Compatibility Issues in Block Conversion for Return Path Concentration

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ABSTRACT

A few months ago we received reports of problems using block conversion with DOCSIS modems. We attempted to duplicate the problems in the lab, but were unable to do so. We are not able to show reasons for the failures, but we are able to discuss possible sources of the problem. Our tests indicate good safety margins with the equipment we used. Block diagrams of practical laboratory tests are shown, which can help identify any possible problems before system deployment.

SUMMARY

Block conversion is a technique used to improve the utilization efficiency of the return path. Return path spectra from multiple nodes are converted to different bands, then the bands are combined to modulate one laser. This provides a convenient, economical way of using one fiber to transport up to 18 return spectra at one wavelength.

A few months ago we heard of field problems involving block conversion and DOCSIS modems. The report was that the modems didn't work over a block conversion system. We set up a simulation in the lab to understand the problem. Commercial concerns precluded our obtaining the same equipment used in the failed field test, so we had to use available equipment. For better or worse, we were not able to induce failures similar to those observed in the field. In fact, we found excellent margins to any failure modes. Thus, we are unable to report the source of the field failure. However, we can speculate on some of the possible reasons for the failure, and show test systems that will allow simulation of field conditions, allowing you to do your own testing.

BACKGROUND

Figure 1[i] illustrates a basic block conversion system. Multiple return path spectra are converted to different frequencies before being modulated onto a single optical transmitter. As illustrated in Figure 1, block conversion is used at a node, where up to four return paths are placed in the spectrum from 5 MHz to about 210 MHz, and modulated onto one laser for upstream transmission. This allows one fiber to be used to transport four individual return paths. In the simple system illustrated, single conversion is used, so that the three bands that are frequency translated are also inverted. At the headend the bands are block down converted, with the spectrum being returned to its normal relation.

An alternate form of block conversion is employed to allow return signal transport from a hub to the headend. In this application all blocks are converted to fit the spectrum from 50 MHz to 860 MHz. In the North American channel plan, up to 18 blocks can be accommodated on one optical path. The composite spectrum is applied to an optical transmitter of the type normally used for downstream transmission. In this configuration, double conversion may be used to eliminate the spectrum inversion of figure 1. Of course, double conversion adds

