How To Not Pop the Balloons —

Migrating The Analog Headend for The Digital Broadband Future Facility

A Technical Paper prepared for SCTE by

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1. Introduction

The transformation of the legacy broadband buildings into Broadband Digital Nexus (BDN) structures that enable the digital connections to millions of people and businesses daily, is at a crossroads. At a fast-approaching time horizon, all legacy analog sites will need to change from housing an analog-facing technology to a digital infrastructure. These structures will gain more useful life in the cable broadband ecosystem. This paper will show in detail the transformative steps achievable in hundreds of locations simultaneously or individually. All these steps can be accomplished while maintaining a limited or negative amount of critical infrastructure equipment. When comparing energy consumed in an analog facility versus a digital facility, the initial data is showing an energy reduction of 200%. Coupling these transformations to adopting sustainable building technics and energy reduction options, the space and power of Broadband Digital Nexus structures is presenting opportunities hidden within physical constrictions setting operators up for rapid growth and digital transformations in the field.

2. Pump up the Volume

To understand the start of the Community Cable Television Antenna (CCTA) systems, we should look back into the ways of the telephone. The switching phone equipment and operator system needed to be housed within a structure. It sounds obvious today, but think about what that required for the telephone and telegraph systems. Engineers needed to evaluate and string telephone wires along with the power conductors of the time. The brick and block buildings that housed this function made possible the birth of the telephony exchange or Central Office (CO). These simple repeatable structures also were built for vertical expansion. Countless buildings were built on a first floor and then an expansion to a second floor and upwards. The telephony buildings were, in fact, the beginnings of the world's internet.

As the usage of the Bell and ATT telephony systems grew, the physical network equipment in the COs were forced to accommodate these new switches. These digital exchange switches were classified as Class 5 switches. These switches came in a vast variety. There was the Bell Technology Lucent 5ESS. The General Telephone Equipment GTD5. Siemens even had their own version I called the Brown Monster. All these large main frame switches ushered in the dawn of the electronic switching age. With the scope, growth and size of these switches, many telephony buildings needed a way to provide energy backup and 24/7 operations. The solutions were the adoption and full usage of DC batteries and power conversion units provided by AC to DC conversion systems. This architecture enabled the telephone powered network. This powering system allowed for the uninterruptable services that society began to rely on for communication, comfort, and business.

As we follow the communication timeline to the 50s, we have the start of the satellite age with the launch of Sputnik and the broad licensing of over the air broadcast television. Amplified Modulation and Frequency Modulation. The world at this time was "wired" for power and telephone and "wireless" for entertainment/news. Communication infrastructure is poised to get another player into the content and via for eyeball time of the population. This brings us to the need for video infrastructure.

The video ingest of the time was via an antenna. The tower would have multiple antennas attached facing a tuned direction to pick up the broadcaster's signals. These signals were then received and attached to the coaxial cable within the building. Encoders and other devices allowed the RF signals to be embedded and modulated upon the coax and to leave the building. The stringing of the coax cables to the subscriber base enabled the community part of the cable systems to fledge. The greater the height of the tower, the better the signal or more signals were able to be received. More receive signals means more channels and more equipment needing space in the buildings.

Figure 1: Image of CATV headend-image by author – circa 03/2016

3. Cup…..String….Cup

The available bandwidth on the coaxial cable was being utilized to its known capability. The MegaHertz signals were determined by the thickness of the coaxial cable, distance between amplifiers and pure decibel signal loss over the distance to the customers. The invention and applications for fiber optical cable allows for the manufacturing and production of radio frequency nodes to be connected into the field. These nodes allowed for the usage of Headend-located transmitters, situated into equipment cabinets. These transmitters received a RF signal over coax and converted the signals to analog optical light that would be transmitted along the glass until it landed at an RF node in the field. At the receiver housed within the field node, the receiver injected the optical analog signal and converted the light amplitudes back to a radio frequency to be embedded upon the RF coax cable to be run down past the homes it was going to serve. This "Cup-String-Cup" methodology allowed the distance of unpowered optical plant to stretch for kilometers. The longer the distance achievable by the lasers, the closer the node could be placed to the end customer.

The lasers began as large form factor units, sized at approximately 6 Rack Units (RUs) per transmitter or receiver. With a standard rack being 19" wide, that's a transmitter-to-receiver density of approx. 3500 cubic inches (19w x 10.5" tall X 18" deep). Given the usage of the transmitter, receivers and the adoption of combining on the RF forward and the RF return decombining… the spatial needs of the headend started to move into not just active equipment, but a new category of passive equipment. The need for passive equipment driven by cost savings, testing necessity, and optimization.

Cost savings on the transmitters happened with the adoption of service groups. Take 1 Transmitter and split it to feed 2 or 3 or 4 field nodes. This service group allows the cost (transmitter) to be distributed into the field connecting to multiple nodes. In this application, the transmitters will still communicate, but their power output needs to be modified. These headend amps will take an input power level and increase it to optimize the dB receive signal in the field.

Every node still needs to transmit the upstream data and information to the headend. The new 2-way communication require new devices to be placed within the Headend. The receiver allows for the receipt of the signal, and new decombining equipment allows for the separation of the return signal. The receive signals are broken down for multiple applications: Conditional Access for video authentication; signal maintenance by the outside plant teams and communication to the cable modem termination station (CMTS). So, when we look at the new spatial needs for these analog touching devices, the Headend space is rapidly being consumed at only the third generation of Headend equipment -- generation 1 equipment being simple receiver and encoders; generation 2 equipment being 300 MHz systems operating with conditional access equipment that controlled the set top boxes, which ensured that only the video programming purchased was made available for consumption. Generation 3 equipment is true bi-directional communication between the Headend equipment and the customer premise equipment (CPE).

