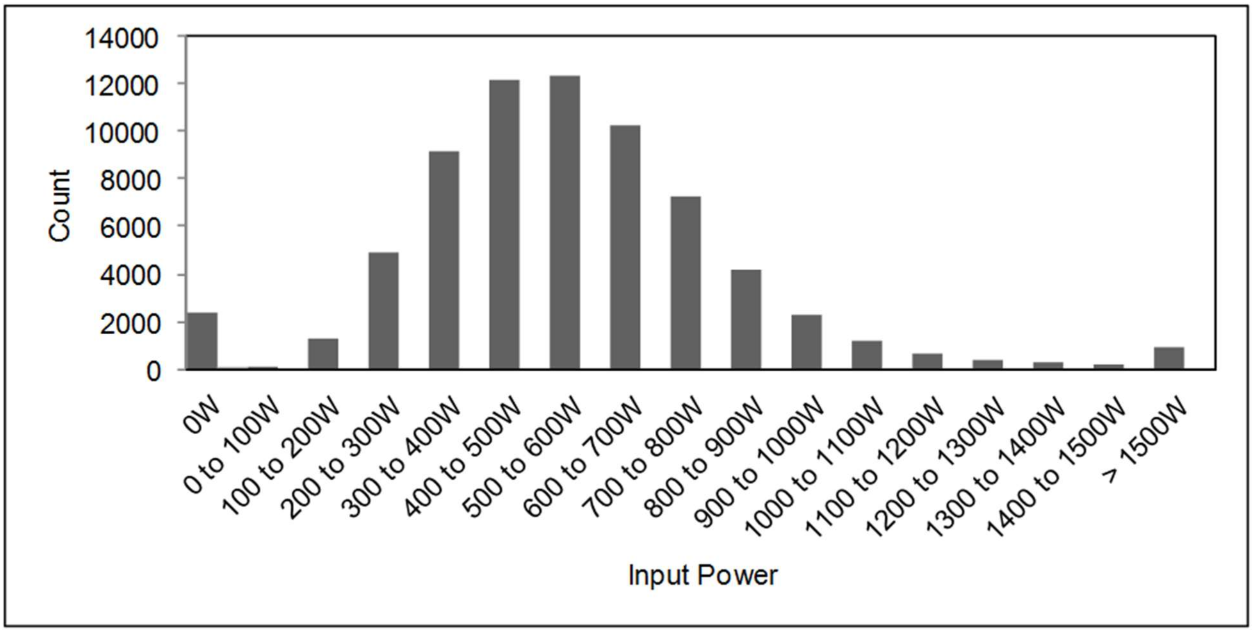


Figure 7 - Metered Power Supply Input Power Distribution (from [4])

In Figure 7, the outliers are those power supplies which report no energy consumption, and those that report greater than 1500 W. Field measurements of these particular units would assist in both eliminating billing for units not actually in use, or units with metering issues or multiple power supplies per cabinet [4] .

For a very basic initial characterization of a system, operators may consider picking a subset of the items shown in Table 4. This is a large set of parameters, so a subset may be sufficient, and the parameters in Table 4 can obviously be augmented with other parameters.

Table 4 - Example MSO Parameters for System Characterization

Item	Value	Unit	Source
Number of Fiber Nodes	16,200		MSO records
Number of Power Supplies	24,700		MSO records, status monitoring
Homes Passed	5,250,000		MSO records
Coax plant miles	65,000		MSO records
Trunk Amps	164,000		MSO records
Average DC loop resistance	4.1	Ohms	Calculated from cable type distribution in MSO records
Average Architecture, N+	5		MSO records
Average PS output voltage rating	73	Volts	Status monitoring
Average PS output current rating	15.3	Amps	Status monitoring
Average PS Load	585	Watts	Utility bill analysis

This info should be relatively easy to compile and can then be used to benchmark and compare with other areas. The system exemplified in Table 4 combines different architectures: mainly N+6, a bit of N+3 and a bit of other. Once the average parameters are established, one could drill down by modeling or measurement to detail out an N+3 vs. N+6 configuration, or possibly look at an area at 90 V vs 60 V or even look at an area using 875 vs 700 cable, and so on. This drill-down process then narrows down the better/worse performing areas of the particular plant, and this knowledge can inform future plant upgrades or changes in architecture.

Cable operators are faced with a multitude of fielded equipment (e.g. manufacturers, capabilities) of varying ages (some very old) and technical characteristics. As illustrated in this document, there are clearly limitations of (a) remote measurement capability/accuracy in brownfield applications and (b) operational impact of detailed field measurements that must be considered when selecting which method above to use.