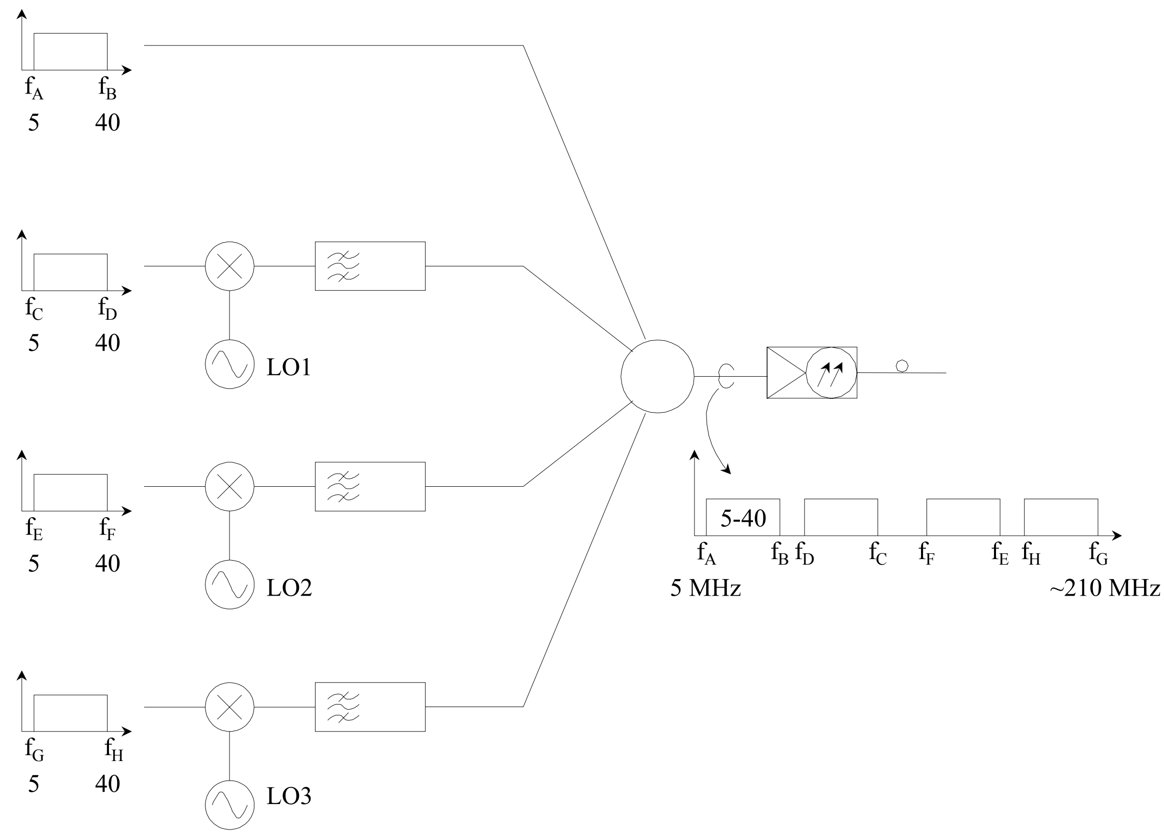

Figure 1. Basic Block Conversion

complexity and potentially more phase noise, but you can show that overall, it provides a more practical block conversion system for the application. It is quite possible to further multiplex different wavelengths, providing up to about 288 return blocks (10.7 GHz) on one fiber.[ii]

SYSTEM SIMULATION

When we first became aware of problems in the field, we set up a simulated system in the laboratory in order to try to duplicate the problems. Unfortunately we were not able to gain access to the system that had shown problems in the field, nor were we able to obtain that equipment for the lab test, so we set up a similar system using different equipment. We were not able to duplicate the problems - the lab system worked quite well - but we did gain insight into what might have happened in the field.

Figure 2 illustrates the system set-up in the laboratory used to simulate the system tested by others in the field. The "headend" on the left supplies downstream signals to a node. The downstream signals consisted of the incoming feed of our local cable system to 550 MHz, combined with the output of an Arris CMTS1000 cable modem termination system operating in the 256QAM mode. This signal was supplied through a typical length of fiber to the node, which in turn supplied signals to two RCA brand cable modems purchased at retail. Each modem was connected to a computer, and the task against which we judged performance was the transfer of a large file from one computer to the other. This exercised both the downstream signaling, which was not under test, and the upstream signaling, which was under

