BNN -- A COMPREHENSIVE BANDWIDTH MANAGEMENT TECHNIQUE FOR THE FORWARD PATH

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Abstract

Standardization of digital capabilities of existing and to-be deployed HFC networks calls for advanced techniques of measuring digital performance.

The authors quantify high-speed forward (downstream) data capabilities through the use of the Bit Error Rate in the Noise Notch (BNN) technique.

Additive White Gaussian Noise (AWGN) is used to simulate full forward path digital loading on a selected portion of a network under test. Inserted into this fully loaded bandwidth is a non-forward-error-corrected 6 MHz, 256 QAM evaluation signal.

Signal levels are varied, and as a result, the true bit-by-bit dynamic range of operation is fully understood. Additionally, the effects of the digital tier on analog channels can also be measured by this technique.

Benefits for the manufacturer are a repeatable test, which quantifies predicted performance and can easily be demonstrated for network operators. Benefits for the operator include the ability to certify and to re verify performance of recently deployed networks.

This technique can also be used successfully in predicting performance of legacy networks when a fully loaded digital tier is to be added.

The authors present lab tests using this technique with analog loading provided by CW carriers or analog headend signals.

By using this technique, bandwidth management of the forward path can be easily achieved, since the dynamics of the path will be understood. This tool will be very important to deployed networks and their need to know how much headroom is available for future digital services.

INTRODUCTION

Rigorous qualification testing of the electronic components in a broadband network was not a consideration in the early days of cable. The immediate goal was to fabricate a device that did the job and get it into service as soon as possible. As our industry has evolved, the need for qualification testing has been discovered and refined. Today, measurement of characteristics like Mean Time To Failure (MTTF) and Mean Time Between Failure (MTBF) are standardized and routine.

Through testing, manufacturers seek to demonstrate to network operators that their products are superior to those of other vendors, and operators seek hard proof that the equipment they are buying meets high standards for performance, quality, and reliability.

This paper shares the results of on-going work to develop test and qualification methods that accurately simulate and predict the performance of RF amplifiers, optical transmitters, and optical receivers in broadband networks transporting analog and digital signals to deliver advanced two-way services.

TESTING TODAY

What Drives the Way We Test?

Currently, several different types of test signal loading are used to conduct qualification testing, with manufacturers using different test configurations and signal loading depending on the network operator's requirements. In nearly all situations, the test requirements are specified by the network operator.

Broadband network operators are driven to specify various qualification testing methods to meet their system design needs. These needs vary widely, and may include factors such as system size, available bandwidth, channel type, channel loading, dollars invested per home passed, business philosophy, and engineering management philosophy. The goal of qualification testing is to identify products that meet performance, reliability, and cost requirements.

How We Currently Test

A channel plan widely used in broadband networks for forward transmission places analog channels from 50 to 550 MHz and digital channels from 550 to 750 MHz.

Standard practice for qualification testing of active devices in the forward path fills the spectrum from 50 to 550 MHz with Continuous Wave (CW) analog carriers. However, a number of different methods are in use for simulating the digital channel loading of the spectrum from 550 to 750 MHz.

One method of simulating the digital load consists of using a bank of individual QAM modulators (64 QAM or 256 QAM). Loading the 200 MHz spectrum with 6 MHz digital channels in this manner requires 33 separate QAM modulators.

A second method of simulating the digital channel loading is to mix the output of a small number of QAM modulators with upconvertors/RF generators to create a wide band of digital loading.

A New Way to Test

This paper presents a third method to simulate digital loading for forward network testing: use Additive White Gaussian Noise (AWGN) to fill the spectrum from 550 to 750 MHz.

The results of testing using a combination of analog carriers and AWGN are shown in this paper. Our tests examined AWGN levels representing full digital channel loading that varied with respect to the CW carriers. The various levels of AWGN loading were selected to represent typical operating levels used in broadband networks throughout the world.

Our tests also simulate the changes that will take place as the high end of the spectrum carrying analog signals is converted to carry digital channels. We do this by expanding the bandwidth loaded with AWGN signals to 500 - 750 MHz, while at the same time reducing the bandwidth loaded with analog channels to 50 – 500 MHz. Each digital channel is capable of carrying the equivalent of up to 10 analog NTSC television channels.

