HYBRID FIBER-COAX NETWORK POWERING ISSUES

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ABSTRACT

One of the most significant and controversial issues facing HFC network designers today is powering. With the deployment of HFC based networks by Telephony providers, the powering systems are evolving into a much different design than previously used by the CATV industry. Issues such as providing power down the drop cable to the home, network interface device power characteristics and power passing taps are important considerations. Other concerns for these new designs include choice of operating voltage and frequency, corrosion, safety, current limiting, NEC and NESC code compliance as well as the unique requirements of Broadband telephony. This paper will review the powering issues specific to the distribution area with emphasis on powering requirements for Broadband Telephony on HFC networks.

INTRODUCTION

Telephone, cable television, and utility operating companies have begun to deploy new full service broadband networks. This upgrade of the information infrastructure will require new approaches to powering and power protection of valuable electronics. Networks currently under strongest consideration include the hybrid-fiber coaxial architecture using asynchronous transfer mode (ATM) electronics. Distributed line card technologies are also a key approach. For these architectures, major issues with respect to equipment protection and safety will be explored. A pertinent body of knowledge has been acquired through years of cable television, computer, and telephone industry use of related equipment when exposed to their respective fault hazard environments. New networks will bring together a broad range of technologies and fault hazards, but at the same time must meet even higher levels of reliability and service availability. Recommendations for circuit protection will be offered, and a summary of efforts being made today on setting standards will be presented.

NETWORK EVOLUTION

Today's cable television and telephone industries are on the verge of massive changes in both how they conduct business and the physical plant that they use. Although traditional telephone service will continue to play an important role in telephone company business, the greatest growth potential is in expanded services, including home entertainment programming. For cable companies, expansion of services will also be desirable, resulting in a convergence of offerings and demand for networking technologies. While telephone companies have an excellent reputation for maintaining their service, their physical plant with its miles of twisted pair copper wire is in many respects obsolete Recognizing this, many operating companies are embarking on huge projects to deploy fiber-coaxial distribution networks.

In upgrading to new networks, companies will be introducing equipment such as ATM network interface cards, Telephony and Data Modems into much more electrically abusive environments than that of traditional LAN applications.

For reliability and performance, ideally all of the existing copper would be replaced with optical fiber. However, bringing fiber to the home presents the telephone companies with several problems that they would rather not address at present. Chief among them is how to interface the optical cable to the electronic equipment being used by the customer. Equipping each customer line with an electro-optic transceiver is very expensive. There is also the question of how to provide power to the customer premises for both transceivers and equipment (Network interface Devices and phones).

PRACTICAL IMPLEMENTATIONS OF FIBER IN THE LOOP: HYBRID-FIBER COAX

Rather than bring the optical fiber inside the subscriber's premises, telephone companies are now thinking of bringing fiber to the curb or further back from the home. In the case of fiber to the curb, the optical fiber is brought to a remote terminal, or optical network unit (ONU), which is connected to customer premises equipment by copper wire, and to video services equipment via coaxial cable. These conductors carry electrical power to remote telephone company equipment and the customer's equipment. Although there are several variations on this theme, industry sentiment appears to favor a hybrid-fiber coaxial architecture. This approach provides a high-quality broadband connection to the home that rivals optical fiber over short hauls, but is much less expensive.

As now envisioned, optical fiber serves as a trunk between the central office/headend and a remote node that contains the opto-electronic translation equipment. Coaxial cables connect this mode directly or through intermediate amplifiers to network interface units located on the outside walls of customers' premises. In a typical proposed implementation, a coaxial distribution cable from the node is hung on utility poles (aerial plant application). This cable carries both the signal information and local operating power in the form of 60VAC or 90VAC, 60 Hz Quasi-square wave. Coaxial taps provide the means through which four or eight subscriber lines can be connected to the coaxial distribution cable One approach is to carry the two-way RF signal over a coaxial cable to the network interface unit (NIU), and to provide power for the NIU and customer premises equipment over a separate pair of copper wires. This approach is attractive to existing Telephony providers that already have the twisted pair drop to the home that can effectively be re-used now as a power conductor. This approach can also be justified for deployment due to concerns of corrosion and high resistance of the aluminum outer conductor of the coaxial drop cable and F-connector interfaces in use today for non-power carrying CATV service.