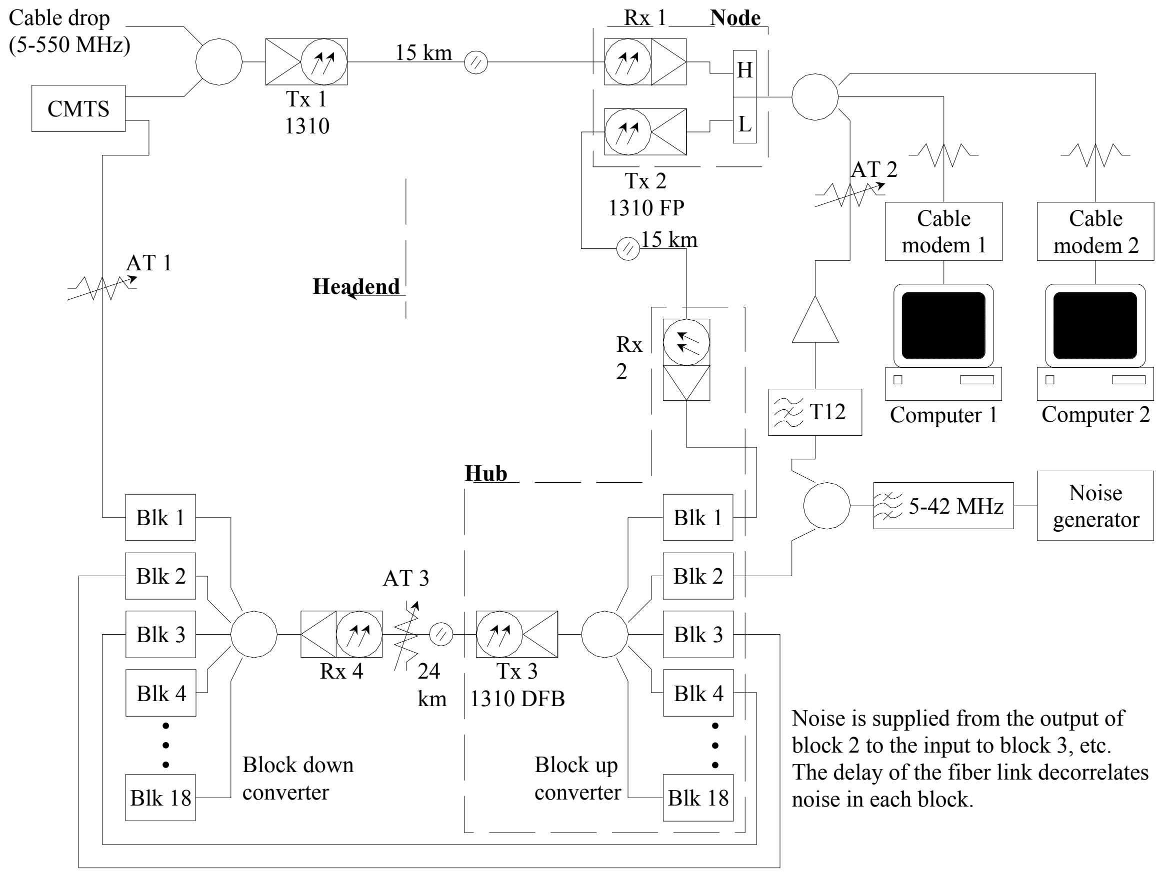

Figure 2. Simulation of Field System

test. The upstream communication was operated in the 16QAM 10.24 Mb/s mode, the highest upstream speed currently defined for DOCSIS-compliant modems.

To simulate a real return path, we used a Fabry-Perot (F-P) return laser in the node, which supplied signals to a "hub," which comprised an 18 band block converter and a DFB return optical transmitter. The return path was loaded using a noise generator with a 5-42 MHz bandpass filter. This signal was split, with a portion of the signal being supplied to the second block converter of the 18. At the "headend," the output of block 2, which contained the noise generator signal, was looped back to the "hub" through a short cable, and supplied to block 3, whose output was supplied to block 4 and so on. By doing this, we de-correlated the noise supplied to each block. This is necessary to make the resultant signal have about the same peak to average characteristics as would real return signals. The roughly 130 µs of delay in the return fiber ensured that peaks in the random noise did not occur simultaneously in each block. For practical reasons, we didn't loop all 18 channels as shown, but we did loop them in three groups, which yielded about the same results.

Result of System Simulation

We were able to transfer files between the two computers through the CMTS with no measurable errors. The operational dynamic range of the system could be tested by adjusting AT1. This attenuator changed the return path signal level received by the

CMTS. Long loop automatic level control resulted in the output level of the two modems varying as AT1 was adjusted. Simultaneously AT2 was changed to keep the noise at a constant level relative to the modem outputs. When the dynamic range was measured at channel T12, we had an error-free range of 27 dB. At the high-level end of the range, we experienced a transition from error-free transmission to complete failure with a 1 dB change in level. This was likely due to clipping in the F-P laser. At the low-level end a 1 dB change produced a transition from error-free transmission to errors reported by the CMTS, and an increase in file transfer time from 223 to 275 seconds. We did not experience a failure to communicate, however.

When the test was repeated using a modem return center frequency of 9 MHz, the high-level limit was similar, but we experienced a worse low-level limit and a dynamic range of 14 dB. This is believed to be due primarily to noise from TX2, which was loaded very lightly. Many modern return transmitters employ dither techniques to improve the dynamic range at low levels, but the transmitter chosen for this test did not have a dither circuit. The problem may have been exacerbated by group delay at the low end of the spectrum.

