To High Split & Beyond
The New Frontier In Leakage Detection

A Technical Paper prepared for SCTE•ISBE by

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1. Introduction

As the industry explores providing higher bandwidth services, leveraging the Data-Over-Cable Service Interface Specification (DOCSIS) 4.0 and look at evolving legacy DOCSIS 3.1, operators are planning to move to 204 MHz split and higher return band splits. In order to meet the existing plant leakage regulatory requirements and ensure that operations are not interfering with licensed over the air signals, operators need to evolve how they measure and monitor cable plants for signal leakage.

This paper will discuss the options which are available to operators, balanced by what is technically possible based on the products available today and the roadmaps for the future. Two methodologies will be explored in this paper. The first method examined will be the use of the traditional downstream transmission of signals through the plant and the options that exist within the preservation of this existing form of transmission. The second method discussed will use the cable modem to generate specific signals to characterize leaks and transmitting them back through the plant.

For context, the paper will present potential deployment scenarios and the associated impact to the existing leakage programs that are being run in the industry and how these options can impact the requirements around the legacy set top box Out-of-Band (OOB) control telemetry.

With an open discussion and alignment about ways to solve these problems and a commitment from industry to build scalable and affordable solutions into future technologies, the industry can move forward and continue to meet regulatory requirements seamlessly.

2. Setting the Stage

Moving to high split is a transformative network change which entails various technical and operational challenges as operators upgrade the relevant plant components. However, operators are up to this challenge because increased upstream will enable them to offer higher speed tiers and unlock additional revenue potential.

Around the world, cable companies operate in different regulatory environments. However, their foundational principals are quickly converging onto a similar framework, and the OOB requirement is agnostic to regulatory requirements. When it comes to high split, every operator is expected to reach the same end state, though different regulatory environments may impact the "how." In addition, each company will have a unique set of business requirements, plant upgrade roadmaps and test equipment configurations that will dictate the optimal path forward.

There are two fundamental designs for the plant transmission and maintenance of leakage signals. The first is the existing paradigm is the generation of the signals in the hubsite. The second is an approach being developed around having the signals generated in the customer premises.

Operators will likely go through a transitionary period where they move to provide higher upstream services, while balancing business and regulatory requirements. A conceptual, roadmap-based approach is required as operators move toward the "end state" for signal leakage detection within the aeronautical band. Throughout the discussion below there will be some simplifications made in both the graphical representation of the concepts, and the descriptions of the solutions therein. These simplifications are made to make the options accessible and clear for the reader, while not removing any of the logical or conceptual challenges that are described within the solutions.

The shift in spectrum is depicted in Figure 1 below.