Another major concern is the RF insertion loss increase and performance degradation possible in power passing taps that will require a power diplexer circuit, current limit circuit and power inserter function in each tap output port. At each network interface device, another power diplexer is required to isolate the power signal from RF for use in the NIU power supply module.

Aside from the use of optical fiber and coaxial cable, the biggest difference between the new and old approach to telephone networks is the location of the subscriber line interface card (SLIC).

The SLIC, which contains the switching relays that connect a customer's equipment to a ring voltage generator and to the network, is traditionally located in the central office or more recently, a remote terminal. However, in a fiber-in-the-loop implementation, the SLIC is moved closer to the customer. Two architectures are envisioned; In one, the coaxial tap on the pole or in a street-level pedestal contains the SLIC. As a result, power is passed directly to the phoneset and the NIU is passive. In the other approach, taken by most of the hybrid-fiber coaxial (HFC) networks being considered today, each NIU contains its own dedicated SLIC, local ring generator and loop power for the subscriber phone devices. Regardless of location, the operating power output requirements of the SLIC station must be compatible with the existing installed base of phones. The worst case architecture from a powering point of view requires an NIU for each subscriber premises location. The power overhead requirements of each SLIC, ring generator and Switchmode Power Supply (SMPS) add an estimated **40 to 60%** increase in total power consumption for a 480 subscriber node. This power consumption is **in addition** to the power required by the fiber node and amplifiers required for a stand-alone CATV system.

The inclusion of the SLIC inside each NIU or curb site significantly increases the total amount of power being consumed by downstream operating equipment. Moreover, when broadband programming and service become available, the customer premises equipment needed to support it will incorporate sophisticated microcontroller based circuitry as well as RF manipulation functions such as interdiction, addressablity, self diagnostics and more. Depending on the design, some or all of this equipment will draw electrical power from the telephone line. As a result, operators providing telephony in this manner face increased power supply output power requirements as well as higher through-currents for active and passive devices in series. As a result, the higher fault currents possible (as well as higher voltages) significantly increases the potential for catastrophe if an electrical fault develops anywhere in the copper or coax portion of the downstream network.

Problems in the power path.

The transmission media used by most local ATM networks today are located in a benign environment -- inside cable tunnels in a campus-wide backbone, for example. However, the situation is quite different in a typical telephone distribution network. Consider, for example, a traditional copper-based telephone system. Calls are routed from one telephone to another through switching circuits over fiber and the copper wire transmission system, much of which is above ground.

These aerial plants are exposed for miles to a variety of environmental hazards. The most dramatic is that of a pole from which a telephone line is suspended being struck and knocked over by a vehicle. If the pole is also carrying power lines, such an event could cause the telephone and power lines to come into direct contact (Power cross), which could place hundreds or even thousands of volts on the telephone line. Less dramatic but more commonplace than these so-called "power crosses" is the induction of high voltage transient spikes on a telephone line due to nearby lightning strikes and utility neutral return currents. Although they may be of short duration, these voltage transients can achieve peak amplitudes of several thousand volts.

Both power crosses and induced transients can have devastating effects on network and customer premises equipment. Of even greater importance, a power cross can be fatal to telephone company personnel working on the line. Under certain circumstances, it also can be fatal to a telephone user.

TRANSIENTS, CURRENT LIMIT ISSUES

To minimize the effect of power crosses and lightning-induced transients, as well as downstream short circuits, telephone operating companies employ a number of voltage and current limiters. Overvoltage protection is typically provided by gas discharge tubes or solid-state transient clipping devices such as Avalanche diodes, MOV's etc. - connecting each line to ground. Voltage is lowered across the load when overvoltage devices are triggered, creating a much lower resistance to ground (gas tube) or through dissipation of energy (metal oxide varistor). Current limiting is typically performed by thermal type devices that go into an "open" state when heated with I^2R internal dissipation. Current limiting is performed by heat coils, thermal resistors, and other fuse-like devices connected in series with each line. In a traditional telephone system, most of these limiters are located in the central office. Because central offices are often staffed around the clock, replacement of a blown fuse or heat coil could be performed within a matter of minutes at a moderate cost.