The tests were repeated using blocks 9 and 18 with substantially identical results.

MARGIN TEST

Finding no problems with the system set-up, we investigated the amount of additional degradation that the system could tolerate. The block conversion system was modified to introduce errors that might cause failure of the return path, and we investigated how much additional error could be tolerated before we encountered system problems.

The block conversion system used in testing has a pilot carrier that is transmitted from each block to the headend. The pilot is used to stabilize the gain of the return path against changes due to temperature and optical path changes. The pilot is also used to force zero frequency error in the block conversion process. Frequency conversion error is not necessarily a problem for all return systems. However, there are some return applications that demand zero error. For example, a few years ago the industry was looking seriously at using cable to link PCS (personal communications service) mini-cells. This is a cellular-like telephone system that uses small base stations. It is common for a phone to be simultaneously in contact with multiple base stations, which are linked back to a master controller by the cable plant. The master controller can work with signals being received simultaneously by multiple base stations, but only if there is no frequency error between the received signals. If the several base stations communicate upstream through different cable nodes, there must be no frequency translation error.

The system tested by the MSO may not have phase locked the up- and down-conversion processes, so we experimented with breaking the loop and introducing intentional frequency error. Another concern is with phase noise in the frequency conversion process. Any phase noise in the local oscillators will be transferred to the signal, and if enough phase noise is added, demodulation of the return signal can fail.[iii]

Figure 3 illustrates the configuration used to test these and other hypotheses regarding what could go wrong. The CMTS was connected to our internal network to provide access to the internet, and was con-

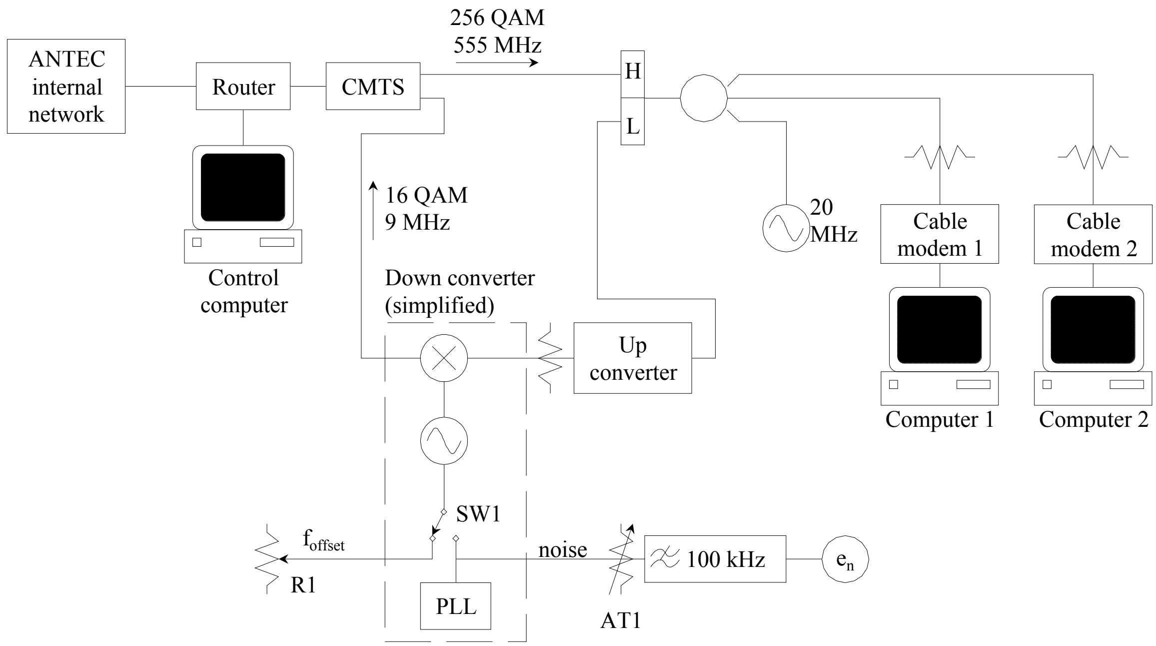

Figure 3. Block Converter Margin Test

nected to the two modems and computers as described above. In this case we did not add the optical network, since we were concerned only with what might happen in the block converter. The forward path was transmitted directly from the CMTS to the modems. A diplex filter routed the return signals through a single up converter and down converter, of the type used in Figure 2. The down converter was modified to allow us to break the phase locked loop in order to introduce frequency errors. We also added the ability to introduce phase noise into the closed loop. The block down converter is actually a dual conversion device as described above, but we have shown only one conversion here, because we did nothing with the other conversion.