The most cost-effective approach is the reference model with lab measurements approach, involving application of some statistical techniques based on known OSP data. This method will likely require segregating an operator's territory e.g. by density, and identification of typical characteristics such as cascade length (N+x), predominant power supply types and voltages, node types, predominant coax and amps used, etc., in addition to folding in the metered power supply utility bills. This would ideally produce a model that on average represents a region, with each individual cascade falling in a multivariable distribution based on voltage, length, and so on. This would maximize the use of existing information to minimize truck rolls and still produce valuable information and even a tool for cable operators to analyze, design, and implement energy efficiency improvements in the outside plant.

In all of the methods just described, the first step is to estimate how the network is performing ***today*** in its current configuration. This will provide a better understanding of what is happening in the network and allow an operator to determine which cost reduction initiatives will have the greatest impact. There are a number of methods that have been looked at which provide various ways to calculate a baseline. It will be up to individual operators to understand which method makes the most sense to apply to their network based on the generation of their power supplies, the type of element management system (EMS) being run, accuracy of their plant maps, and readily available data for the both the coax and the actively deployed equipment in the network.

9.2. Ubiquitous metering and monitoring

ANSI/SCTE 212 2015 [2] details creation of a baseline power measurement for OSP networks. The document specifically discusses how operators can use utility billing information, as well as estimation techniques for non-metered supplies, to create a baseline overall measurement for an operator's OSP networks. ANSI/SCTE 212 2015 [2] sets out procedures for attaining and utilizing utility meter and billing data to attain input power information for all metered power supplies in the network as a part of the baseline development process. If an operator uses the methods detailed in ANSI/SCTE 212 2015 [2] for the metered power supplies in their serving territory as part of their work to create a baseline energy measurement for their OSP networks, then by default, they would have input power data for each of the metered power supplies for a given timeframe (usually by month). With this data, the power supply efficiency can be calculated directly using available EMS data for each individual power supply, the maximum accuracy resulting from using modern monitoring solutions so that the EMS data is known to be accurate.

How to best calculate efficiency from this data depends on how the available data is presented. Utility billing information typically provides input information for the power supply as a kWh reading over a period of days. EMS information, when available, typically provides output power readings as snapshots in time, with some EMS systems having the ability to capture data every six hours. Since power supply efficiency is input power divided by output power, the input data and the output data would just need to be matched for time period for the measurement to be made. As an example, input power over a month in kWh divided by output power over the month in kWh, would provide the average efficiency over that month. If a month doesn't work, but other timeframes do, then the timeframes can be adjusted accordingly. If time-based information isn't available for some reason on the output power side, then if a snapshot from the EMS of output power is available, snapshot efficiency could be calculated by converting the input kWh to an average power load measurement for the month.

9.3. Partial metering and ubiquitous modern monitoring

If certified meters are not available on all OSP power supplies, but modern, accurate monitoring solutions are deployed on all power supplies, the power supply efficiency can be calculated directly using available element management system (EMS) data and power supply efficiency curves from the vendor. If the current EMS does not pull input power or current values, then the approach would be to:

1. Pull the output voltage, output current and power supply type from the power supply with monitoring solution via the EMS
2. Match the data to known power supply efficiency curves from the vendor in order to determine power supply efficiency based on the EMS-reported amount of load.

An automated tool for converting EMS data into power efficiency based on power supply type would be the ideal way to perform this measurement across all power supplies.

As a check on this approach, it should be applied either to an existing power supply where there is a certified meter to compare the two results, or, especially if there are no meters installed for a widely-deployed type of power supply, a new certified meter should be installed at each different type of power supply with monitoring add-on included, again to validate the approach and determine any variation/error in the results thereby obtained.

9.4. Partial metering and partial monitoring, including legacy monitors

In this, perhaps the most typical case for some cable operators, there is a fraction of the power supplies with meters, and a fraction that support monitoring, some of which are older, legacy monitoring solutions and others are recent, modern monitoring solutions. The power supplies with certified meters and modern, accurate monitoring solutions installed can be addressed using the methods just described. For the remainder and perhaps majority of the network, an issue for some legacy power supply monitoring solutions is that the transponders only provide voltage (V) and current (I) which is not 100% accurate due to there being no power factor available. Thus, the power factor would either have to be estimated at "typical" values for each operator/architecture with the potential to introduce some error, or measured directly. While matching to curves can still provide a good method in this case, even more diligence in calibrating the approach via sample measurements is required when neither power metering nor accurate monitoring is available.

In this case field measurements are warranted to ensure valid data for characterizing the OSP power consumption and efficiency.