The tests documented here seek to determine the performance of forward path DFB optical transmitters when fully loaded from 50 to 750 MHz with analog carriers and AWGN. BER performance was measured as a function of RF drive level to a transmitter under a variety of analog to digital schemes.

USING BNN FOR FORWARD TESTING

The Bit Error Rate in the Noise Notch technique (BNN) is not a new idea. Previously, this technique has been used successfully to quantify bit error rates of common digital modulation modes (QPSK and 16 QAM) used in the reverse path under a fully loaded bandwidth condition. The additional benefit of this type of testing is to validate and demonstrate dynamic ranges of operation of various components of the HFC network. (See R. Thomas and J. Monroe, "Reverse Path Characterization: A Summary of Field and Lab Test Results," SCTE Cable-Tec Expo 2000 Proceedings Manual, 2000, pp. 475-491.)

Overview of the BNN Technique

In general, the BNN technique works as follows. First, define the bandwidth of operation. For the forward path testing, this was chosen as 54 to 750 MHz. Then, fully load the bandwidth of operation with analog and digital signals.

The analog portion of this bandwidth is typically loaded with NTSC-based video channels, spaced at 6 MHz from 55.25 MHz to 547.25 MHz. For lab testing, these channels are simulated with CW carriers generated by a stable crystal-controlled signal generator source.

Complete analysis of forward network performance, requires loading the bandwidth with the full digital component also. To load the 550 to 750 MHz bandwidth we used AWGN because of its large peak-to-average power ratio, which is typical of the 64 and 256 QAM modulation techniques used in today's forward path. This fully loaded condition is shown in Figure 1.

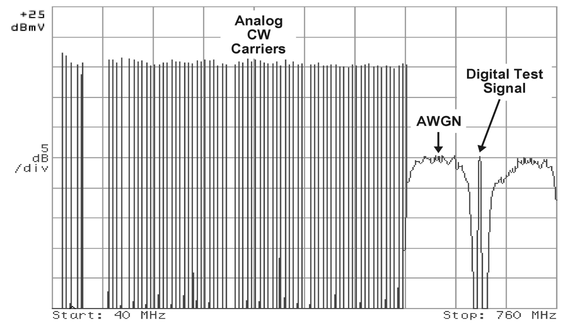

Figure 1.
Fully loaded forward test has analog CW carriers and AWGN to simulate digital loading

Note the "notched" out portion of the AWGN bandwidth. We inserted a 6 MHz wide 64 or 256 QAM test signal into this notch. The IF-based test signal is "up converted" to the desired frequency--in this case 651 MHz. This non-Forward Error Corrected (FEC) test signal is monitored for bit errors. The data signal uses a Pseudo Random Bit Sequence (PRBS) which allows for precise bit-by-bit evaluation. The HFC network, or a portion thereof, can now be evaluated for BER in addition to traditional performance parameters such as carrier-to-noise, composite triple beat and composite second order.

Test Setup

As shown in Figure 2, the test setup for evaluating performance in the forward system calls for three signal sources: a CW signal source; a band-passed, filtered broadband AWGN source; and a 64 or 256 QAM modulator.

Output of the CW signal source is combined with output of the AWGN signal source. The combined signal is notched at the test frequency and has the QAM signal to be evaluated for BER inserted into it. In this test setup the QAM signal is originated from a 43.75 MHz IF-based modulator,