If you were keeping count so far, we have:

Table 1: Video Analog Equipment

Receivers	Encoders	Transmitters	Receivers
Signal testing equip	Controllers	Amplifiers	Signal Combining
Signal Decombining	Test ports	EAS equipment	

All the above equipment works as a homogeneous group of standalone equipment needed to send 1 defined signal down the coax line to the homes.

We are approaching a situation where power to these devices is critical. Two developments within the electronic space are driving to what is being called clean power and/or conditioned power. The electronics have more and more solid-state components needing a clean and uninterruptible sine wave to bridge the gaps on an alternating cycle. The original equipment handled the under-voltage section of the sine wave by embedded capacitors that would hold the electrical current charge to the device for the other ½ cycle. The adoption of the Alternating Current Uninterruptable Power System (UPS) would allow for not only the conditioned, clean power but also the opportunity for backup power. The UPS systems are currently a simple dual power conversion unit that takes AC power in. Rectifies the power and allows some of the energy to be stored within batteries. The System then takes the direct current energy and feeds it into an inverter system. The output of the converter system them passes out of the unit and feeds into the Headend electrical outlets to power the headend signal generating equipment. But everything comes at a cost. The space needs for the UPS would take up rack space or floor space. For a typical 22kva UPS, you could or would lose about 2 racks of space within the equipment 4 walls of the Headend.

With the wide usage of UPS systems taking hold within the industry, there is another push to protect the UPS system. This came with the adoption of on-site power generators and Automatic Transfer Switches (ATS). The ATS serves as a large power selector switch. During 99% of the operation of the building, the Utility power grid provides the power to the building. For the 1% of the time when the utility power company cannot provide power to the building, a signal is sent to the generator to start. The ATS then sees a reliable voltage on source 2 emergency input to the switch. The ATS will then select the generator voltage over the lack or no voltage coming from the power utility. This transfer from utility failure to Generator start and transfer is usually less than 12 seconds.

The physical nature of the ATS is that it is a basic electrical component. It is placed within a UL listed enclosure based on its size and configuration. Typical for this time within the history of cable, the units are wall mounted and typically less than 12 inches in depth. Since these unit are not on the floor, we have some level of relief from losing rack space. However, since the access to the unit is front hinged door, we have the need to leave what is called a safe working border to the front of the unit. This will typically require 36” of free access space from a grounded location. The ATS can be placed outside the building on a concrete slab or a wall mount location at the desire of the engineering agent. This spatial offload allows for some space relief within the building but comes at a cost of reliability and capabilities. We want to always strive to keep this equipment within the conditioned space of a building.

4. Can I phone a Friend

Bidirectional communication between a customer and the communication facility begins to usher in the age of coaxial cable television voice or Voice over IP (VoIP). This meant that, unknown to the customer at the time, their experience at home was tied directly to the successful operation of the building supporting the services. The functionality of the legacy CO joined the video content delivery subscription services of the time: The voice over internet opportunity needed space in the Headend.

Voice over Internet Protocol was the third leg of the triple play stool pitched by many cable operators. The equipment in the headend was identical to the voice soft switches that began to replace the legacy Mainframe Class 5 switches of the CO. The advancements of the CPE equipment to be able to inject a common telephony phone input and ring service output connected the equipment platforms in the homes. The other end of the wire at the Headend removed the voice modulation signals from the RF carriers and sent the signals out to the world telephony network.

This advancement was not without difficulty. This new internet-based voice system was built commonly as a modernization effort for the big phone companies, that have been operating on a 48v platform of power for the network/telephony equipment for scores of years. This legacy power platform is rigid, hardened by years of OEM investments and backup systems that would cause a massive shift in facility architecture and mindsets of the Cable TV Facility Engineers. The video side of content was content with the platform being supported by only utility voltage (120v). With the onboarding of a UPS, the equipment was still predominantly AC powered. So emerged equipment co-habitation issues, with specifically different powering needs. Would the equipment be AC powered or DC powered?

Figure 2: An analog-only two-way Headend. Image by Author. Circa 12/2018

5. Rock, Paper, Scissors.

In that timeframe, the battle for power supremacy was fought on a square foot by square foot basis. The telephony camp was locked-in on the operation of the power input to the power supplies to be 48v nominal. This allowed for the most typical and standard power supplies available to be procured with the telephony devices. The uptime argument between the cable TV guys and the Telephony Central Office guys entered the regulated space in the Code of Federal Regulations (CFR)47. If the companies entering the telephony service provider space wanted to compete and market a reliable, capable, and cheaper service than the legacy land line carriers, they had to prove a reliable and available network. The answer: Cable companies would use the same equipment as the telephone carriers. DC powered equipment backed up by batteries for 4 hours and generators for 24 hours. The OEMs continued to provide DC power supplies to make the power delivery reliable and enable the headend to run under multiple failure conditions -- first, a failure of utility power; second, a failure of the utility generator. Operational survivability on batteries via direct current power to the network devices.

With the supportive adoption of the DC power input to critical network routers, optical transport nodes and by default the CMTSs that communicate with the cable modems in the home. With the supportive adoption of the DC power input to critical network equipment, the stage is set to run and operate (2) independent power delivery systems to the multiple devices within a headend space. The adoption of telecom grade 2 volt batteries would also drive a rapid consumption of network-required space allocation.

At the worst, I have seen where the power and batteries needed to deliver back up energy and distribution to the network consumed as much space as the network equipment. In completing over 8 years of planning for the space and power within the headend, indications are that spatial consumption distribution from a per sq foot perspective leaves only about 40% of the total under roof space available to the network engineers to populate revenue generating equipment. Chewing through more footprint for multiple power providing equipment would only continue to diminish the spatial ratio.