9.5. Field measurements

This is the most accurate power supply efficiency measurement for equipment in operation since the load will vary greatly from the maximum rated value and there are different generations of equipment currently deployed. Measure power efficiency with a volt/clamp or amp meter as follows:

a) Measure power supply input voltage, current, and power
b) Measure power supply output voltage, current, and power
c) Calculate actual power supply efficiency
d) Measure power factor, but note architectural dependency

One way to reduce the cost of such measurements is to schedule them along with regular power supply visits, if that is the MSO policy. While onsite a technician can be asked to:

a) Perform a complete site survey
b) Run battery self-tests
c) Perform other proactive maintenance activities
d) Perform the above power measurements using appropriate test equipment

The technician should also capture time of measurement (day/season) and any other constraints on measurement.

Thus, one would use test points on power supplies to measure voltage, and use an amp-clamp to measure current. Note that the power supply may be mounted on the ground in a pedestal or on the pole, as shown in Figure 8 and Figure 9 below. There may also be a power meter mounted on the pole (Figure 9).

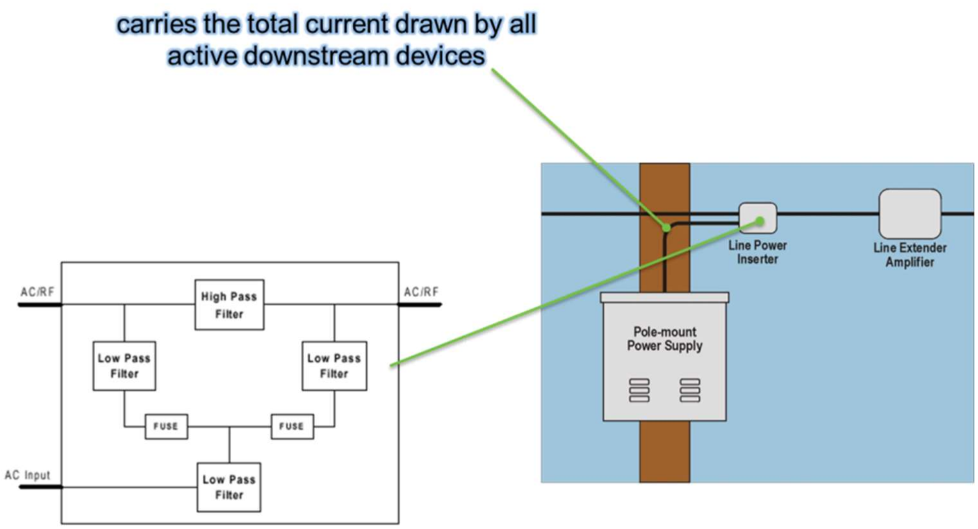
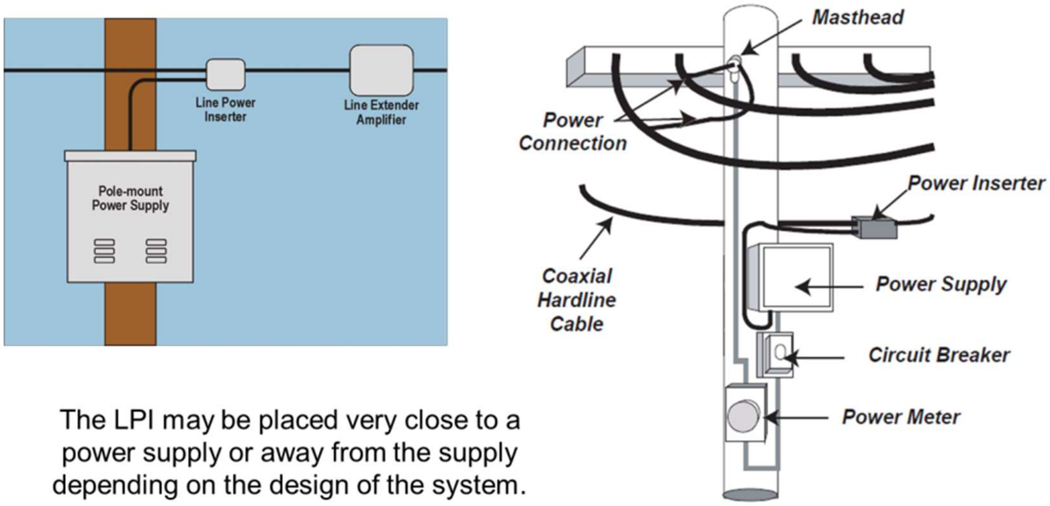

carries the total current drawn by all active downstream devices

Figure 8 - Line Power Inserter (LPI), Aerial Mount Type, Showing The Output Line For Measuring Power Supply Output Current Using Amp Clamp. (From [5])



The LPI may be placed very close to a power supply or away from the supply depending on the design of the system.