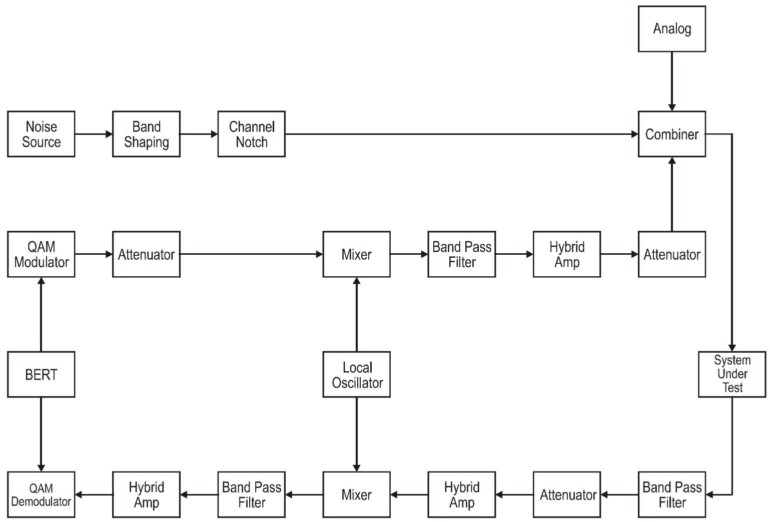

Figure 2.
Setup for using BNN for forward testing

which is unconverted and bandpass filtered to the correct operating frequency. A similar means of down conversion is used to feed a matching demodulator also operating at 43.75 MHz. Both the QAM modulator and demodulator are data and clock driven from a common digital transmission analyzer.

Setting Levels

Setting of digital levels relative to the analog video levels is critical. The following technique is valid for a 50 to 750 MHz amplitude flat (zero dB tilt) test signal only.

First, determine the desired operational levels (For example, digital at –8 dB relative to analog, CW carriers +15 dBmV, digital carriers +7 dBmV). Next, use the band power marker function of a spectrum analyzer to set the digital band power of the QAM channel accordingly. Then use the same technique to set the remainder of the digital bandwidth. Since the AWGN signal is essentially flat, a representative 6 MHz portion of this bandwidth is all that is necessary for establishing the correct level. See figure 3.

A proof of proper digital level relative to analog level can also be performed as follows.

Analog signal level	=	+15 dBmV
Digital signal level	=	+7 dBmV
Digital signal bandwidth	=	200 MHz
Number of 6 MHz digital signals in 200 MHz bandwidth	=	33 channels (200 ÷ 6)
Theoretical total bandpower of digital bandwidth (10 log 33 + 7 dBmV)	=	22.2 dBmV
Actual measured bandpower of 550-750 MHz using spectrum analyzer	=	22.5 dBmV

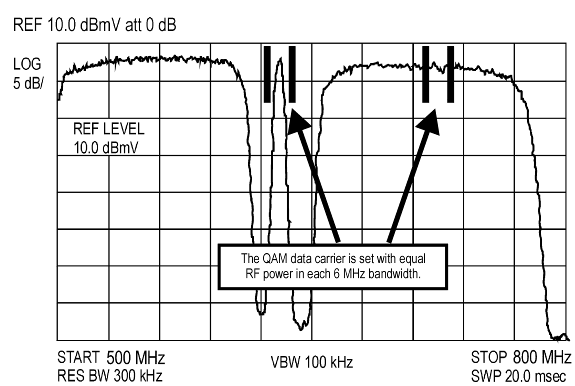

Figure 3.
AWGN with QAM data carrier in the notch

Comparing Apples to Oranges

The power and simplicity of this test is that it allows the user the freedom to use an AWGN source generator to simulate a full complement of digital modulators for a given bandwidth.

However, to verify that AWGN does not present a worst case or less than worst case condition, the following correlation testing took place. A bank of twenty-two 64 QAM generators was used in a direct comparison to an identical bandwidth of AWGN. In each bandwidth scenario, the same 64 or 256 QAM modulated test signal was evaluated, as shown in Figures 4 and 5.