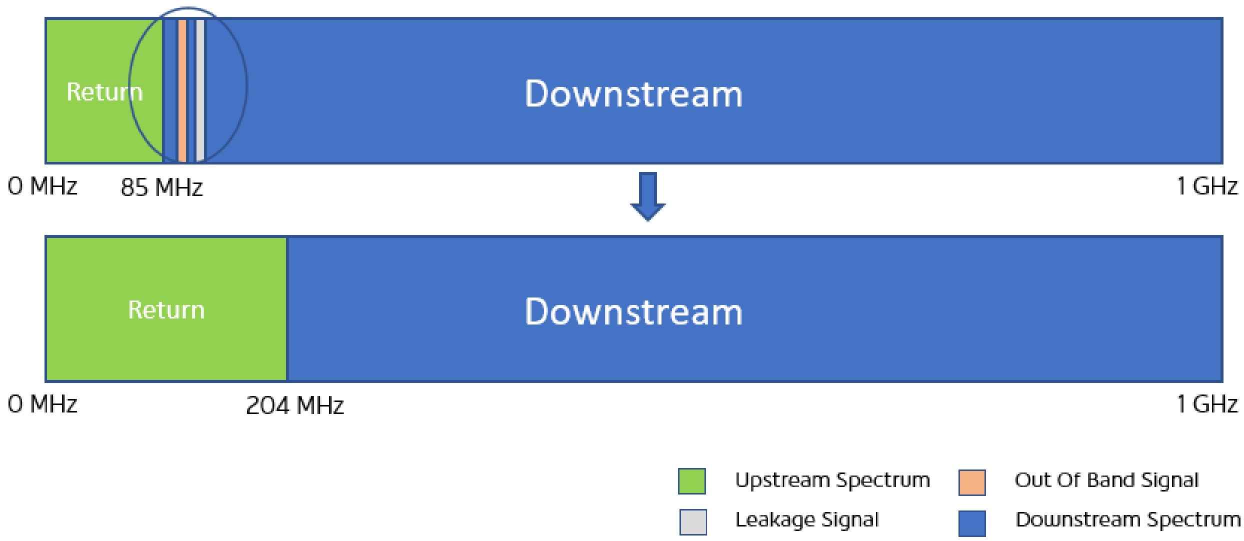

Figure 1 - Transition from 85 MHz to 204 MHz

Due to the fundamental properties of signal transmission in the access network and customer premises, any signal trying to traverse through the access network plant in a direction opposite to the allocated spectrum (i.e. upstream signals on the downstream or vice-versa) may cause interference. These signals will also be blocked when they encounter a diplex filter in an active or passive piece of equipment. There are some creative solutions around using these features of the plant to the operator's advantage which will be explored throughout this paper.

The other consideration operators will need to address throughout this transition is their oversubscription rate, which can be described as the percentage of available capacity being offered to each customer over and above the capacity required for each customer to achieve their maximum data rate simultaneously. Upstream capacity complicates the calculation when compared to the downstream oversubscription rate because large portions of upstream traffic are in bursts and latency sensitive. The in-depth considerations of these implications will not be addressed in this paper, where the focus will remain on the transmission of different telemetry signals.

3. Methodology

Throughout this section, we will cover the direction of transmission of the signals through the plant. There will be the existing downstream transmission of the signals from the hubsite to the customer premises and then that existing paradigm will be inverted and the transmission of these leakage signals will be generated in the customer premises and back towards the hubsite.

There are two main types of leakage signals that will be referenced throughout the course of this paper. The first signal is a dual sideband suppressed carrier (DSB-SC) signal. This is demonstrated conceptually below and was the next step of leakage signals after switching from analog video carriers. Today this is generated by two carrier waves (CW) that have a specific frequency offset and amplitude relative to the regular downstream transmissions on the plant.

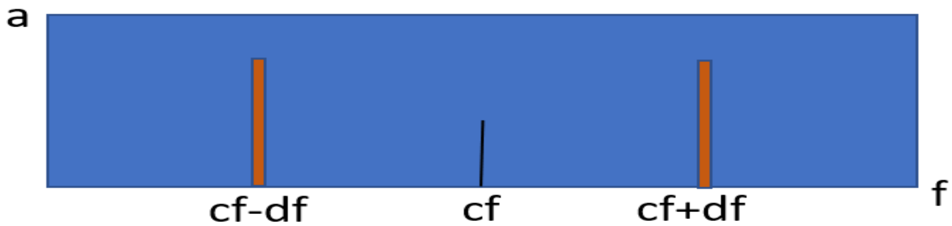

Figure 2 - DSB-SC Signal Block Diagram

The second type is contained within the DOCSIS 3.1 specification, specifically the utilization of pilot carriers that exist within orthogonal frequency-division multiple access (OFDMA) known as OFDM upstream data profile (OUDP)

Tables of calculations that follow are based on the following assumptions:

- Single carrier quadrature amplitude modulated (SC-QAM) channels are 6 MHz wide with a capacity of 25 Mbps
- OFDMA channels are 1024-QAM with an expected bit rate of 8 bits/sec/Hz

These numbers and assumptions are approximations based on information available today.