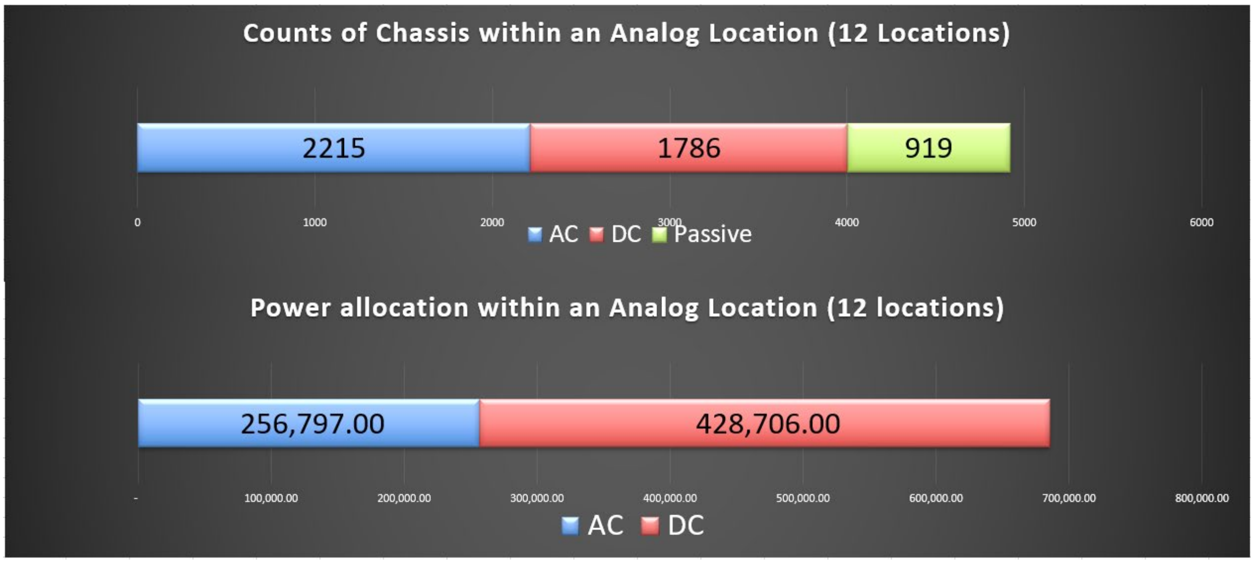


Figure 3: AC vs DC energy consumption relative to RUs consumed

6. "I Want It Now"

With the enhancements of the cable spectrum and capabilities, the industry was able to launch video on demand as a service. This service required the adoption of something within the headend not typically used… Servers. Servers allowed for the VOD content to be stored as close to the customer location as we could get based on needs and caching library. The server farms were typically located within the datacenters of the blossoming Internet world. The easiest ways to get a lot of content to the masses of people was to centralize the content and release the content when requested by the user. This would require massive transport builds from locations spread out across the nation. Over time and the adoption of Video on Demand (VOD), the scalability of the transport networks showed a level of weakness. This weakness was only resolved by placing local content caching as close to the packet build of the time. This location was called the headend. Eventually, the thoughts of putting servers everywhere were scaled back to placing it in a multi transport hop location so that multiple local edge sites can grab the content from 1 hop or two. Terabits of storage at this point was being located as close to the customer as possible to support VOD and the fledging over the stop streaming services content.

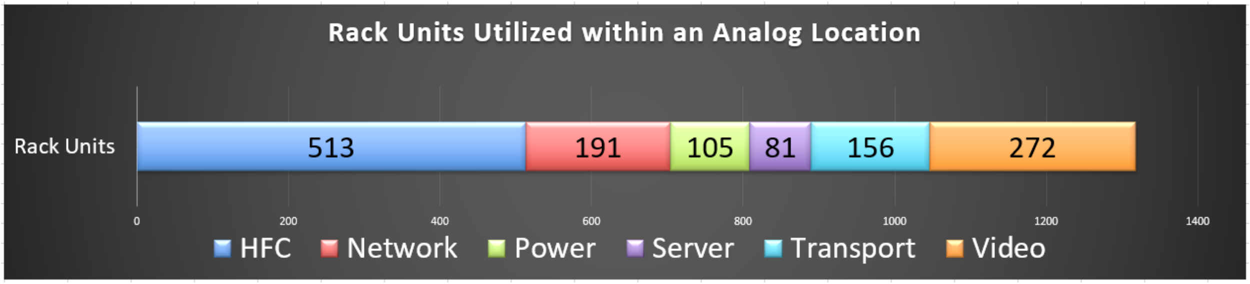


Figure 4: Rack unit allocation within 1 headend

The headend was almost at the peak of physical loading the in the early 2010s, but there was still a growing customer base needing fiber optic connections and speed tier offerings. Small, Medium and Enterprise businesses were growing rapidly. This rapid opportunity for revenue was based on the premise of providing a direct fiber connection to a place of business. This Metro-ethernet connection afforded customers the opportunity to choose a path of speed they could choose to fund. These full fiber connections required a multitude of new equipment to also be located within the Headend. These were also the most robust, largest, power hungry and feature rich devices companies could engineer and code. As more and more of these customers loaded up on the boxes, services and support needs also grew at the physical layer to supplement what was provided at the customer locations accompanying virtual command and control. These enterprise scale routers, with the drive for redundancy, stretched the footprint consumption within the smaller Headend to the point of costly expansions, utility upgrades hampered by abandoned technology not ready to go to the grave.

7. If The Shoe does not Fit…Stretch the Shoe

For those keeping track, we are now at the below list of items and services within the small cable TV building at the top of the hill:

Table 2: Active Equipment Groups in an Analog Headend

Receivers	Encoders	Transmitters	Servers
Signal testing equip	Controllers	Amplifiers	Signal Combining
Signal Decombining	Test ports/gear	EAS equipment	UPS
Routers	DC Power Plants	Batteries	Battery Distribution
Commercial Edge Gateways	MetroE Switch	OLT	VOD QAM chassis
Linear Video Edge Qams	Fiber Muxes	Optical Panels	Pilot Carrier equipment

The buildings were at a max capacity, providing most of all traffic via analog linear video spectrum, with a minor amount (one to two 6 MHz channels) of HSD digital spectrum.