Implementation of fiber-in-the-loop architecture moves the focus of protection out of the central office and into the field. Even in copper-based systems, the telephone network is rapidly changing to accommodate changes in population and expansion of commercial zones from center city areas to outlying districts. As part of this change, some of the functions traditionally performed in central offices are being moved to remote terminals adjacent to areas with heavy telephone use. Whether the remote terminals are part of an all-copper network or a fiber/copper network, they contain sensitive switching circuits that must be protected against power crosses, induction, and transient voltage spikes. Of equal importance, the customer premises equipment also must be protected.

Remote equipment can be protected by the same kind of voltage and current limiters used in central offices. However, the use of heat coils and other fuse-like current limiters in remote terminals may not be pain free. If a power cross or voltage transient with sufficient energy occurs, these fuse-like current limiters will blow to protect the equipment in the remote terminal. The problem is that these remote terminals are not staffed, which means a technician must be dispatched to the terminal to replace the blown current limiters. Not only is this expensive, it results in a loss of telephone services to a potentially large number of subscribers for a significant period of time.

When fiber-in-the-loop architecture (e.g., FTTC and HFC) is implemented, the potential for power crosses or the induction of high voltage transients between the central office and remote node virtually disappears. However, there is still a significant potential for power crosses between the node and the Network Interface Unit (NIU) if the copper distribution cable is hung on power poles, as is often the case.

If a hybrid-fiber coax architecture is being used, the distribution cable is coaxial. Because the coaxial cable's outer conductor (sheath)is bonded to Utility neutral and ground periodically, lightning induced voltage transients can affect the network. In fact, Cable TV systems that have "Over grounded" their plant have actually increased the problem by reducing the coax plant apparent impedance to utility neutral imbalance currents thus increasing current flow through the sheath and strand ! A study covering two Southeastern cable TV systems revealed a number of instances in which currents were induced in the grounded shield as a result of nearby lightning strikes and resultant utility imbalance.

A significant issue is the transient voltage protection approach used for coaxial distribution verses the previously described copper twisted pair. Solid state protection devices cannot be placed directly across the coax center conductor to sheath due to the parasitic capacitance and inductance that will cause unacceptable RF degradation. Use of Gas tube devices has been discouraged in the CATV industry due to the AC power supply voltage present on the network that provides a follow-on current when a Gas tube triggers. Over time, the gas tube will fail in a conductive state causing network failure. "Crowbar devices" have been proven effective for use in transient protection but can only be used on the RF isolated side of a power inserter or power diplexer in an amplifier.

Because the potential for a power cross or induced high voltage transient is real, especially in broadband systems, telephone operating companies must provide adequate protection.

Cable Television Companies are currently deploying broadband telephony. The SCTE-Society of cable television Engineers and the NCTA-National Cable Television Association as well as Cablelabs are CATV oriented organizations working towards recommending broadband telephony solutions. Various telephone standards and specifications promulgated by Bellcore, ITU-T (formerly CCITT), and other similar organizations have dealt with copper systems (although this is changing rapidly). These can be applied to the copper portion of the hybrid-fiber coaxial system and other fiber-in-the-loop architectures. However, the distribution of fault energy onto the outer conductor of coax must be better understood before more exacting recommended practices are drafted. Key provisions of pertinent specifications are shown in reference Table following this article. The table shows points of protection, potentially applicable standards, and recommended practices.

None of the Bellcore and ITU-T network standards and specifications address systems in which the SLIC and associated power consuming electronics are attached to the wall of a customer's premises. Instead, the portion of the system that exists from the coaxial tap to the customer's premises has been interpreted by many to be covered in whole or in part by the National Electrical Code (NEC). Section 800 of the NEC covers telephone lines along with the AC powered fire and burglar alarms. According to Section 800, a listed protector shall be provided on each circuit run partly or entirely in aerial wire or cable not confined within a block. Also, a listed protector shall be provided on each circuit, aerial or underground so located as to be exposed to over 300 volts to ground. Listed protectors to date, however, are not functional for use with coaxial cable RF systems.