3.1. Transmission Downstream

There are two methods that leverage existing downstream transmission signals. These methods have compromises made in terms of spectral efficiency for the newly available upstream and require a complex amplifier design that is expected to result in a higher cost for this equipment. This is balanced by two main benefits, both of which are centered around the retention of existing leakage detection test equipment and video technology platforms. The intent of this is not to provide a cost analysis but to succinctly lay out the options that exist if an operator wishes to preserve these legacy signals.

The first primary benefit is the retention of the existing leakage program that is currently being used by the operator. Depending on the size and scale of the operator and their operations, outfitting the field teams with new leakage equipment may prove to be a large undertaking from a capital standpoint. Additionally, as an industry, there is an increasing focus on the operational cost of technology changes and any time there is a change to equipment, practices, and methodology there is the introduction of an operational cost that will also need to be captured.

The second primary benefit is preserving any relevant downstream signals, specifically OOB. The removal of the OOB signal is not an option for many operators, as the number of set tops boxes that rely on only this signal and cannot use other telemetry is in the millions in many cases.

3.1.1. Notching Out Spectrum

When looking at keeping the existing legacy signals intact, the first thing considered was preserving a portion of the existing downstream spectrum by using notch filters for the switch to a 204 MHz return, known as high split, as pictured in Figure 3.

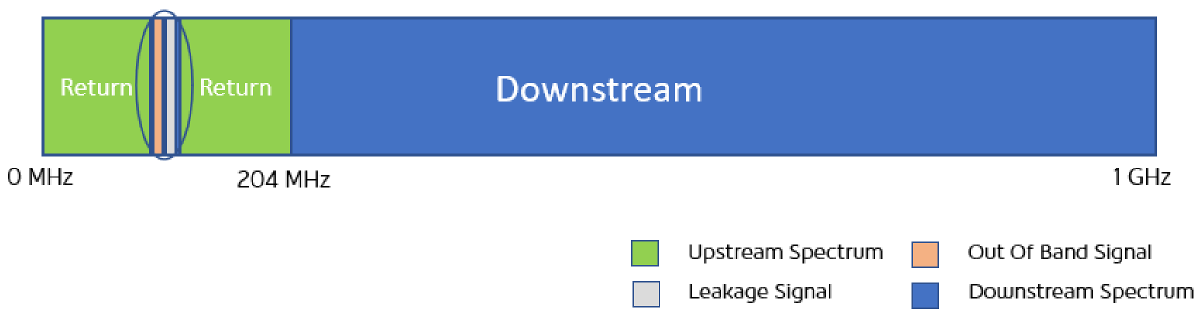

Figure 3 - Conceptual Spectrum Notch

Sacrificing any portion of the newly increased upstream spectrum, especially as operators look to reap the benefits of the newly opened return band in terms of both congestion relief and providing higher upstream tiers to customers, may seem counterproductive at first glance.

The cost of creating this notch in the upstream and sacrificing the return spectrum should be understood contextually in terms of what it means from a capacity perspective for the operator, what it means for speed tiers and potential to help capacity to help relieve congestion. The capacity calculated itself is not sufficient for determining the true costs of this spectrum sacrifice to a specific operator.

To determine the size of the notch required in the spectrum to preserve the downstream transmission of legacy signals, it is important to keep in mind that the OOB signal has some room to move within the downstream spectrum. The leakage signal may also have some room to move within the aeronautical band depending on the regulatory environment of the operator. Placing these signals are close together as possible will minimize the size of the notch required and keep the available capacity as high as possible given these constraints.

The table below details three potential notch-width scenarios based on manufacturing technology available today, and what can be reasonably expected for spectrum required to preserve the signals. A thinner notch would allow for the preservation of the OOB signal, while a wider notch could accommodate both the OOB and the leakage signals. For the purposes of this calculation, it is assumed that there would be six 6.4 MHz wide SC-QAM channels and the remaining of the spectrum would be utilized by OFDMA.