The 20 MHz generator was used to give us a return path signal that we could measure in order to determine frequency offset and phase noise. By observing the 20 MHz signal on a spectrum analyzer at the "headend" we could tell how much frequency error or phase noise we introduced.

To introduce phase noise, we used a pseudorandom noise generator followed by a low pass filter to limit the noise to about 100 kHz. Attenuator AT1 allowed us to adjust the amount of added phase noise until we encountered errors. We monitored the control computer for errors reported in the return transmission, and defined failure as occurring when we saw any reported errors or delays in file transfer. We used the same file transfer test reported above. We also tried using a web radio broadcast as the source, but there is little return data required to keep the broadcast alive, so it didn't really stress the return path at all. Also, we found so many internet problems that it was hard to tell when the return path was at fault.

<u>Frequency Offset</u>

We were able to offset the frequency +30 kHz and -35 kHz by changing the control voltage to the oscillator. Over this range no change in operation of the return path was noted. This corresponds to a worst case

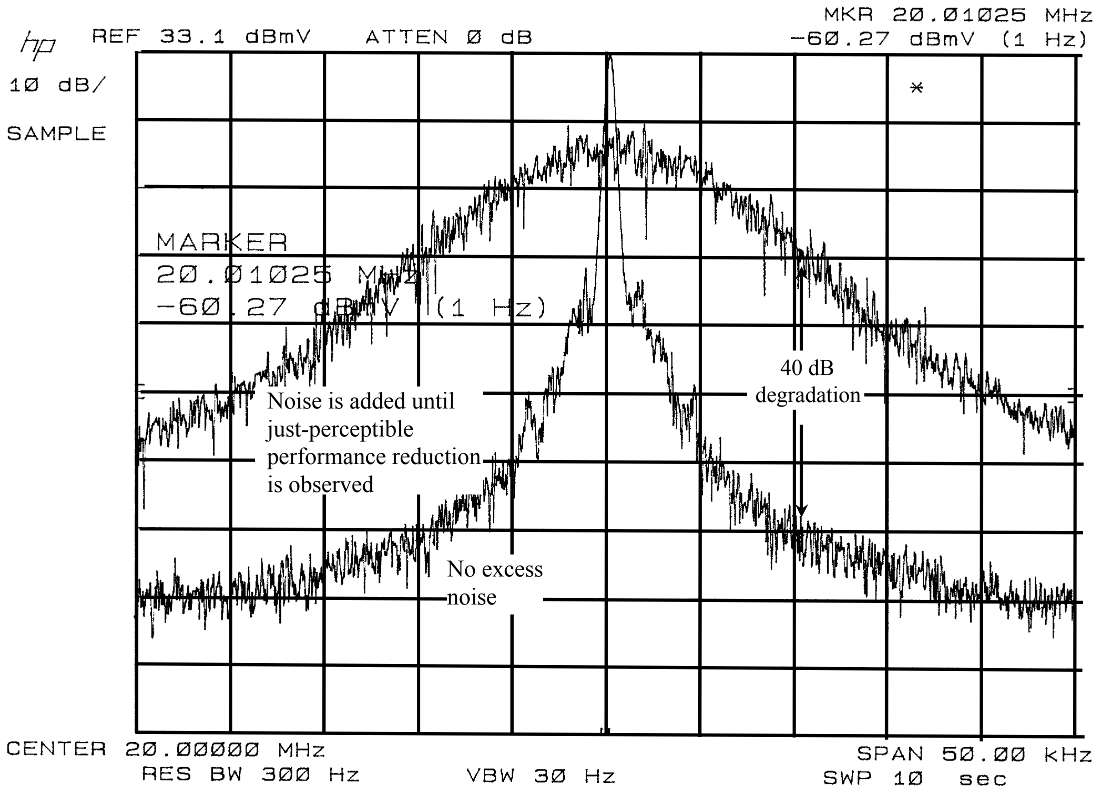

Figure 4. Normal Phase Noise and Enough Phase Noise to Stress System to the Threshold of Error Introduction