Another key provision of the NEC is in section 725 which suggests that a protected circuit be limited so that the total available power during a fault near premises wiring does not exceed 100 VA. While the NEC provides overall limits regarding the power capacity of telephone and CATV lines, they do not specifically address the lines that run from the NIU to the equipment inside the customer's premises. As a result, the CATV and telephone operating companies are applying those standards and specifications they believe are applicable, most notably Underwriter's Laboratories UL 497 and 497A. Even so, the question of which standards and specifications really apply remains unresolved and controversial. Circuit protection devices should encompass potential specification applicability, and, in addition, strive for resettability in order to maintain minimize down time.

POWER NODES

Due to the combined power consumption of the broadband devices and the telephony related interface equipment, the size and complexity of the network power source has changed. Typical HFC architectures feature a centrally located fiber optic transceiver (node) with four coaxial feeder cables leaving the node in four directions to serve the four "quadrants" of the node. These feeders carry the two way RF signal as well as to conduct power from a power source located at the node to the amplifiers in series with the feeders to each quadrant distribution area. CATV only systems can just barely conduct sufficient power from the node to the active devices. Coax cable and connector resistance causes voltage drop and power loss and depending upon amplifier power consumption, coax size and feeder distance, quadrant power transmission is very limited. The most important factor is the through-current limitation of the power passing inductors and connectors integral to the amplifiers and passives. These devices have a fundamental through-current limitation of 12-15 amps with acceptable RF performance from MHz to 1GHZ. CATV HFC networks require 2400 to 3600 watts for the actives and transmission losses for an approximate 500 home node. Using 60 volt powering, up to 15 amps is required through each feeder from the central power source. This is at the upper limit of the power passing capability of the broadband devices. Parallel feeders could be employed from the node to each quadrant to double the power transmission capacity. This approach is not very attractive due to the extra construction cost and network operating cost. Another option is to increase the power system voltage. (As of this writing, several RBOC's have committed to use either 60 VAC or 90VAC, 60hz). At 90VAC, using the same example, only 10 amps is required to be conducted through each feeder. This is within the existing device power passing capability. All is not well though ! Our example only considers the power consumption of CATV actives and transmission losses. When the Telephony device load is added, we need all of that extra current and more (15-20amps!) even at 90 volts. Typical 500 home nodes with central powering require 40% more power for curb side telephony devices that provide loop power and ring voltage for say, 12-24 homes. Due to sharing of the power overhead for the loop power and ring generator by so many lines, overall node power required is lower. The side of the home NIU approach requires power to be transmitted to the furthest extremities of the network, the home! This means that power is routed through a power passing tap, down a coax or twisted pair drop to the interface device at the subscriber premises. Each of these devices contains the SLIC "line card" function, ring generator and loop power supply. This extra power consumption and loss can result in 500 home nodes requiring 5-7 kilowatts of power each. In addition, these power nodes are physically large, often include battery banks, integral generators and other features for redundancy.

PROPOSED OVERVOLTAGE AND OVERCURRENT PROTECTION METHODS.

Because each NIU or coaxial tap would contain its own dedicated SLIC, each would also have to contain its own overvoltage and overcurrent protection devices. This means that if a power cross occurs or high energy transient appears on the line, the protection devices in dozens or even hundreds of NIUs or taps could be affected. If fuse-like current limiters are being used, it could mean that dozens or even hundreds of customers would lose their telephone service until a technician could replace all of the affected protection modules.

Not only would this result in considerable loss of customer good will, it would represent a significant expense to the telephone operating company. Clearly, if broadband networks are to be implemented on a large scale, traditional fuse-like current limiters will have to be replaced by devices that automatically reset themselves after the fault clears. Not only to meet the code required 100 VA fault power limit, but to ensure that device damage is limited and undamaged devices reset automatically.