Table 1 – Calculated Available Upstream Capacity based on Notch Width

Notch Width	Available Spectrum	SC-QAM Spectrum	OFDMA Spectrum	Projected Capacity
20 MHz	5-105 & 125-204 MHz	5-55 MHz	55-105 & 125-204 MHz	1182 Mbps
30 MHz	5-105 & 135-204 MHz	5-55 MHz	55-105 & 135-204 MHz	1102 Mbps
40 MHz	5-100 & 140-204 MHz	5-55 MHz	55-105 & 140-204 MHz	1062 Mbps

There is another consideration for notch filters in longer cascades known as Group Delay. Group Delay is caused by a multitude of issues, which are relatively known, understood, and compensated for in deployments today. The introduction of a notch filter will create the same characteristics around the upper and lower bounds of this filter that cause group delay in upstream transmission. It is expected that an operator will end up with group delay issues on either side of notch filters in longer cascades in addition to the other group delay issue that are expected for the channel bounded by the high split filter. The spectrum that can expect to see group delay issues arise in is highlighted in Figure 4.

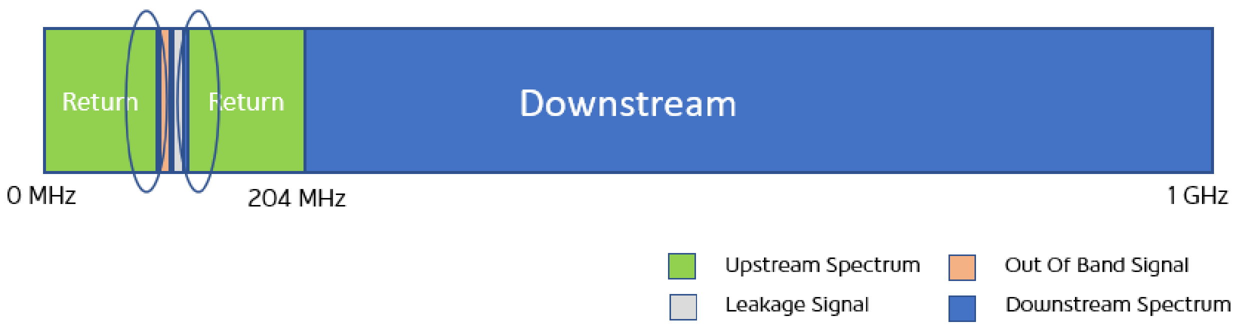

Figure 4 - Additional Group Delay Locations

There are not currently any deployments of this solution currently available for study and evaluation, so any discussion around this expected loss in modulation for the OFDMA channels that border this filter will be based on existing upstream deployments and understanding of OFDMA. It is difficult to say whether the OFDMA channel is so robust that it can overcome the majority of the impairments introduced from group delay, or if it will degrade the whole channel to a point that leaving a small exclusion band is preferable. An in-depth analysis of the optimal size of the notch filters and exclusion channels requires future investigation and is beyond the scope of this paper.

3.1.2. Up-Conversion

The second method of downstream transmission that will be discussed will be referred to as up-conversion. This concept is based on the idea of transmitting the signals which are required higher in the spectrum than where they are needed, in what would still be downstream. Once the signal reaches an active device in the plant, it will be transposed from the higher frequency and inserted as a downstream transmission in the return band on each output legs of that active. Once the signal is inserted into the return band, it begins to traverse that span of coaxial cable in a direction opposite to the other signals on that cable. It would be bound by the diplexers in the plant, where the signal would effectively be discarded since it would be trying to traverse the filter in the wrong direction. These leakage detections and OOB signals would then be regenerated on the other side of the active equipment.