Figure 9 - LPI With Pole-Mounted Circuit Breaker and Power Meter (From [5])

The power directing plug-in or switch in the outside plant provides a means of directing power into and out of specific ports of the amplifier station or node. It can take the form of a plug-in jumper, fuse, or switch. It also provides a means of interrupting or directing power between the various ports of a device. These plug-ins are configured at initial system installation to control how power is routed through the network from the line power supplies. Some amplifiers and nodes have plug-in power diplexers.

It may be necessary to both open the enclosure as well as remove the cover of a switching regulated power supply, as shown in the figure below to access the voltage measurement points.

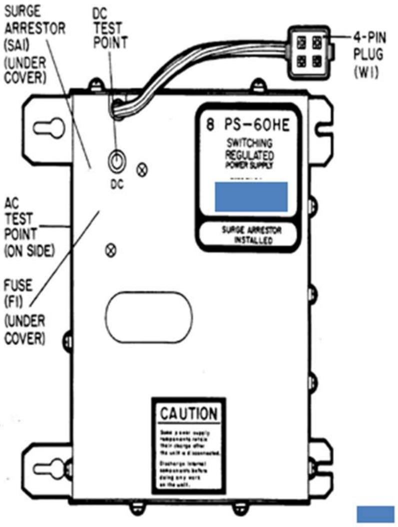


Figure 10 - Switching Regulated Power Supply Test Points and Fuse Locations (From [5])

9.6. Reference model with lab measurements

The *EMS-ANE* working group is currently developing a reference model for a separate document (*EMS*-033) and plans to include for example procedures for developing detailed models and examples of typical OSP architectures, lab testing/characterization of individual components as they are submitted for repair, and building a table of product by age to cross reference against a cable operator's network map, as well as other methods to accomplish the reference model with lab measurements method.

9.7. Component characterization

There are two ways to consider power consumption of a node itself: one is to assume that the power consumption of a given amp or node doesn't vary when it is in service, because the hybrids are always biased full-on to handle maximum load. However, when there is a smaller load on the RF amplifier (e.g. fewer carriers) in today's actives, the power ends up being dissipated as heat, versus as signal (which only represents about 1-2% of all energy) down the cable. While the power of a given amp or node does vary with the voltage supplied, which is a function of how far away from the power supply it is, this power variance is very well characterized; see Table 5 from the Cisco GS7000 1 GHz Node Data Sheet as an example:

Table 5 - Example Power Consumption Variance of a Fiber Node Vs. Voltage [14]

Station Powering Data												
GS7000 Node	I DC (Amps at 24 VDC)		AC Voltage									
			90	85	80	75	70	65	60	55	50	45
with: 1 forward Rx, 1x4 forward config module,1 reverse Tx, 4x1 reverse config module	2.95	AC Current (A)	1.4	1.4	1.4	1.5	1.5	1.6	1.7	1.8	2.0	2.2
		Power (W)	96.4	96.2	95.9	95.6	95.4	95.4	95.3	95.3	95.5	95.8
with: 4 forward Rx's, 4x4 forward config module,4 reverse Tx's, 4x4 reverse config module	3.70	AC Current (A)	1.7	1.7	1.7	1.8	1.9	2.0	2.1	2.3	2.5	2.8
		Power (W)	121.5	121.1	120.8	120.6	120.6	120.5	120.5	120.7	120.9	121.0

Note: Data is based on situations configured with a status monitoring transponder. AC currents specified are based on measurements made with typical CATV type ferro-resonant AC power supply (quasi-square wave).

Power usage may go up at temperature extremes. One approach to resolve the temperature dependence would be to monitor temperature via weather sites to correlate with power consumption measurements from metered or power supplies capable of status-monitoring, for example. Even if the status monitoring results are not absolutely accurate as discussed elsewhere in this document, a significant variation with temperature in the results would be grounds for further investigation.