Not only is this clear for transient voltage events but for short circuit conditions such as caused by pinched drop cables, NIU faults, etc. The new power nodes can deliver 2 kilowatts or more down each feeder prior to current limiting. This is significant energy to deliver into a fault! Operators are very wary of the liability issues for field staff as well as for customer premises faults. Often, the coax drop is stapled to the outside of the home and faces significant heating and potentially, combustion if the current limit circuit in the tap or feeder is not effective. Another consequence of drop fault current is the load on the adjacent tap output ports that causes loss of service to other subscribers - potentially all that are connected to the affected feeder. A method of current limiting in multiple network locations is required to reduce the fault affected areas to the minimum number of subscribers.
A proposed schematic of the drop is shown in the reference section, showing resettable fuses in addition to the traditionally resettable overvoltage protection.

One resettable device that has proven useful in other applications is the conductive polymer positive temperature coefficient (PTC) resistor . This device acts like a resettable fuse. Unlike conventional PTC resistors, which more linearly simply track temperature, conductive polymer devices provide the "snap action" associated with fuse-like devices. The key to their operation is the existence of conductive chains running through the nonconductive polymer body.

At normal operating temperatures, the polymer exhibits a crystalline structure. However, when the device's temperature rises above a critical level, its structure changes to an amorphous state and, as a result, the conductive chains break. This rapidly increases the device's resistance by several decades. Although this increase in resistance reduces the current flowing through it, the remaining current is sufficient to maintain the device in its amorphous state. This, in effect, latches the device into its tripped condition. When power is removed and the fault corrected, the device cools and its structure reverts to its crystalline state, restoring the conductive chains, and thereby reducing the resistance to its normal values.

This, in effect, resets the device. Use of these devices to limit current at remote locations provides protection for fault conditions and have been used effectively in existing SLIC twisted pair applications.

Additional approaches to current limiting also include active semiconductor based circuits such as a "smart circuit breaker" using relay contacts or thyristors for the interrupting function. A pulse width modulation or phase angle control can provide immediate disconnection or a constant current mode. These devices add cost, complexity and size to the tap and other locations such as the amplifier feeder outputs. Although accurate, and consistent over ambient temperature range, There is concern about the reliability of solid state devices like these exposed to the previously described transient voltage and energy discharge conditions.

Network operators are considering a distributed current limit system similar to utility power distribution. Circuit breakers and solid state current limiters are used in the power node outputs. The amplifiers would also employ individual current limit circuits in each of the feeder outputs of a lower threshold. A standalone device in series with the feeder could provide additional current limiting with an operator adjustable current limit set point. Each power passing tap would also require the PTC or active limiting options as previously described for each of the output ports. Further current limiting is required in the NIU to limit fault current that could be conducted into the home by the NIU SMPS. As can be seen, the highest current limit set-point is at the power source and each limiting device in series to the home employs a decreased let-through current threshold. In this manner, faults are limited to a reduced area by isolation of the current limit or disconnect function.

To summarize, the increased network power demand caused by the combination of broadband and telephony devices has resulted in the need for higher voltage and power output power sources. These centralized power nodes are required to economically provide power to the most area with the least number of power nodes required. This saves the operator not only the capital cost but the ongoing maintenance cost for batteries, generators and other internal components. With a minimum back-up time of 8 hours for lifeline telephony, these power nodes require a combination of battery banks for the UPS function as well as generators for economical long term back-up operation during AC power outages. Use of a power node for less than 500 subscribers further increases capital cost if the same 8 hour back-up requirements remain. Another consideration is the sheer number of these power sources required. Operators are concerned that in a disaster situation there would not be enough personnel available with generator or inverter equipped vehicles to provide back-up power to numerous power node sites. CATV operators are approaching this from the direction of currently using 3-5 900 watt power supplies per node and perhaps reducing the number to 2 or 3 with higher output voltage (90VAC)and 1.5 to 2.5 kW output power for equivalent reach to the actives but with reduced power supply locations to reduce capital cost. This approach still does not provide increased power margin for the added telephony device load. When this occurs, the single large wattage power node for 400-500 subscribers seems to reach the economic equilibrium point.