frequency translation error of about 37.5 ppm, which is not a difficult number to achieve today. Since we saw no problems with this much error, we concluded that even a block conversion system that was not phase locked should work, at least with this combination of modems and CMTS.

Phase Noise

It is known that if enough phase noise is introduced into a transmission path, digital transmission will fail. Figure 4 shows the phase noise on the 20 MHz carrier without any added noise, and also shows the phase noise with enough additional noise to induce errors into the 16QAM transmission. Often phase noise is measured as so many dB down from the carrier at a 10 kHz offset, measured in a specified bandwidth. For this test, we were not as much interested in the exact number of dB the phase noise was down, but we were interested in knowing how far we were from problems.

We found that we had to add enough noise to bring the noise sidebands up 40 dB (at 10 kHz offset) in order to induce errors. Note that this was so much noise that the carrier peak is not discernable at the resolution bandwidth used. Comparison of the no-excess noise plot with archival records dating back to initial product approval showed that we were measuring more than 10 dB more noise here than in the approval measurements. We suspect that this is due to noise on the 20 MHz oscillator, which was a medium-quality variable signal source. Thus, we probably had more than 50 dB margin in phase noise.

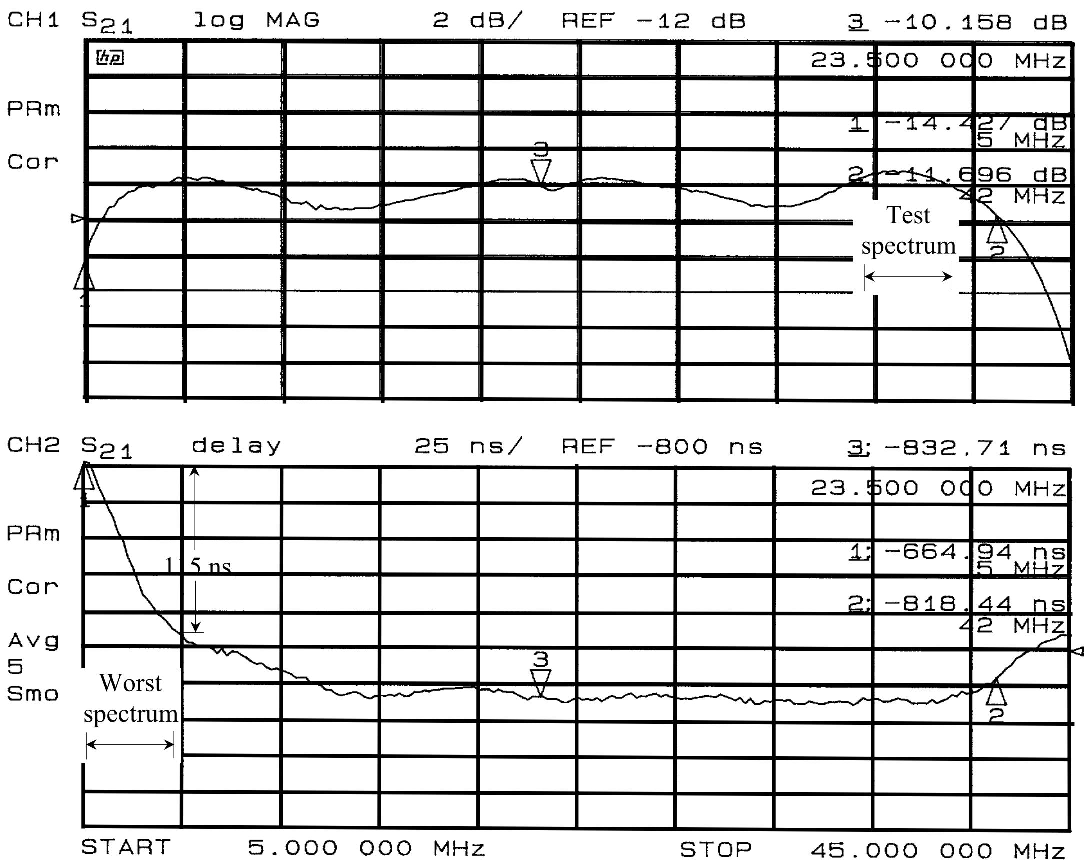

Figure 5. Amplitude and Delay Response of Block Conversion System

WHAT ELSE CAN GO WRONG?

Having not found any significant problems that would explain the field failures, we searched for other issues that may have been limiting factors in the field performance of the other equipment. It certainly is possible that errors in frequency or delay response of the block conversion system could cause premature failure to communicate. In the present DOCSIS specification, there is no adaptive equalizer in the return path. Inclusion of adaptive equalization is difficult because the amount of equalization required is different for every modem, depending on the equipment between the modem and the headend. Also, lower order modulation methods, such as the QPSK and 16QAM used in DOCSIS return paths, are not that susceptible to errors. (In future generations of DOCSIS specification, where higher levels of return path modulation are used, the specification may provide for pre-distortion in the modem transmitters, based on headend measurements relayed back to the modem.)

Figure 5 is archival test data showing the amplitude and delay response of a typical block conversion system, including a 15 km optical path. In the S_{21} log MAG (amplitude response) path at the top, we show the test spectrum where the return path signal was operated for this test. The spectrum is 3.2 MHz wide, the widest bandwidth currently specified by DOCSIS.[iv] The peak-to-peak amplitude error is negligible over this bandwidth. Placing the return carrier at other frequencies would have made little difference.