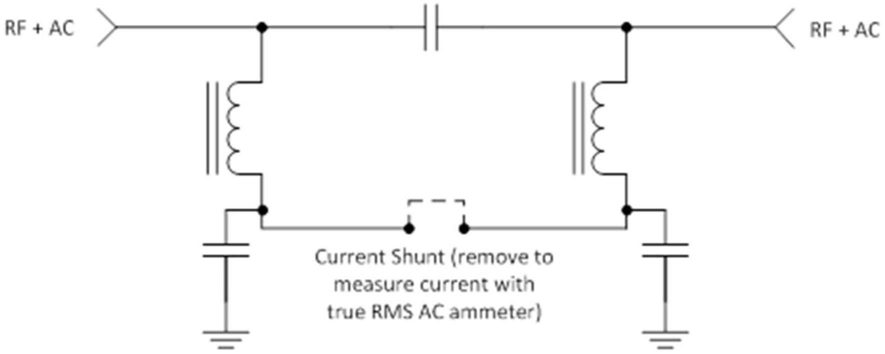


Figure 11 - In-Line AC Current Measurement Circuit

Figure 11 illustrates one way that in-line AC current could be measured in the lab or in the field using a bench-modified power inserter. One could modify a line power inserter as shown to facilitate in-line AC current measurements. The modified in line power inserter could be connected to an amplifier or node with a housing-to-housing adapter at the point where the current measurement is to be made (e.g., amplifier input port). Remove the current shunt and connect a true RMS AC ammeter to measure the line current. Temporarily splicing in this setup in an operating cable network would, of course, be service-disruptive, so this method may only be used in lab settings on equipment that is removed from the field for maintenance. A true RMS AC ammeter is necessary because of the quasi-squarewave plant powering. An average-reading AC ammeter would read about 10% high. Note that this device exists and can be ordered as a four port device.

Another approach, whether in a lab or in the field, is to use the fuses on the OSP devices. In this case, the device would need to be opened to be tested, possibly even disconnected to get readings. For example,

Figure 12 shows the location of the fuses that could be used for measuring voltage applied to the active and with an adapter, the current as well.

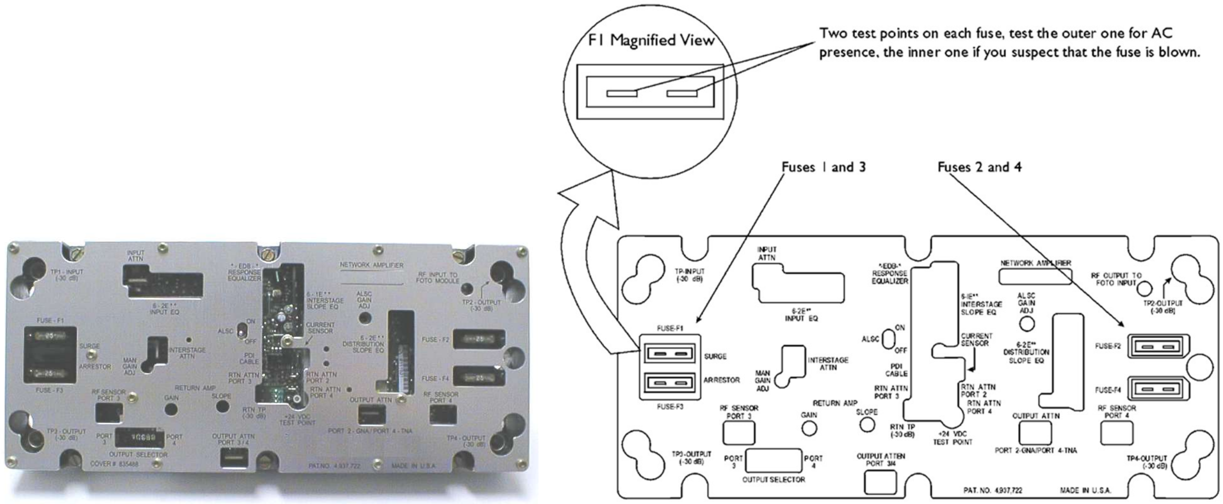


Figure 12 - Actual Active Component Plate Showing Location Of Fuses To Be Removed For Power Measurement (From [5])

Note that the above methods, while useable in the field, are not generally recommended due to the service disruption that occurs, and thus measurement in a lab setting, with an emulated OSP setup is preferable. If a large number of different types of devices are to be tested, an adapter should be developed and used during testing to make testing quicker.

10. Case Study of OSP Power Measurement in Active Plant

10.1. Description

Liberty Global performed an example measurement of OSP equipment power consumption on their Newcastle C1KC node, shown schematically in Figure 13 below:

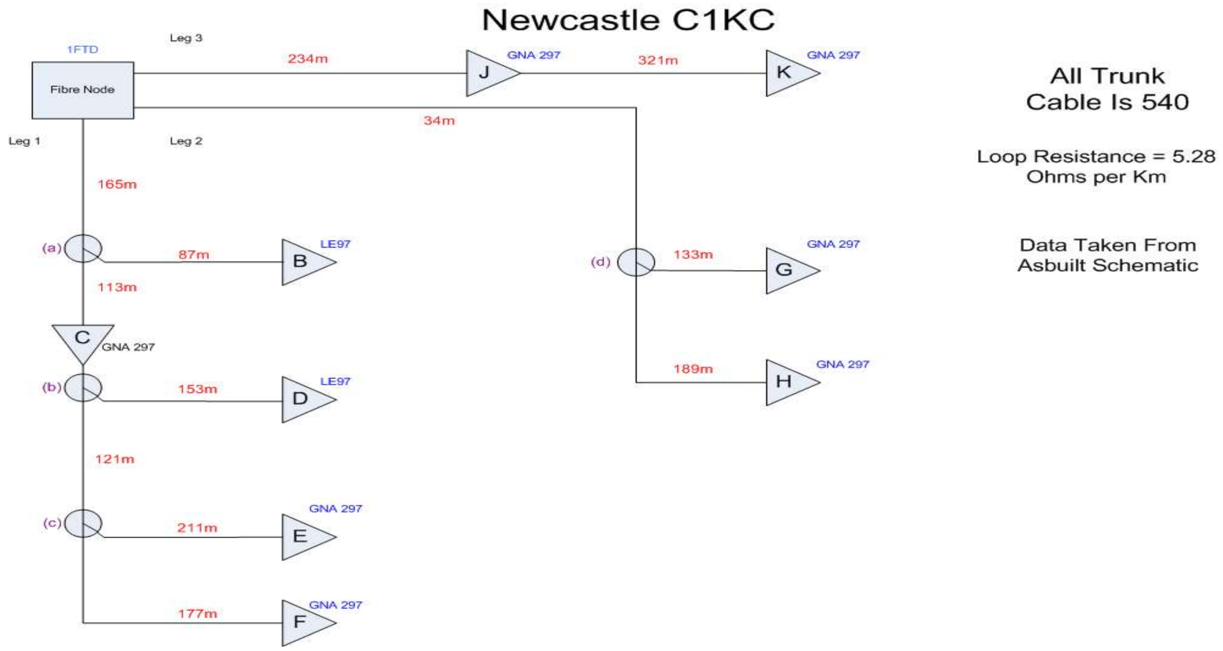


Figure 13 - Newcastle Node C1KC Used For Case Study Power Measurement

The measurements were performed subject to the following conditions:

- Cable lengths were taken from the “as-built” schematics.
- The power drawn by each component is taken from the manufacturer’s specification.
- It was assumed that the output of the dual power supply was 60 VAC.
- Losses due to the effect of phase (power factor) were not been included.
- In addition to the HFC cable power, there was also 48 VDC telco power in the network

10.2. Theoretical prediction

Current through each section of the cable was calculated and from the expected input voltage. The I^2R losses across each section were calculated, and the total theoretical power loss across the coax was calculated to be 22.66 watts. Note, however, that the actual loop resistance depends greatly on the bonding and grounding of the network. Once bonded, there are shared neutrals which can add or subtract or even be at 120-degree phase to the ground currents in the cable shield. This will impact the correlation between theoretical and actual performance. The results of the theoretical calculation are shown in Table 6 and Table 7:

Table 6 - Components of Theoretical Power Consumption Calculation

Section	Distance of Cable Section	Loop Resistance (540) Per km	Loop Resistance of Section	Current Flowing Through Section	Volt Drop Across Section	Power Loss Across Section
Leg 1						
Unit of Measurement	**Meters**	**Kilometers**	**Ohms**	**Amps**	**Volts**	**Watts**
Optical Node A to splitter (a)	165	5.28	0.87	3.45	3.01	10.37
Splitter (a) to amplifier B	87	5.28	0.46	0.45	0.21	0.09
Splitter (a) to amplifier C	113	5.28	0.60	2.7	1.61	4.35
Splitter (b) to amplifier D	153	5.28	0.81	0.45	0.36	0.16
Splitter (b) to splitter (c)	121	5.28	0.64	1.5	0.96	1.44
Splitter (c) to amplifier E	211	5.28	1.11	0.75	0.84	0.63
Splitter (c) to amplifier F	177	5.28	0.93	0.75	0.70	0.53
Total Leg 1					7.68	17.57
Leg 2						
Unit of Measurement	**Metres**	**Kilometres**	**Ohms**	**Amps**	**Volts**	**Watts**
A to splitter	34	5.28	0.18	1.5	0.27	0.40
Splitter (d) to G	133	5.28	0.70	0.75	0.53	0.40
Splitter (d) to H	189	5.28	1.00	0.75	0.75	0.56
Total Leg 2					1.54	1.36