In addition to implementation of higher AC voltages, some projects have looked at DC powering or low frequency AC powering such as 1 cycle per second. There is a valid concern about safety with 60 volts although the CATV industry has used this standard for 15-20 years without apparent problems. At 90 volts, there is more of an issue. There is research data that shows increased heart fibrillation danger at frequencies above 10 hertz. So some have drawn the conclusion that a lower frequency of operation would trade the increased safety provided by the lower frequency for the increased risk of the higher operating voltage. Too low of a frequency or DC still is questionable due to the corrosion issues posed by the galvanic junctions of the cable and connectors etc. Plant reliability could be a problem at lower power frequencies and definitely would be with DC powering. At this time, there is not enough field experience to draw a fair conclusion. One effect of the different powering frequency is the increased cost and complexity of the power conversion devices in the power node. Full time inverter modules are required to provide the output power and redundant devices are also employed. This precludes the use of line frequency transformers and power circuits that have proven MTBF superiority in the CATV industry experience over the last 30 years.

As of this writing, The second largest MSO has started to implement 90 VAC, 60 Hz powering and several other MSO's are considering this. Three RBOC's have started deployment using 60VAC, 60hz power systems and two are planning on using 90VAC, 60HZ. One RBOC is deploying a 90V, Hz power system. In either Hz or 60hz, 90 volt systems, safety is a major concern. Amplifiers, taps and other devices need to improve shielding of fuses, conductors and voltage access points to improve safety. Improved warning labels and training will be required. There is concern about the use of the plastic ATO automotive type fuses in the amplifiers at the 90 volt level. In addition to the potential rating limitations of these fuses, the interest in self resetting limiters on feeder outputs for network reliability will most likely prevail.

POWER PASSING TAP

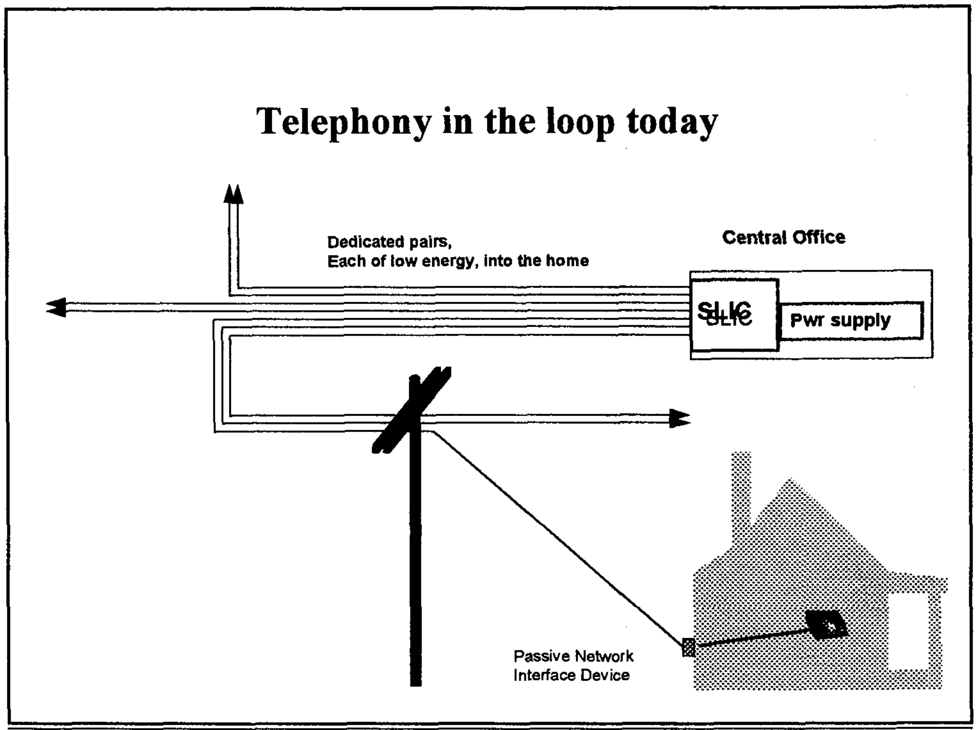
As discussed, the power passing tap requires an RF bypass network to provide power only to the current limit devices. The output side of the current limit circuit is fed to the output connector in the case of the twisted pair power drop option.