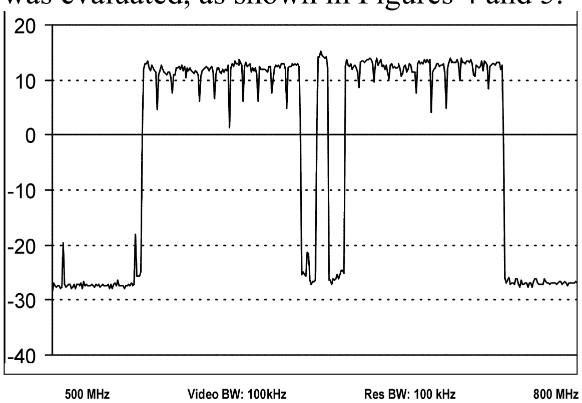

Figure 4. BER measurement of QAM channel + 22 x 64 QAM

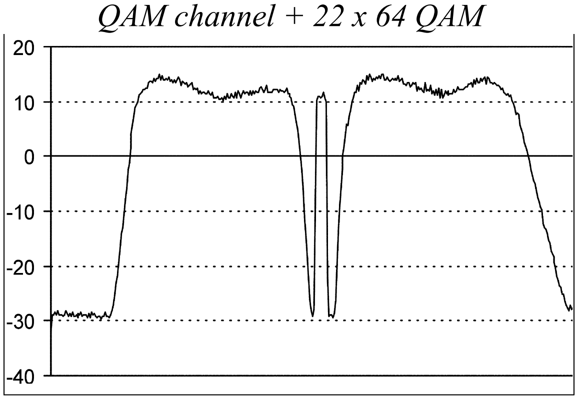

Figure 5. BER measurement of QAM channel + AWGN

Performing this test on a forward path DFB optical transmitter showed identical BER results when using either power-loading scheme; therefore, AWGN is a valid signal source.

VALIDATING THE BNN TECHNIQUE WITH SAMPLE TESTS

To validate the appropriateness of the BNN technique, we used it for nine sample tests measuring forward path performance. These tests successfully used the BNN technique to characterize BER of a forward path transmitter. This evaluation was chosen because of the increased scrutiny of laser clipping and its impact on digital transmission.

Setup for Sample Tests

As shown in Figure 6, the test setup used a +12 dBm transmitter to feed a 15 dB link composed of an optical attenuator plus 10 km of single mode optical fiber. This link was then evaluated under a variety of RF input conditions.

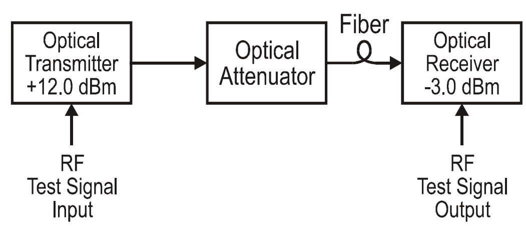

*Figure 6.
Setup used for tests to validate BER technique*

Analog Test to Baseline the Transmitter

The transmitter was tested with the 78-channel CW load from 50-550 MHz and the digital load carried at -6 dB.

CTB, CSO and C/N were measured to determine the relationship between the transmitter under test and clipping or the point at which the distortion levels change in a non-linear fashion. Results of this test are shown in Figure7.

Observations: Clipping of the transmitter takes place at an analog carrier drive level of +18 dBmV. This is indicated by the non-linear increase in both CTB and CSO for a given dB increase in drive level.

BER Test with Digital at –6 dB

The test transmitter was evaluated for BER for both 64 and 256 QAM. Transmitter input level of the digital signal remained at –6 dB relative to the analog carriers. Measured BER was recorded as a function of RF drive level. Results are shown in Figure 8.

Observations: Analog techniques indicate that clipping occurs at a drive level of +18 dBmV; however, minimum BER degradation does takes place at +15 dBmV for 256 QAM and at +17 dBmV for 64 QAM.