The advent and adoption of the virtual cable modem termination station (vCMTS) and the potential to generate RF quadrature amplitude modulation (QAMs) at the node has opened a new world. This ability of sending 0s and 1s to the node and for the node to change digital into RF signals to extend the useable life of the existing RF plant will drive even more equipment into analog buildings as they move to be Digital Broadband Nexus structures.

The vCMTS is made up of many different components likened to the "medusa" boxes of the legacy VOD-connected CMTS. Eventually, the medusa boxes collapsed into a converged cable aggregation platform (CCAP). There are two key items to the new vCMTS. Routing and video…. Sounds like the entire buildings of the 1990s. The difference is that this new vCMTS platform is function built for the digital world. For the bargain price of servers, layer 1 switches, and a robust routing table and chip set, the first part of the vCMTS will allow the sites to send broadband digital traffic to and from the cable modems. The second part of the platform is the video generation units. This is a must carry due to the legacy needs of the existing customer base, the customers who are on a legacy RF only tuning set top boxes that are still on network. The adoption of an IP only set top was not universally given nor forced to the customers. The business decision to continue allowing analog devices in the home will maintain a legacy of analog equipment base operating withing the headend that would inevitably need to move to the RF strand or leave the home.

8. Now Boarding At Central Station

We have the base platform needed to accommodate the digital goodness in the HE and the nodes in the field with the capability of the remote physical layer conversion (RPHY). Where do we place all this equipment? This raises two additional questions that are repeatedly is addressed by CEOs and CTOs across the industry. Do we place all this equipment in one location, like a data center, or do we disperse it into the network like a neural feed to all the buildings, and keep the equipment at the edge?

Using the Centralization theory:

- Less infrastructure to maintain at a "five 9s or better" status
- Fewer locations to staff
- Fewer sites needing "big iron"
- Already probably exists with a heavy loading of fiber.

Using the Distributed theory:

- Smaller "blast radius"
- Shorter latency
- Cheaper Transport costs
- Already inhabited by legacy analog CMTSs

The platform architecture is the origination of the new digital packet train that transfers data from site A to Site K. In the physical layer, we have a laser or transmitter that will send a packet of information down the fiber pipe. This pipe has only 1 entrance and 1 exit. In the analog world, you could take a signal from the Master Headend and channelize the signal onto an analog transmitter. This allowed you to send this signal to multiple hubs. At these Hubs, more RF signals could be injected into the coax stream and allow for combining locally as needed. In the binary world of digital signals, packets need to be assembled at the origin and be understood at the destination. The packet build can only occur at a vCMTS location. This will inevitably require a centralization effort of all legacy dispersed servers to cohabitate with the vCMTS. Pulling to a centralized location will eliminate the edge equipment located at the existing locations. This edge equipment we have identified above refers to mostly caching servers and edge VOD qam devices. These two items were needed in the legacy analog world to support the demand for less transport and more edge services. As the VOD QAMs also deprecate with the general adoption of IP content delivery, there is less need for edge linear video equipment. However, the product still needs to get to every customer. Pushing out would refer to the location and placement of the vCMTS into the edge locations. There are multiple benefits and detriments to address.

Pushing the vCMTS to the edge effects the operational efficiency of the vCMTS and the transport layer to support it. In the first assumption of decentralization, deployment and efficiency of equipment modernization will be key cost determining items. The assembly of the vCMTS is completed in a centralized location akin to an assembly line or production center. This assembled platform requires a level of assembly control through the physical build to configuration and onto deployment and original testing on network (OTON). Pre-configurations loaded for the end location will drive very tangible and cost savings opportunities. Speed to deployment, speed to growth, and value-added remote access from a centralized configuration support center. This will all require building to scale effectively with the nodes attached to the physical location. The existing and total node counts need to be reviewed before anyone can make a best utilization decision on vCMTS locations.

A vCMTS is connected to the node via a chip set on the server/ line card within the platform. A Hub may have 400 nodes. A HE may have 90 nodes. A master Headend may have 1000 nodes. We need to understand the math of the connections to validate the options for locational placement of the vCMTS. If your vCMTS is capable of 50 nodes to 200 nodes, the ideal location may be in the edge location. If the vCMTS is cable of supporting 200 to 500 nodes per cabinet, it would be better to centralize so the disbursement of compute would be efficient to the subtending Broadband Digital Structure (BDS)s.

9. The Slinky Effect

Do you remember as a child playing with a Slinky? Standing at the top of the stairs, starting a slinky, which by the forces of gravity and nature crawls down the stairs, much to our amazement. The other thing we did as young engineers, of course, was pull the slinky apart. Hopefully, you never pulled the slinky too far apart and then it would never compress back to original again. The effect of stretching a slinky too far is deformation. The spring never returns to an original dimension, and the original dimensions are never recovered. Stretching the cable network will have good and bad effects on the facilities. The optical limits of fiber and the effective usefulness of transmitters and receivers allow us to stretch digitally for 80 KM from the switch originating the packets to the node. This allows the facilities to range in homes served from a modest amount to a large amount based on the location and serving density.

Space in a legacy analog site has (4) classifications: AC powered network equipment, DC powered network equipment, passive equipment, and non-functional units. In every facility, operators should understand the requirements and dependencies of these assets. AC powered equipment is anything that is powered from a UPS, inverter, or standard utility power. The power distribution to these locations typically is a power strip in the back of the cabinet or rack. No RUs within the cabinets are consumed by these power strips. DC powered equipment is from a fuse alarm panel (FAP)s/ Distribution Circuit Breaker Panel (DCBP) or direct feed from a power system. These FAPs and DCBPs are typically located in the top of equipment cabinets, taking space away from the active equipment. Passive equipment is anything that does not consume energy but has a purpose within the building. These are typically fiber pre-terms and RF combining on the upstream or the downstream. Non-functional units are a great level of opportunity when we talk about the transition from analog to digital.