The coax drop power output version requires a power insertion function in series with the each output port to re-insert the current limited power to the RF output. Another power isolation network is required in the NIU to remove power only and route it to the SMPS and ring voltage generator. Thus the twisted pair output adds one additional RF insertion loss penalty compared to a standard tap where the coax power output version adds three insertion loss penalties. This is a concern because even if the operator is attracted to the simplicity of one drop to the home that carries both power and RF, the loss penalty of this approach could exceed the slim signal level margin that may exist and force the use of an additional amplifier in cascade. This then "ripples" through the design reducing performance and requiring even more power for the extra actives. Another required feature for both tap designs is a power and signal bypass function. If the tap cover plate is removed for service of a single port failure etc. all other downstream subscribers *loose signal and power.* Although this is irritating for subscribers of CATV only, it is unacceptable for networks carrying lifeline telephony. The next generation power passing taps will require a bypass function to avoid disconnect of downstream subscribers.

SUMMARY

HFC Networks that carry telephony require significantly different approaches to power source size and configuration as well *power architecture*. Increased power consumption of the additional devices has forced consideration and use of higher voltages. Higher energy outputs of the power nodes has in turn focused designers on the current limit and fault protection functions from the power node to the telephone. In addition to code compliance, safety and reliability issues have come to the forefront in both network and equipment design. Several NIU manufacturers are working on reduction of power consumption, "sleep mode" functions etc. to reduce power load. Further marketing requirements for more sophisticated NIU signal functionality may counteract these power savings though. Also under consideration is subscriber power units with battery back-up in each network unit. Although outside of the scope of this article, this approach may prove feasible especially for wireless telephony designs and may prove reliable and functional while reducing operator cost compared to network powering. This is too early to confirm.