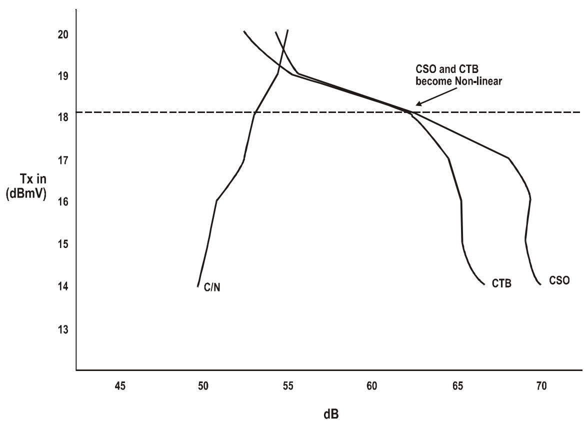

Figure 7.
Transmitter input level vs CTB, CSO, C/N

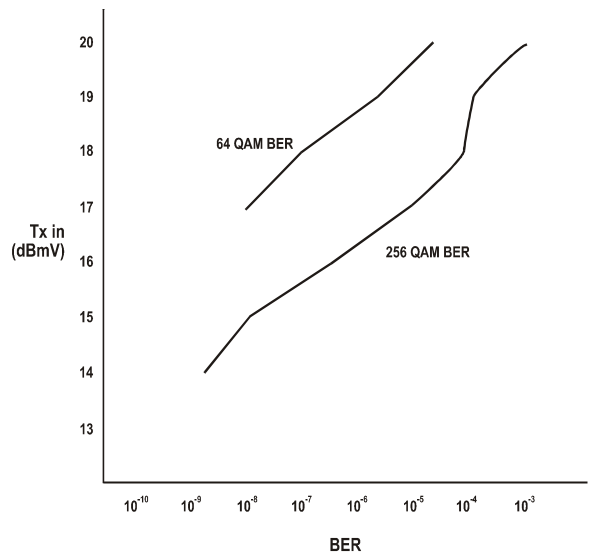

Figure 8.
Transmitter input level vs BER
with digital at –6 dB

BER Test with Digital at – 8 dB

In this test, transmitter BER was evaluated for both 64 and 256 QAM. Transmitter input level of the digital signal was –8 dB relative to the analog carriers. Measured BER was recorded as a function of RF drive level. Results are shown in Figure 9.

Observations: Results are very similar to when digital operated at -6 dB down, with negligible variation in 64 and 256 QAM.

BER Test with Digital at –10 dB

In this test transmitter BER was evaluated for both 64 and 256 QAM. Transmitter input level of the digital signal was –10 dB relative to the analog carriers. Measured BER was recorded as a function of RF drive level. Results are shown in Figure 10.

Observation: Results are again similar to when the digital is operated at –6 and –8 dB down.

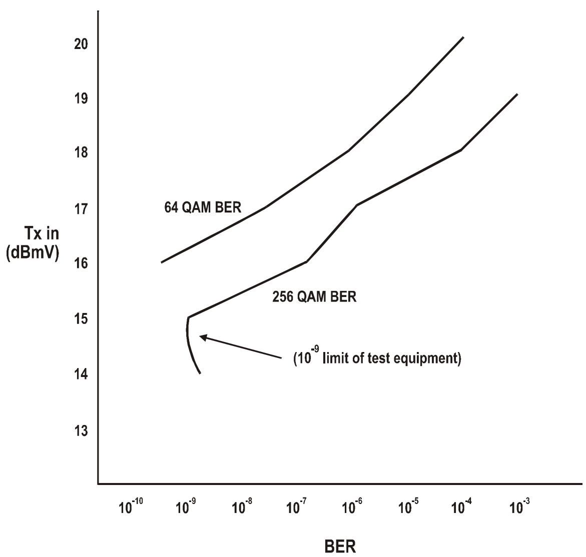

Figure 9.
Transmitter input level vs BER
with digital at – 8 dB

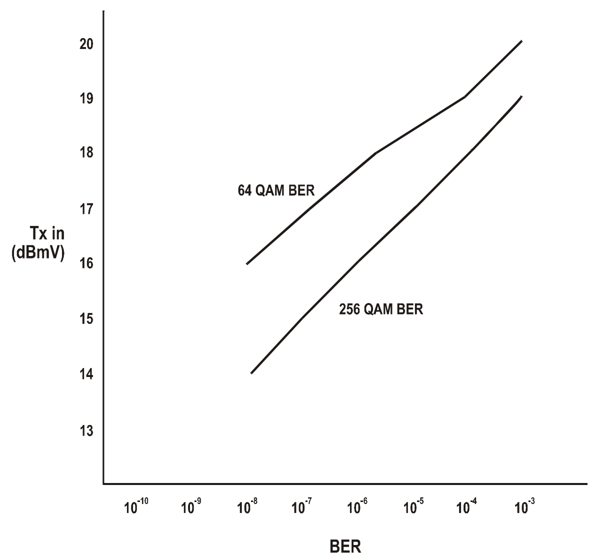

Figure 10.
Transmitter input level vs BER
with digital at –10 dB

Analog Test to Baseline the Transmitter with Expanded Digital at – 6 dB

Input signal was modified to 69 channels of analog (50-500 MHz) and digital loading from 500 to 750 MHz at –6 dB relative to the analog carriers. The transmitter was baselined. Results are shown in Figure 11.

Observation: The clipping point with 69 analog channels remains within a dB of the clipping point measured when loaded with 78 analog channels.

BER Test with Expanded Digital at –6 dB

In this test, transmitter BER was evaluated for both 64 and 256 QAM. Transmitter input level of the digital signal remained at –6 dB relative to the analog carriers. Measured BER is recorded as a function of RF drive level. Results are shown in Figure 12.