For this Up-Conversion, there is additional complexity created in the amplifiers and downstream spectrum plan when compared to adding a notch filter, but up-conversion could be a more efficient use of the available return spectrum. There is also the option to handle the OOB and leakage signals differently in this deployment. The OOB will still have to be generated in the head-end or hubsite and transmitted through the plant since it is a signal that requires specific intelligence and transmission characteristics. The leakage tones however may be generated at each amplifier, or at the node, as required. This is due to the fact that although the signal is very specific, it does not require a two-way communication path or any acknowledgements from the equipment receiving the signal. The option to transmit the OOB in the downstream and convert the leakage signals as required in actives, may prove to be advantageous in the manufacturing of the actives, tuning or deployment. However, the benefits are not measurable at this time.

This is conceptually depicted in Figure 5.

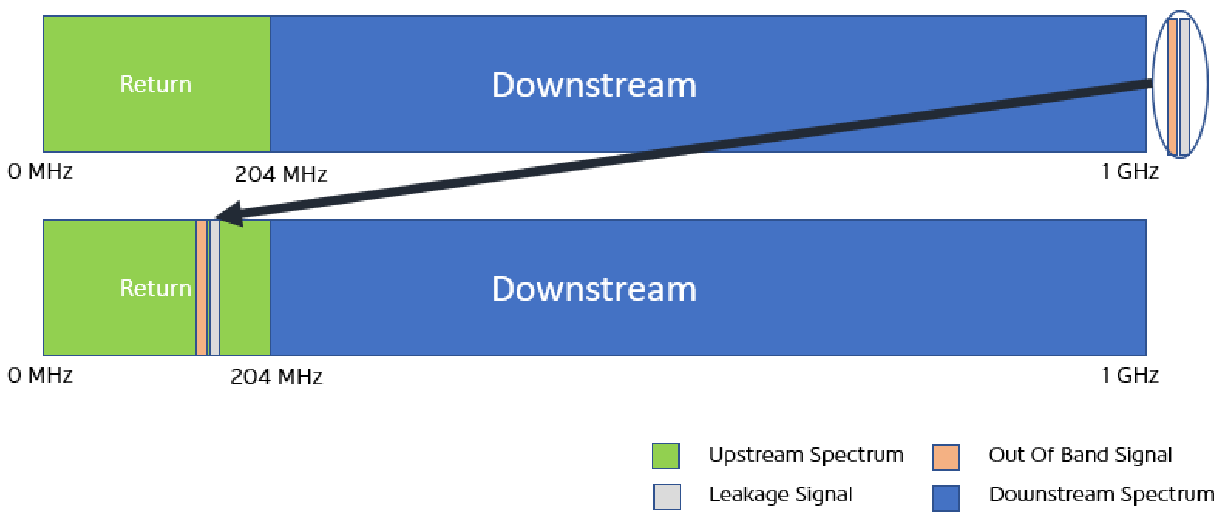

Figure 5 - Up-Conversion

The inclusion of these signals on the return band does come with a reduced return spectrum available for transmission at the customer premises. To the modem in the home, these incoming signals will be blocked by the diplex filter within the modem and not cause interference. The spectrum that these signals are arriving into the modem on however will be occupied, and therefore unavailable for the modem to use in upstream transmission. The specific placement of these signals will likely vary in every cable operator deployment due to various interpretations of the optimal spectrum plan, manufacturer guidance and other debate, but the fact remains that there will be a small area of upstream spectrum that the modem should not be allowed to transmit on due to the fact that there will be existing signals there. This is illustrated in Figure 5.