All network designers need to focus on the choice of the powering infrastructure including transmission issues, current and voltage limiting, safety and reliability of the design.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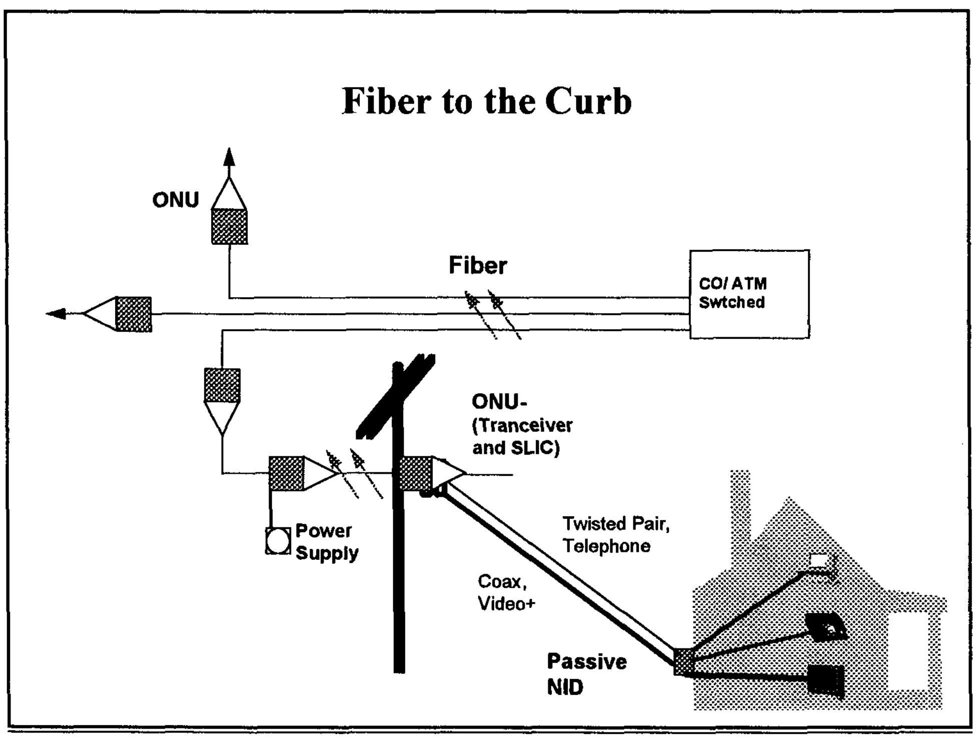
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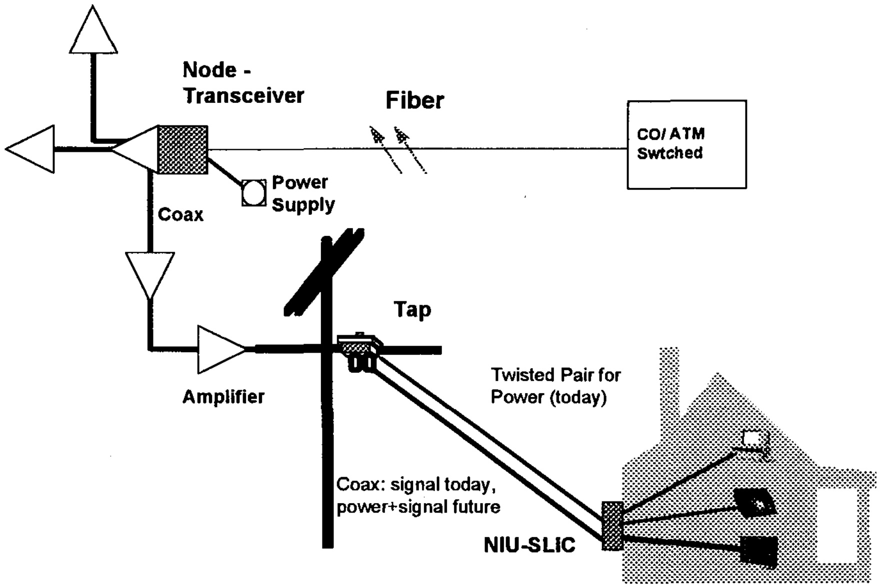
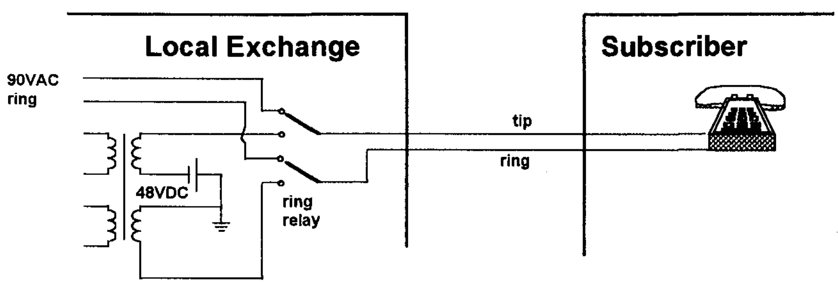


Telephone Powering

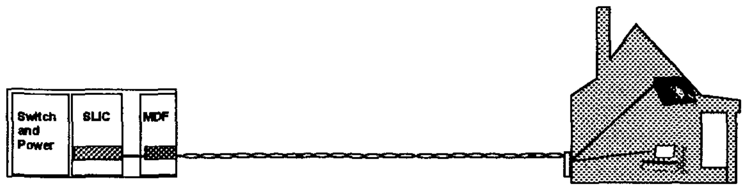


'Local Exchange' location:
- Traditionally: Central Office
- HFC: Side of home (NIU)
- FTTC: At the curb (ONU)

System Voltage	**- 48 VDC**
Ringing Voltage	**90V rms, 20Hz**
Operating Current	**20 mA**
Max. Current	**70 mA**

Traditional Telephone Conditions

- Traditional Hazards:
- Post Lightning effects: High voltage, short duration
- AC Power contact: High energy, varying voltage and duration
- AC Power induction: Variable



Dedicated Power, SLIC to Phoneset:

System Voltage	- 48 VDC
Ringing Voltage	90V AC rms, 20Hz
Operating Current	20 mA
Max. Current	70 mA

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