Of possibly greater interest is the group delay shown at the bottom. The block converter uses ceramic resonator filters that do exhibit group delay, but delay equalization is provided. Note that the residual group delay is worst at the very low end of the spectrum. Over the bandwidth occupied by the DOCSIS signal, the delay is about 115 ns. The maximum symbol rate specified in DOCSIS for the return path is 2.56 Ms/s (mega-symbols per second), so the period of one symbol is the reciprocal, or 391 ns. This is still longer than the delay, so we might suppose that group delay alone would not be fatal to a data signal carried in this spectrum. However, other delay issues and, more importantly, noise considerations, would preclude use of a return path this low in frequency. If any signals are placed this low, they should only be extremely robust BPSK or FSK signals at very low data rates, with the ability to accept errors.

Marker 2 is at 42 MHz, the highest frequency specified for the block converter system under test. Note that the group delay is starting to rise slightly, but group delay at this frequency will be dominated by that of the diplexers in the node and amplifiers. For this reason it is not recommended to use frequencies above about 40 MHz with a 42 MHz return cutoff.[v]

CONCLUSION

We received reports from an MSO that he had tried a block conversion system with DOCSIS modems, and experienced unsatisfactory performance, which was attributed to block conversion. We were unable to obtain the equipment used in his test for commercial reasons, but we did set up several laboratory experiments to try to duplicate the results, using equipment available to us. We were not able to experience the same failures, but we were able to define some parameters that an operator may want to look at to ensure satisfactory performance. Our test confirmed that DOCSIS modems can work very well with block conversion.

CREDITS

We appreciate the help of David Hodgdon of Arris Interactive, in getting the CMTS up and running in our laboratory quickly. John Kenny directed much of the testing.

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[i] Ciciora, Walter et. al., *Modern Cable Television Technology: Video, Voice and Data Communications*, San Francisco: Morgan Kaufmann, 1999, p 579

[ii] Kenny, J., *DWDM Block Converted Return Transmission Performance*, companion paper presented at the 2000 NCTA Technical Program

[iii] Ciciora op. cit., pp 178, 179

[iv] ibid., p 209

[v] ibid., p 579. Another reason for not using frequencies above 40 or 41 MHz is the leakage of return path signals into the IF section of TVs connected directly to the cable.