Section	Distance of Cable Section	Loop Resistance (540) Per km	Loop Resistance of Section	Current Flowing Through Section	Volt Drop Across Section	Power Loss Across Section
Leg 3						
Unit of Measurement	**Metres**	**Kilometres**	**Ohms**	**Amps**	**Volts**	**Watts**
Optical Node A to amplifier J	234	5.28	1.24	1.5	1.85	2.78
Amplifier J to amplifier K	321	5.28	1.69	0.75	1.27	0.95
Total Leg 2					3.12	3.73
Power Loss Across Nodal Area						22.66

Table 7 - Results of Theoretical Power Consumption for C1KC Node

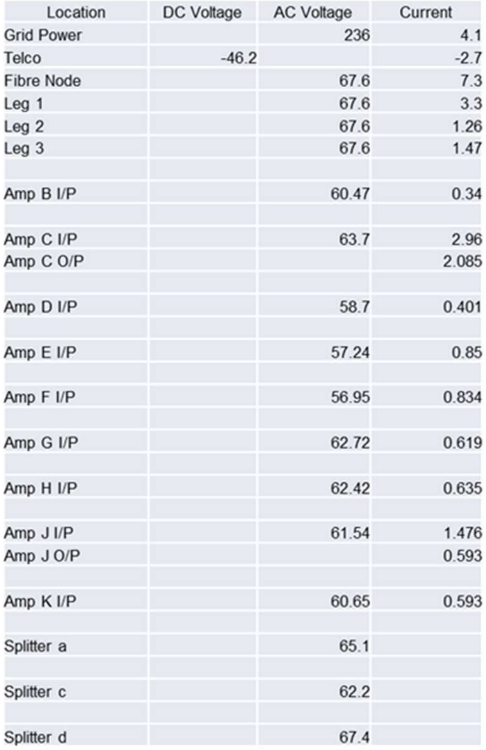
C1KC Calculated Power Consumption			
Item	**Power Drawn Manufacturers Spec**	**Number of Items**	**Total Power**
Fibre Node	50	1	50.00
GNA	45	7	315.00
LE97	20	2	40.00
I^2R Losses	22.66	1	22.66
PSU Losses	115.53	1	115.53
Telco Power	150	1	150.00
Total Power			693.19

10.3. Measurement Results and Analysis

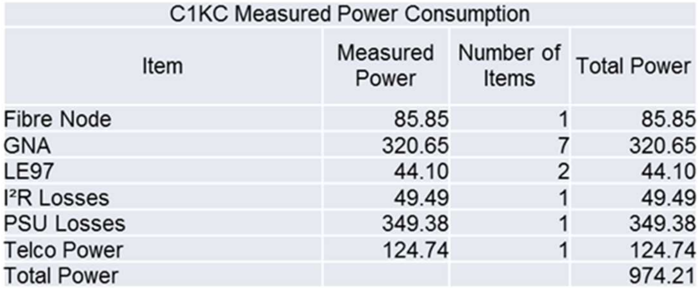
Voltage and current was measured at various points on the network, and these included the power drawn from the grid. It was possible to measure the voltage and current of the 60 VAC supply as well as the -48 VDC telco supply. All measurements were completed and the resulting losses calculated, as shown in the Table 8, Table 9 and, Table 10.

Note that the network was a dual power supply network and thus are not representative of a pure HFC node. These results may be redone on a pure HFC node in a subsequent version of this document.

Table 8 - Measurement Results

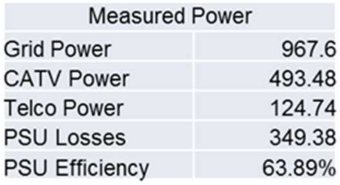


Location	DC Voltage	AC Voltage	Current
Grid Power		236	4.1
Telco	-46.2		-2.7
Fibre Node		67.6	7.3
Leg 1		67.6	3.3
Leg 2		67.6	1.26
Leg 3		67.6	1.47
Amp B I/P		60.47	0.34
Amp C I/P		63.7	2.96
Amp C O/P			2.085
Amp D I/P		58.7	0.401
Amp E I/P		57.24	0.85
Amp F I/P		56.95	0.834
Amp G I/P		62.72	0.619
Amp H I/P		62.42	0.635
Amp J I/P		61.54	1.476
Amp J O/P			0.593
Amp K I/P		60.65	0.593
Splitter a		65.1	
Splitter c		62.2	
Splitter d		67.4	