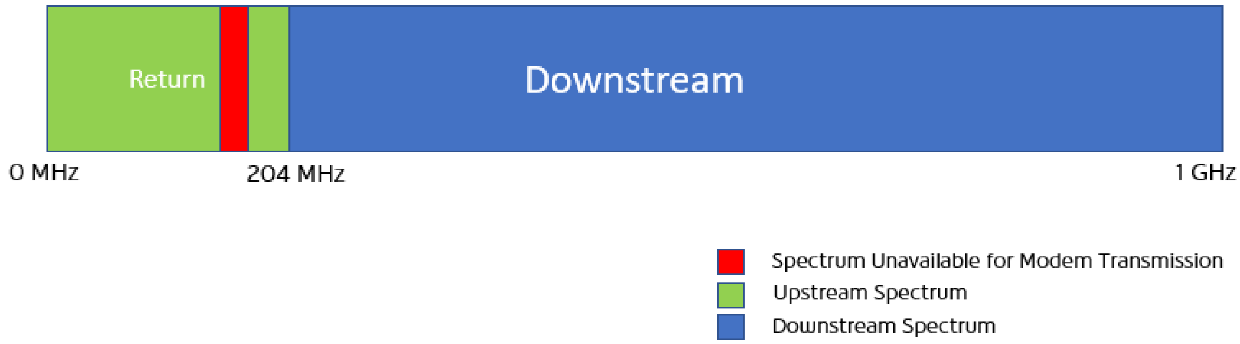

Figure 6 - Spectrum Available For Modem Transmission

The size of the notch in Figure 6 is not to scale and is provided for illustrative purposes only. The amount of unavailable spectrum will vary depending on how the signals are placed and layered into the spectrum. The calculation provided in Table 2 could be considered a conservative estimate of what would be available for upstream capacity.

The group delay issue reappears in the up-conversion deployment due to the fact that it will still require a filter on the output leg of the amplifier to insert the leakage and OOB signals without further interference or ingress. The placement and function of the filter would be only on the output of the amplifier, and not the input which would lead to approximately half the group delay impact of the notch filter.

Table 2 – Capacity for Modem in Up-Conversion Plant

Available Upstream Spectrum	SC-QAM Spectrum	OFDMA Spectrum	Projected Speed
5-105 & 115-204 MHz	5-55 MHz	55-105 & 115-204 MHz	1262 Mbps

This allows for a more efficient usage of the upstream spectrum than the notch method and largely avoids the issues introduced by group delay. This comes at a cost of increased complexity in both sides of the spectrum deployment due to the specific configuration required for the modem, the likely requirement of a very specific upstream channel plan and finding space for the signals to be transmitted in the downstream.

3.2. Transmission Upstream

Leveraging the modem to generate the required leakage signals would allow for the signal to be created in every area of the plant, where there is live signal. These methods provide what is required for the leakage signal generation and having it created by the modems themselves ensures that they are in every portion of the plant that is transmitting in that spectrum. Conceptually, this is essentially turning the transmission of these signals around, where before they were going from the hub site to the customer, now they will go from the customer into the network.

While discussing the solution based around the modem transmit leakage signals, the plant being modeled is one that has removed the OOB requirement for the set top boxes. The reason for the removal of the OOB signal is not a technical requirement of the solution and it is possible to maintain the downstream transmission of this signal in the following scenarios. The reason for OOB from the discussion for the upstream transmission scenarios are twofold. The first is that the methods of preserving the signal have been covered above, since it will need to remain a downstream signal that has a two-way communication to the hub site. The second is that removal of this signal before inverting the leakage model is programmatically aligned with the tradeoffs considered in the transmission methods, as well as conceptually aligned with transforming the plant in a manner that is easy to understand.

The measurement of these signals is in the same portion of spectrum that is currently measured and meets existing regulatory requirements in the aeronautical band without adding great complexity to the rest of the plant. Figure 6 is a high-level diagram of how this would look, with the new transmission area of the modem depicted in purple.