The power capabilities at a facility are among of the easiest to understand, trend, project and manage. The service entrance ampacity is the single energy gate and can measure what I have, what I have capacity to add, what will I have left after I add it. The Electrical service utility entrance is a single energy gate. This allows for an Engineer to measure what they have, what energy capacity they can consume, and project what is left after that decision is made. This measurement is typically in amps or in kilowatts. Simple meters and measuring tools have been exhaustively added to the buildings, allowing for the consistent trending and tracking of this metric. We would also look at the capacity of energy conversion at the DC plant level and UPS level. The final power draw component is the HVAC consumption measurements.

Cooling energy is a necessary evil, as it is called: Energy must be spent, in order to cool energy. Since most energy processes are consumable in nature, we traditionally see a 1 to 1.6 relationship on energy consumed, to energy needed to cool. These energy metrics and options generate our “Facility Spring”. If we work within the facility spring, we can survive the transition to digital without a major influx of capital (the “deformation,” in Slinky terms.)

10. I Think I can Fit One More Thing

The start of a journey begins with a plan. Our planning takes place with the kickoff called Blueprint-531. The B-531 is a planning assisting workflow that allows space planning managers and engineers to understand the destination. Once you decide where to go, it is easy to map your journey. The B-531 looks at the finite data available to be understood at the facility level. The physics around the transmitter/SFP distance limitations, lambda restrictions in a piece of glass and the availability to mux and demux optical paths are defined parameters we can engineer solutions from.

The other parameter feeding into the blueprint is the fiber density in and around the physical building. This fiber density looks at all services available to be rendered from a facility in way of commercial customers and SMB connections. Fiber consumption take rates for the embedded customer bases and designs the number of households passed (HHPs) per node split within the digital transformation end state. The equation is:

$$C = D_{nt}\,(\text{@Xhhp density}) + (O_n{*}d) + S^{2ch} + V + U + F_p$$

Equation 1: Cabinets needed = total digital nodes at “X” HHP density + Degrees of Optical transport nodes + number of redundant chassis needed per service + Video + utility + passive fiber terminations.

The above would indicate the total cabinet need of a site with 22,000 homes passed and commercial customers requiring PEG channel origination would equal 1+3+2+4+1+1 = 12 cabinets needing approximately 190 square feet for cabinets and aisle space walkways. With the average size of any BDS being 300 to 500 square feet, building additions based on space end state are very rare. At the time of this writing (summer 2021), after evaluating over 218 locations, only 9 sites would have no path to sustained footprints when a proper execution path is achieved.

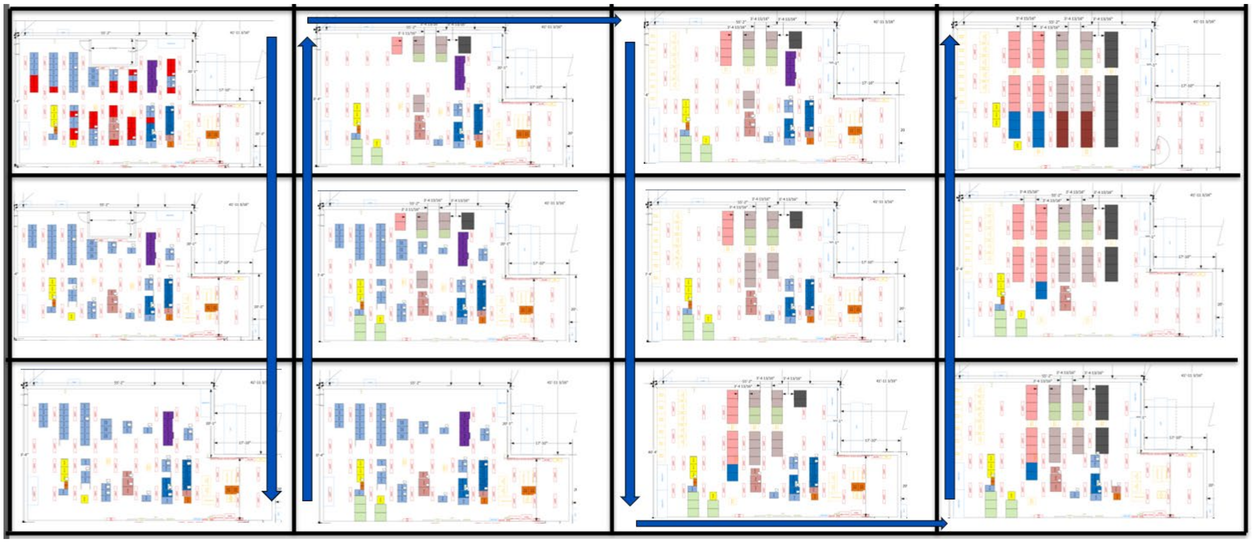


Figure 5: Facility Equipment location migration plan for a vCMTS location

What comes into the building first to facilitate a digital conversion is an effort of trial and error. Due to capital intensity, modernization efforts and customer needs consuming items at the port level, multiple B531 start points are to be "war gamed." The first most obvious path to free space is the conversion of the legacy analog CCAP cable CMTS to a vCMTS platform. As we evaluate the opportunities for space conversion, a decision of transition process needs to be understood. Original equipment Manufacturer (OEM) vendors have the hardware available to utilize a vCTMS Digital to analog shim called Shelf Physical (SPHY) Layer. This shim allows for the installation of multiple RF output ports to tie to existing transmitters and receivers allowing for the removal of all supporting analog hardware.