Observation: The 64 and 256 QAM performance with 50-500 MHz analog and 500-750 MHz digital was similar to the performance with 50-550 analog and 550-750 digital.

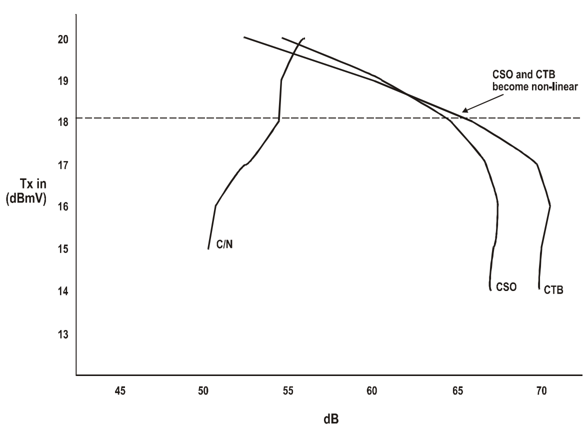

Figure 11.
Transmitter input level vs CTB, CSO, C/N
with analog 50–500 MHz
and digital 500–750 MHz

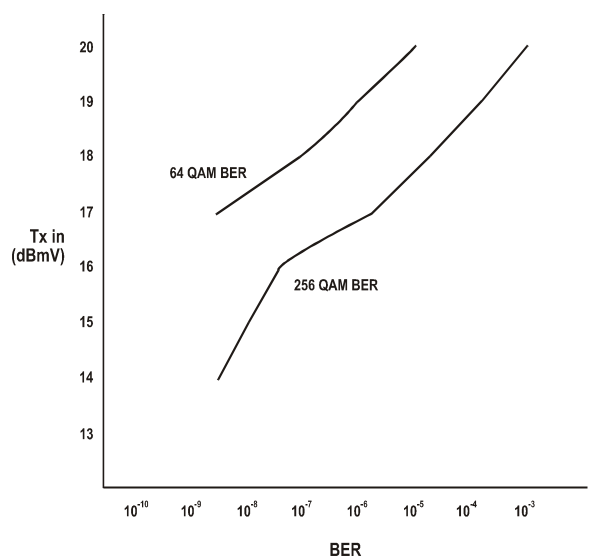

Figure 12.
Transmitter input level vs BER
with analog 50–500 MHz
and digital 500–750 MHz at – 6 dB

BER Test with Headend Analog
and Digital at – 6 dB

This test used a live, high-quality, direct cable television headend feed to provide analog loading from 50-550 MHz. The digital load was inserted at –6 dB relative to the analog carriers. The system was tested again for 64 and 256 QAM BER. Results are shown in Figure 13.

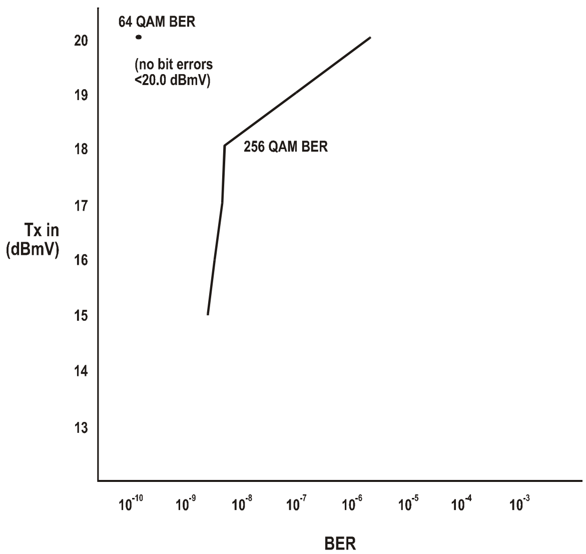

Figure 13.
Transmitter input level vs BER with headend analog and digital at – 6 dB

BER Test with Headend Analog
and Digital at – 8 dB

This test used local cable television headend as the analog channel feed for 50-550 MHz and digital load inserted at –8 dB relative to the analog carriers. The system was tested again for 64 and 256 QAM BER. Results are shown in Figure 14.