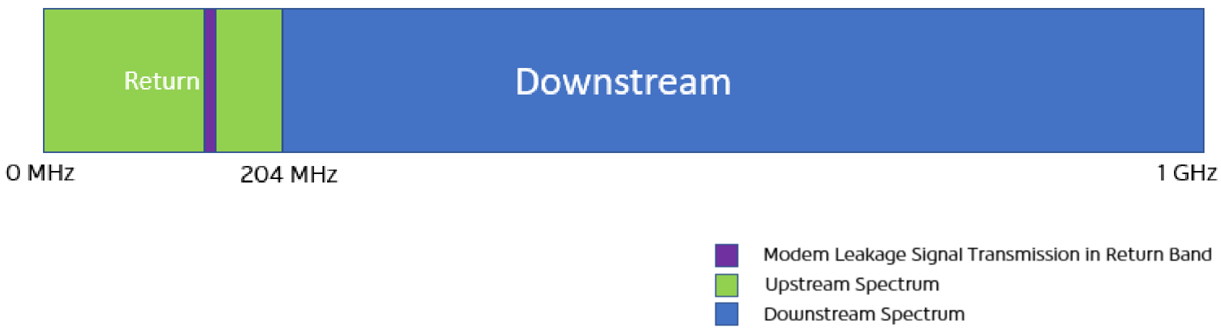

Figure 7 - Conceptual Modem Transmission

Initial findings from silicon manufacturers centered around having the modem transmit the required signals have led to the assumption that there will be minute-to-negligible sacrifices in the upstream, allowing the full spectrum to be provided as capacity as pictures in Table 2. The distribution of spectrum between SC-QAM and OFDMA channels has remained due to the fact there will be previous generations of DOCSIS in the plant for a long time to come.

Table 3 – Full Upstream Available

Available Upstream Spectrum	SC-QAM Spectrum	OFDMA Spectrum	Projected Capacity
5-204 MHz	5-55 MHz	55-204 MHz	1342 Mbps

The deployment of this solution has a caveat that comes from the following scenario. The Operator has taken node ABCD and upgraded it to 204 MHz. At this moment, all the existing modems, or at least the majority, only support 42/85 MHz split, and the operator may be out of compliance with a regulatory body. This is a challenge every operator will have to resolve. One suggested path involves ensuring that there is a modem installed, either in the customer premises or an environmentally hardened cabinet, that is transmitting the leakage signal back through the plant from the last tap in every run. This modem cannot distribute the required signal to all the other drops on the tap run due to the nature of coaxial distribution plant, specifically around port-to-port isolation between taps. The lack of leakage signal on every drop without a 204 MHz return modem is not immediately a problem. This is because if there are no 204 MHz return modems in an area, there is no transmission within that band that will need to be measured. The 42/85 MHz modems will continue to function as normal, and not transmit within those restricted bands. As the homes on the node become populated with 204 MHz modems that can transmit in the areas that require monitoring, those modems will be transmitting the required aeronautical band leakage signals for detection.

3.2.1 Generation of Carrier Waves from Cable Modem

The first option examined for the inversion of signal generation will be using the Cable Modem to generate the CW tones at spacing (refer to Figure 1 for an illustrative example) and power for the existing leakage equipment to detect. The immediate advantage in this method are clear, the cable modem can effectively generate the same signal that the leakage detection equipment has been detecting before, and at very low cost in terms of upstream spectral usage.

Using the chipset to generate the two CW tones does count towards the maximum number of channels available on the tuner. The chipset that was examined for the purpose of this analysis was the Intel Puma 7. This chipset has eight SC-QAM channels available on the tuner, which would be reduced to six available channels while having these two additional tones allocated for leakage detection. This means that there would be a limitation to the number of SC-QAM channels that could be run, and the remainder would need to be OFDMA. It is not considered to be a material cost because most operators do not run more than six SC-QAM channels today. Once the spectrum is expanded, it is much more spectrally efficient to add OFDMA channels instead of further SC-QAM channels.

During testing of this methodology where the modem chipset generates these narrow and powerful tones, some harmonic signals have been observed. The behavior of the CW tone generation and resulting side effects are detailed in Table 4.

Table 4 – SC-QAM CW Harmonics

CW Center Frequency	CW Signal Strength	Harmonic Location	Harmonic Strength
85 MHz	34 dBmV	215 MHz	-38 dBmV
108 MHz	33 dBmV	192 MHz	4 dBmV
137 MHz	31 dBmV	163 MHz	23 dBmV

The creation of these harmonics may require additional regulatory, specification or investigation considerations that are beyond the scope of this paper.