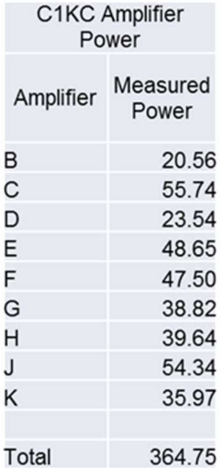


C1KC Measured Power Consumption

Item	Measured Power	Number of Items	Total Power
Fibre Node	85.85	1	85.85
GNA	320.65	7	320.65
LE97	44.10	2	44.10
I^2R Losses	49.49	1	49.49
PSU Losses	349.38	1	349.38
Telco Power	124.74	1	124.74
Total Power			974.21



Measured Power	
Grid Power	967.6
CATV Power	493.48
Telco Power	124.74
PSU Losses	349.38
PSU Efficiency	63.89%



C1KC Amplifier Power

Amplifier	Measured Power
B	20.56
C	55.74
D	23.54
E	48.65
F	47.50
G	38.82
H	39.64
J	54.34
K	35.97
Total	364.75

Table 9 - Measured I^2R Losses

Section	**Calculated Equivalent Distance of Cable Section Based on Measured Losses**	**Loop Resistance (540) Per Km**	**Loop Resistance of Section**	**Current Flowing Through Section**	**Volt Drop Across Section**	**Power Loss Across Section**
Leg 1						
Unit of Measurement	**Metres**	**Kilometres**	**Ohms**	**Amps**	**Volts**	**Watts**
Optical Node A to splitter (a)	143.48	5.28	0.76	3.3	2.50	8.25
Splitter (a) to amplifier B	2579.10	5.28	13.62	0.34	4.63	1.57
Splitter (a) to amplifier C	89.58	5.28	0.47	2.96	1.40	4.14
Splitter (b) to amplifier D	2361.52	5.28	12.47	0.401	5.00	2.01
Splitter (b) to splitter (c)	136.25	5.28	0.72	2.085	1.50	3.13
Splitter (c) to amplifier E	1105.17	5.28	5.84	0.85	4.96	4.22
Splitter (c) to amplifier F	1850.79	5.28	9.77	0.834	8.15	6.80
Total Leg 1					28.14	30.11
Leg 2						
Unit of Measurement	**Metres**	**Kilometres**	**Ohms**	**Amps**	**Volts**	**Watts**
A to splitter	30.06	5.28	0.16	1.26	0.20	0.25
Splitter (d) to G	1431.93	5.28	7.56	0.619	4.68	2.90
Splitter (d) to H	1485.33	5.28	7.84	0.635	4.98	3.16
Total Leg 2					9.86	6.31
Leg 3						
Unit of Measurement	**Metres**	**Kilometres**	**Ohms**	**Amps**	**Volts**	**Watts**
Optical Node A to amplifier J	777.59	5.28	4.11	1.476	6.06	8.94
Amplifier J to amplifier K	2219.71	5.28	11.72	0.593	6.95	4.12
Total Leg 3					13.01	13.07
Power Loss Across Nodal Area						49.49

Table 10 - Summary of Measured Power Metrics for Node C1KC

	Measurements		Plant Statistics					Metrics				
OSP PS Location	Input Power	Output Power	Nodes	Actives	HP's	Coax (Mtr)	Subs	PSU Efficiency	PSU Loss	W/HP	W/kM	W/Sub
CK1C (Include Telco Network)	968	618	1	9	544	1938	229	64%	349	1.78	0.50	4.23
CK1C (CATV Only)	774.4	493	1	9	544	1938	229	64%	349	1.42	0.40	3.38

Thus, the measured losses were in excess of the theoretical losses: the actual loss was 49.49 Watts compared to 22.66 Watts from the theoretical calculations. The additional losses were determined to be due to excessive voltage drop across some sections of the coax cable. It is believed that the additional voltage drop is due to high resistance connections at the PIN connectors screen connection.

Interestingly, an investigation of the high voltage drop on the section of coax feeding amplifier B uncovered a damaged cable on the output of the splitter. It is possible that the screen of the cable was cracked, and thus as an added benefit of the measurement program, replacement of damaged or otherwise impaired cable sections were scheduled.

Although this case study revealed a fault in the network, the process and data collected are nonetheless valid, and if the study were to be redone subsequently to reflect a more typical operational state of the network, the results should correlate more accurately.

11. Conclusions

It is possible to characterize power consumption and efficiency in the outside plant in a variety of ways, some easy but perhaps costly, others more laborious, potentially service impacting, but also less costly. An added benefit of field measurements is the opportunity to detect and repair plant issues that may have escaped detection in traditional maintenance programs. Finally, the SCTE metrics for OSP (ANSI/SCTE 211 2015 [3]) and for edge facilities (SCTE 213 2015 [7]) are invaluable partner publications to the present document, since these metrics are the vehicle by which improvements in energy efficiency will be gauged and measured against the goals of the SCTE Energy 2020 program.