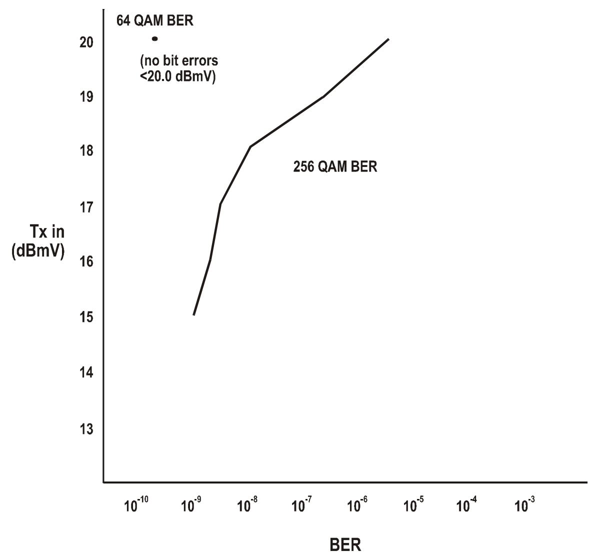

Figure 14.
Transmitter input level vs BER with headend analog and digital at – 8 dB

BER Test with Headend Analog
and Digital at – 10 dB

This test used local cable television headend as the analog channel feed for 50-550 MHz and a digital load inserted at –10 dB. The system was tested again for 64 and 256 QAM BER. Results are shown in Figure 15.

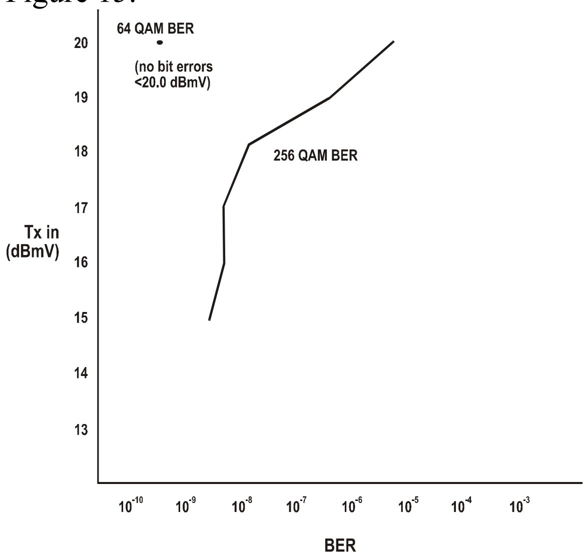

Figure 15.
Transmitter input level vs BER
with headend analog and digital at – 8 dB

Observation: All three tests using headend signals as the analog feed show a significant improvement in BER for both 64 QAM and 256 QAM, as compared to an analog feed of CW carriers of the same peak level.

CONCLUSIONS

The actual testing results show the BNN technique to be a valid means for measuring the performance of the forward path in networks carrying a combination of analog and digital signals.

When applied to the forward path, the BNN test technique clearly yields results that very accurately document bit error performance. This technique relies on readily available resources and inexpensive filters for band shaping to easily create and duplicate a variety of test signal loading conditions.

Manufacturers and system operators can use this technique for system qualification and optimization with confidence in the results derived.

Initial testing indicates that the optical DFB-based transmitter is clipping at drive levels approaching +18 dBmV with the digital load operating at –6 dB relative to analog. Manufacturer specified drive levels for this particular device are at +15 dBmV

It is interesting to note that measurable 256 QAM degradation of BER does appear to take place several dB before measured CTB and CSO clipping (and to a lesser degree 64 QAM).

However, even at the drive level of +17 dBmV, for which the CTB and CSO were observed to be linear, both 64 and 256 QAM are still not at bit error rates of $E10^{-4}$ which is considered a worst case operating level for digital set top boxes and cable modems.

Removing the top eight NTSC channels and increasing the digital tier by another 50 MHz was demonstrated to have minimal effect on 64 and 256 QAM BER, as the actual clip point remains essentially the same.

Most interesting is the final set of tests where the actual CW analog carriers are replaced by high-quality live analog video carriers originated at the headend. A significant decrease in optical modulation index was noted, and as a result associated BER for 256 QAM modulation was reduced.

This test should give confidence to network operators that negligible or no clipping of the laser occurs when a full tier of digital signals is added to the forward path. (Provided, of course, that the transmitter is operated per typical manufacturer recommended drive levels).