The method of deploying the SPHY equipment is a major decision point for energy and customer impacts. If the decision is made for equipment velocity, the result is a fragmented mess of analog abandoned equipment running in a very inefficient space and powering plan. Legacy best methods of collocating combining with TX/RX may leave the building with no recovered space until a defragmentation plan is enacted. This will impact the customer experience twice: One time to cut over to vCMTS, and the second time on the transmitter centralization plan to free up needed space. In the world of hardware modernization, velocity usually trumps efficiency.

Table 3: Dual Platform BDS - Analog and Digital

Receivers	Encoders	Transmitters	Servers
Signal testing equip	Controllers	Amplifiers	Signal Combining
Signal Decombining	Test ports/gear	EAS equipment	UPS
Routers	DC Power Plants	Batteries	Battery Distribution
Commercial Edge Gateways	MetroE Switch	OLT	VOD QAM chassis
Linear Video Edge Qams	Fiber Muxes	Optical Panels	Pilot Carrier equipment

Receivers	Encoders	Transmitters	Servers
DAAS Switch	SPHY chassis		

The sister step to the transition from CMTS to vCMTS involves the deployment of Distributed Access Architecture Switches (DAASs). The isolation of the DAAS to a separate cabinet may seem a gratuitous consumption of space, but it layers in a "forever rack". These forever racks allow for the long-term build and spatial reservation for nodes to terminate to mux shelves and switches. Existing density architecture allows for the build of over 554 nodes within 1 cabinet space consuming 15.83 sq feet. When addressing the legacy CMTS spatial consumption of over 285 sq foot via a spatial consumption of 95 for the same digital node, a savings of over 300% is realizable. But that requires taking the first step, which is installing the Digital DAAS cabinet.

The next parameter to understand is time. The time horizon to a location conversion to vCMTS and SPHY will drive the downstream part 2 conversion plans -- commercial chassis modernization and transport updates will inevitably conflict with the time horizon on the digital node conversions in large sites. The actual upgrade of transport chassis and routers to absorb the dedicated pipes running from the DAAS switches to the Broadband Digital Primary (BDP) centralization center will potentially drive more chassis before a hardware refresh can begin. The growth of the commercial side of the business may require separate routing networks that will scale differently than the routers for residential traffic. When the site has been converted to an entire SPHY connected DAAS, the beginning of the digital transition can begin and end. Within the table shown below, the highlighted equipment can at this point be removed from the edge locations.

Table 4: Analog Items to remove post vCMTS connectivity

Receivers	Encoders	Transmitters	Servers
Signal testing equip	Controllers	Amplifiers	Signal Combining
Signal Decombining	Test ports/gear	EAS equipment	UPS
Routers	DC Power Plants	Batteries	Battery Distribution
Commercial Edge Gateways	MetroE Switch	OLT	VOD QAM chassis
Linear Video Edge Qams	Fiber Muxes	Optical Panels	Pilot Carrier equipment
DAAS Switch	SPHY Chassis		

11. Do Not Stop At Go

As we reflect to where we are in this long process of removing the first round of analog equipment, we may have left a path of inefficiency in our wake. Leaving the existing Tx and RX in their existing locations will cause a level of effort that in some sites will be minor. In other sites, it will be immensely difficult. On the level of easy, I have injected an image of a location that has left the analog world behind but still has the leftover equipment sparsely located with the HE:

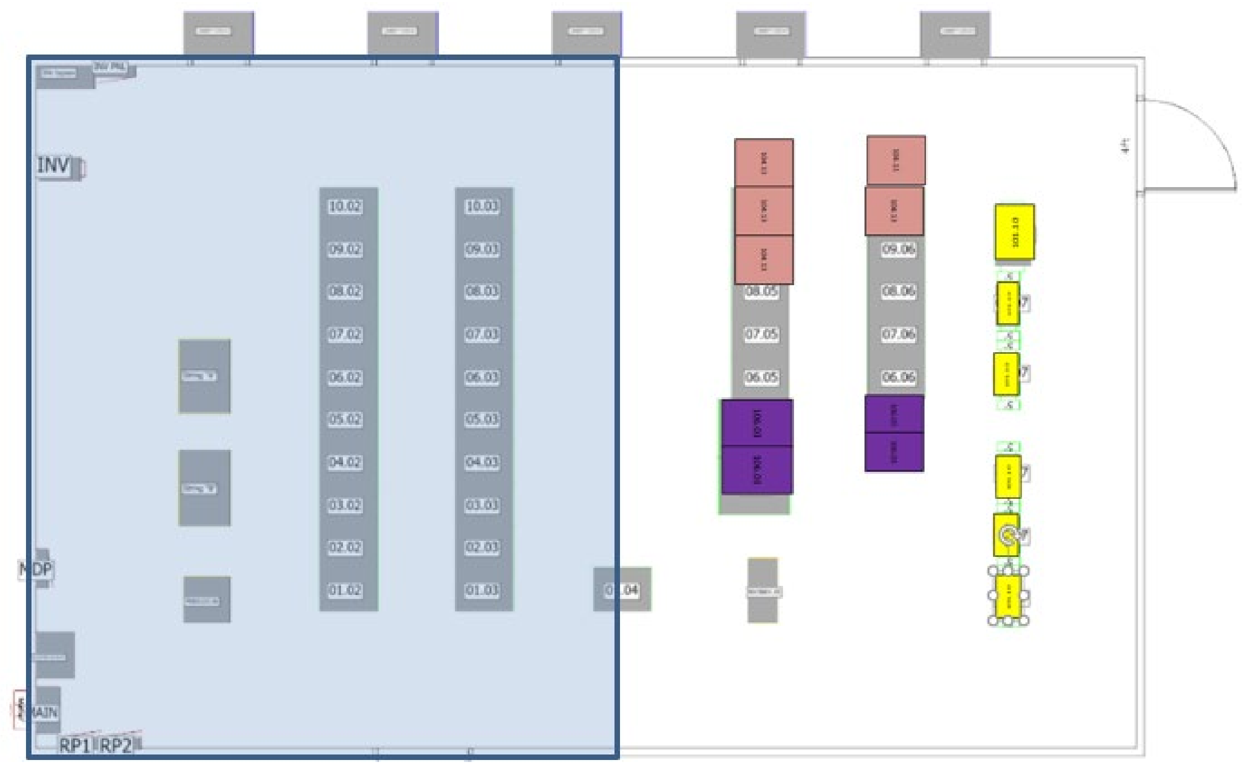


Figure 6: Active Digital Cabinet surrounded by legacy analog equipment

The leftover spare locations are inhibiting not only the ability to make the site as efficient as possible, but also leaves a complex legacy of old transmitters and receivers that no longer have a meaningful return in investment to be upgraded. At this point, a cost benefit analysis for the replacement of legacy RX and TX instead of a forced conversion to digital nodes in the field and connections to only the Digital DAAS. This will cause conflict and discussions and analysis and meetings and more conflict in priorities. As you see in figure 6, the blue highlighted area is capable of 100% vacancy. The SCTE champions the energy conservation of the MSO industry. Leaving so much analog active equipment burning through the HVAC airflow problems will be a counter argument to the reliability plans and limited touch operation that drives our strategic objectives. We as an industry need to understand there is a tradeoff between digital improvement opportunities, energy efficiencies and the customer experiences and that they all should be in balance.

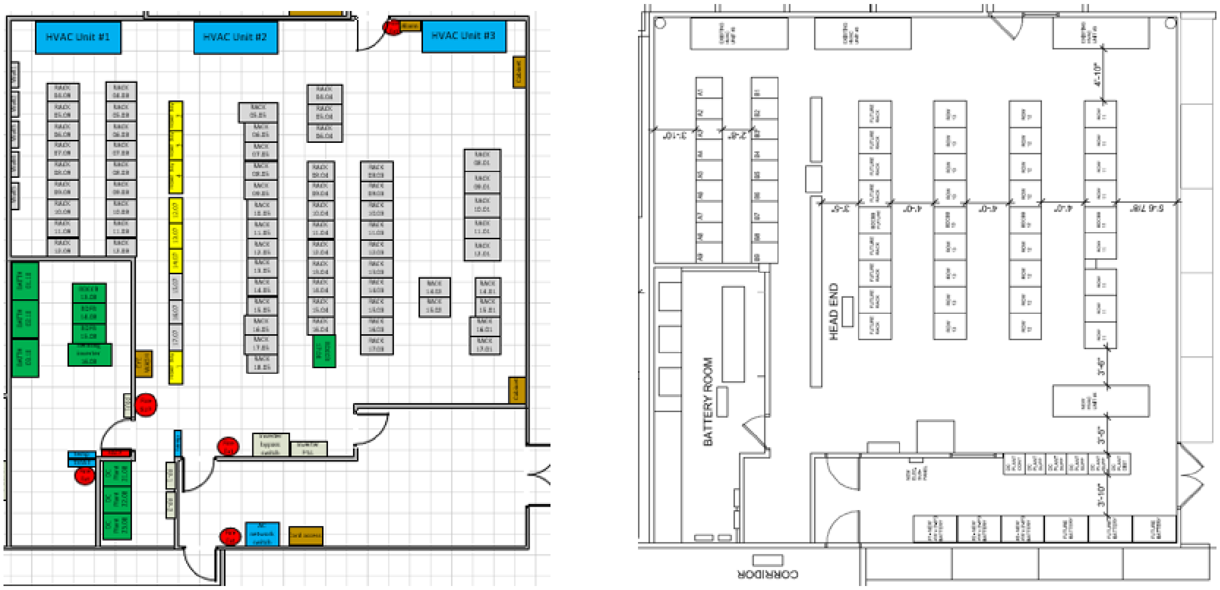


Figure 7: Before and after planning showing a path to all Digital

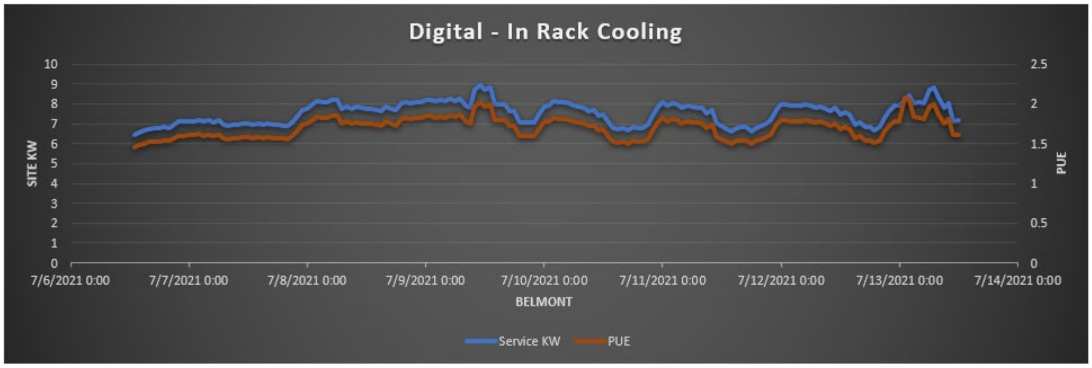
The final transition to digital will require the outside plant to do a significant amount of work to support the final transition. This may or may not require the replacement of actives downstream of the node by either replacing the amplifiers and or the nodes and split the service groups to a manageable amount of cable modems on each of the remote physical devices (RPDs). This activity and business cases need to take many items into consideration. The acceleration into a permanent standard cabinet and layout will accelerate the potential year over year growth opportunities. Speed to complete future activities can be achieved via this spatial and energy consolidation efforts. As efforts have been realized, the below items need to be understood as to the level of need for the final conversion to digital:

- Energy savings to be achieve by the digital conversion
- Recovery of energy capacity within the former edge sites
- Recovery of space within the former edge sites
- Operational improvements from the conversion to digital
- Additional bandwidth available due to the conversion to digital
- Elimination of OEM Analog equipment due to the conversion to digital
- Better OSP efficiency from operating digital nodes in the field
- Eliminating infrastructure equipment within the headends and hubs due to the conversion to digital equipment
- Right sizing of space needs within leased locations due to the conversion to digital operations
- Optional removals of underperforming sites within the networks due to the optic reach from digital small form factor pluggable (SFP)s to the nodes in the field
- Low-cost expansion into rural markets due to the range and options digital provides.

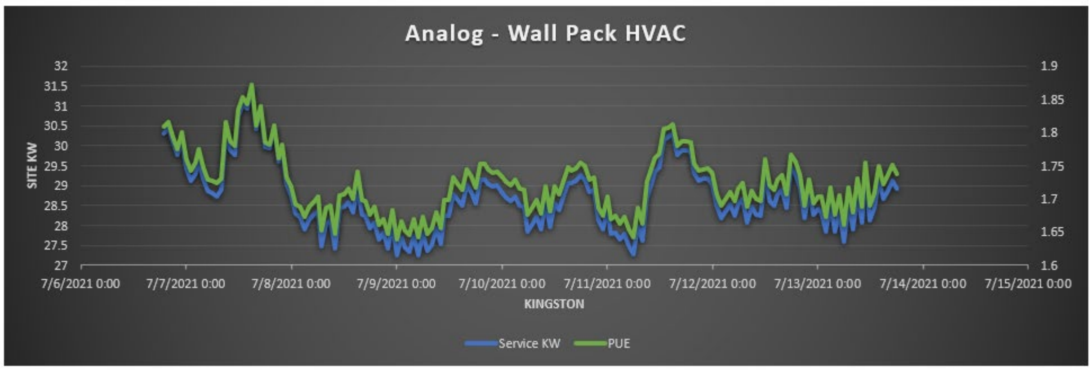
Table 5: BDS items left after analog leaves

Receivers	Encoders	Transmitters	Servers
Signal testing equip	Controllers	Amplifiers	Signal Combining
Signal Decombining	Test ports/gear	EAS equipment	UPS
Routers	DC Power Plants	Batteries	Battery Distribution
Commercial Edge Gateways	MetroE Switch	OLT	VOD QAM chassis
Linear Video Edge Qams	Fiber Muxes	Optical Panels	Pilot Carrier equipment
DAAS Switch	SPHY Chassis		

Within the above list of tangible improvements realized from the full conversion to digital, the 1 item that provides a meaningful tangible capability is the recovery of usable energy capacity at the edge locations. If we take a review of the imbedded energy opportunities within a former edge site, we can calculate the available energy and available space at a today cost to build the same surplus. In a presentation produced back in 2017, an MSO had the MW of embedded energy capacity at the edge locations of 73mw, of which only 44mw was being consumed. Since then, the overall capacity of energy has grown to approximately 87mw and a consumed amount of approx. 55mw. With the known advantages of a digital conversion to eliminate 80% of energy consumption at the edge locations, the asset value of unused and provisioned energy capacity can be measured in megawatts of network available energy for growth and new edge technology. When our industry looks back of the growth opportunity at the edge locations and the almost-free cost of connectivity to energy to serve customers, the low cost of expansion and opportunity will be plentiful, if digital realities are strategically aligned to the opportunities within the facilities we operate.



114 nodes



110 nodes

Figure 8: Digital vs Analog

12. Conclusion

The name “Cable TV” is becoming synonymous with antique, legacy, old and clunky. The names Headend, Master Facilities and Signal Buildings are becoming just as legacy. We are in the Information Age as a sea change event since 2003. The brick and mortar headend of the 60s, 70s, 80s and 90s have a long roadway available to them. Buildings we have built since 1963 to enable the analog age are still able to grow the Information Age and the upcoming Age of Digital Expansion. Innovations of the future will inevitably need to be connected to a physical layer; the cloud will always need the ground. This paper reviewed the opportunities to plan the layout and location of items within a building and how to phase plan for all activity. By following a pre-determined playbook of tech refresh, capacity augments and right sizing infrastructure, you also will achieve a building able to sustainably grow with the network that demands its support. The Age of Digital expansion will connect the future world within the bricks laid in the past.

Abbreviations

AC	Alternating Current
AC UPS	Alternate Current Uninterruptible Power Supply
ATS	Automatic Transfer Switch
BDNS	Broadband Digital Nexus
BDS	Broadband Digital Structure

BDP	Broadband Digital Primary
CA	Conditional Access
CATV	Community Antenna Television
CCTA	Community Cable Television Antenna
CFR	Code of Federal Regulations
CMTS	Cable Modem Termination Station
CO	Central Office
CPE	Customer Premise Equipment
DAAS	Distributed Access Architecture Switch
DC	Direct Current
DCBPs	Distribution Circuit Breaker Panels
FAPs	Fuse Alarm Panels
HE	Head end
OEM	Original Equipment Manufacturer
OTON	Original Testing on Network
QAMs	Quadratic Amplitude Modulation
RF	Radio Frequency
RPD	Remote Physical Device
RPHY	Remote Physical Layer
RUs	Rack Units
SFP	Small Form Factor Pluggable
SG	Service Group
SPHY	Shelf Physical
SSD	Solid State Drives
UL	Underwriters Laboratory
vCTMS	Virtual Cable Modem Termination Station

VOD	Video on Demand
VoIP	Voice over Internet Protocol