3.2.2 Utilizing Cable Modem Pilots

The DOCSIS 3.1 standard includes protocols within OFDMA that can be used as pilots for leakage detection in the inverted leakage detection paradigm. There is a feature known as the OFDM upstream data profile (OUDP) that utilizes very specific pilot signals and although they are designed for a different purpose, there is the potential to leverage these pilot signals for leakage detection. Through optimized cable modem termination system (CMTS) scheduling, an operator may be able to remove any encumbrances to the spectrum entirely and allow a fully open return spectrum free from any notches, areas unavailable to transmit, or destructive interference.

The utilization of an existing carrier or protocol which does not add additional costs or limitations to the access network would be a huge benefit to any leakage program. Leakage has evolved from requiring whole channels, to potentially fitting in between SC-QAMs. The end goal is to use existing signals, transmitted without a penalty in bandwidth, to meet regulatory and plant hardening requirements.

There are three main areas to consider when it comes to using OUDP for leakage detection:

- The DOCSIS side requires creation of a CMTS scheduling scheme to minimize the cost to the access network. The evolution of the cable modem transmission profiles to the point where the OUDP pilot signals represent a consistent and distinct signal to be measured and profiled are still in the exploratory stages. The framework exists within the DOCSIS standards to support this initiative.
- From the test equipment perspective, measurement of these new pilot signals will be a technical challenge for equipment manufacturers. This is a new type of signal being generated, and it will have different propagation and measurement characteristics. At minimum, this will require firmware upgrades. For existing leakage test equipment, a hardware upgrade may be necessary.
- After the technical challenges are resolved on how the signal will be generated, scheduled and measured in the field, there will need to be extensive testing around the signal equivalency to existing leakage systems to ensure regulatory compliance.

4. Conclusion

This paper examined four solutions for leakage and OOB issues which occur in high-split and the considerations for each of these options. There are advantages and disadvantages to each, and the opportunity for other permutations of these solutions is still possible. Table 5 summarizes the proposed solutions and the main factors that have been discussed.

Table 5 – Summary of Options

Proposed Solution	Available Capacity	OOB Removal Required	Replace Test Equipment
Notch	1062 Mbps (min)	No	No
Up-Conversion	1262 Mbps	No	No
Modem CW	1342 Mbps	Yes*	No
Modem OFDMA Pilot	1342 Mbps	Yes*	Yes

*If OOB is left on the plant, it is still possible to move to these solutions. The capacity available will closely resemble the in the "Up-Conversion" solution.

The industry needs to align on the optimal milestones in the roadmap for evolving leakage detection. This will drive the development of solutions, as well as testing and detection of these new signals and configurations.

Once operators align on one solution, the industry will be better equipped to advocate for their needs with both regulators and suppliers. This will allow for manufacturing efficiencies and lower maintenance and upgrading costs for plants.

The size and scale constraints that come with a physical cable plant drive the need for a thoughtful, balanced approach to change. This can be a delicate act with regulatory requirements, operational requirements, business demands and technology changes. Evolution of leakage detection methods must happen concurrently with the evolution of the cable plant; it cannot be treated like an afterthought.

Creating an open and transparent dialogue around the move to high-split creates an excellent opportunity for operators to transition smoothly to high-split and continue to increase their offerings to customers, especially at a time when upstream is becoming more important than ever.

Abbreviations

OOB	out of band
DOCSIS	Data Over Cable Service Interface Specification
MHz	forward error correction
CW	carrier wave
OUDP	OFDM Upstream Data Profile
Hz	hertz
MHz	megahertz
GHz	gigahertz
OFDMA	International Society of Broadband Experts
DSB-SC	Dual Sideband Suppressed Carrier
CMTS	Cable Modem Termination System
SCTE	Society of Cable Telecommunications Engineers

Bibliography & References

Data-Over-Cable Service Interface Specifications DOCSIS® 3.1, Cablelabs

Leakage detection using SCQAM channels, Intel

