# Hybrid AM/16-VSB Lightwave Transmission System in Presence of Optical Reflections


Shlomo Ovadia, Chinlon Lin, and William T. Anderson

Bellcore

Steve Heinz and Ron Lee
Zenith Electronics Corporation



## Abstract

The performance characteristics of the 16-VSB cable modem was measured in a hybrid AM/16-VSB lightwave video transmission system using three different laser transmitters with the 16-VSB signal 6 dB below the AM carriers. The hybrid video lightwave system-based externally-modulated laser transmitters had ≤ 1.5 dB reflection-indepedent penalty due to impulse noise with a operating margin ≥ 9.1 dB for the 16-VSB signal even at high reflection levels (≥ -30 dB). In contrast, the hybrid video lightwave system-based directly-modulated DFB laser transmitter showed a 2.4 dB penalty due to impulse noise with a 9.6 dB operating margin at low reflections with no operating margin if the reflections are above -35 dB. However, for good performance of the AM channels, reflections less than -50 dB are needed.


## 1. INTRODUCTION

Hybrid multichannel AM/QAM (quadrature-amplitude modulation) or AM/VSB (vestigial sideband) subcarrier-multiplexed video lightwave transmission systems are attractive for video distribution and trunking.[1-3] Such systems can deliver existing broadcast multichannel analog video services while allowing the delivery of new compressed digital video and data services in the 500 MHz - 1GHz band. Recently, the 8/16-VSB modems were selected by the Grand Alliance as a transmission standard for terrestrial and cable broadcast of high-definition television (HDTV).[4] Currently, there is a technical discussion about the advantages and disadvantages of using 8/16-VSB versus 64/256-QAM (quadrature amplitude modulation) cable modem technology for digital video transmission over fiber/coax networks.[5] A digital cable modem standard would accelerate large scale deployment of digital set-top boxes and reduce future network cost.

In this paper, we report the first study of 16-VSB cable modem performance in a hybrid multichannel AM/16-VSB video lightwave transmission system. Impulse-induced clipping noise and optical reflections are known to cause degradations in hybrid AM/QAM video lightwave systems.[6] In a typical transmission link, there are many potential sources of optical reflections such as fiber optic splices, connectors, and couplers. Three different types of laser transmitters are compared: a directly-modulated (DM) 1310 nm DFB laser transmitter, an externally-modulated (EM) 1319 nm YAG laser transmitter, and an EM 1554 nm DFB laser transmitter. The performance of these laser transmitters are compared using (a) CW video carriers from a Matrix generator, and (b) a 50%/50% mixture of AM CATV video signals and CW video carriers from a Matrix generator.

## 2. 16-VSB CABLE MODEM DESIGN

The Zenith's 16-VSB cable modem operates at 43 Mb/s with SNR threshold values of 28 dB (in a 6 MHz bandwidth). The 16-VSB signal spectrum is flat throughout the band except at the band edges where it is roll-off with a 11.5% root-Nyquist filter, and a pilot carrier approximately 310 kHz above the lower channel edge.[4] Although the pilot carrier uses only 0.3 dB of the 16-VSB signal, it is essential for synchronous detection of the RF data signal and the symbol clock recovery. The 16-VSB modem receiver uses a symbol-spaced equalizer running at 10.7 MHz with a 63 tap real FIR filter. Forward error correction (FEC) code is employed to protect the transmitted data from burst of errors that might occur. The 16-VSB cable modem uses a T=10 (207,187) Reed-Solomon (R-S) forward-error correcting code (FEC). In our testing, T=10 (170,150) R-S FEC was used because of hardware availability. This modem is the same as the one tested by the Advisory Committee on Advance Television for HDTV.[4]

## 3. EXPERIMENTAL SET-UP

The experimental set up and the frequency allocation plan is shown in Fig. 1.

A 43 Mb/s 16-VSB signal centered at 537 MHz (channel 76) was subcarrier-multiplexed with 78 AM-VSB CATV signals (55.25 MHz to 547.25 MHz) and was used to modulate each of the laser transmitters. The RF power of the transmitted 16-VSB signal was 6 dB below that of the AM carriers. After transmission through two variable backreflectors (VBRs) and 4.4 km of standard single-mode fiber, the 16-VSB signal was detected at -1.8 dBm optical power, demodulated, and then fed to an error-detector. Better than 50 dB optical isolation was measured between the VBRs and each of the laser transmitters. A double-loop fiber polarization controller was used to maximize phase-to-intensity noise conversion (worst-case measurement). FC/APC SMF connectors, which typically have a return loss of less than -60 dB, were used in all measurements to minimize additional interferometric noise. In order to evaluate the impact of impairments on the 16-VSB modem performance with the R-S FEC, a white Gaussian noise (WGN) was added to the received 16-VSB signal to determine the required signal-to-noise ratio (SNR) threshold to achieve a bit-error-rate (BER) $\leq 3 \cdot 10^{-6}$. This BER has been defined as the threshold of visibility for the HDTV.[4]

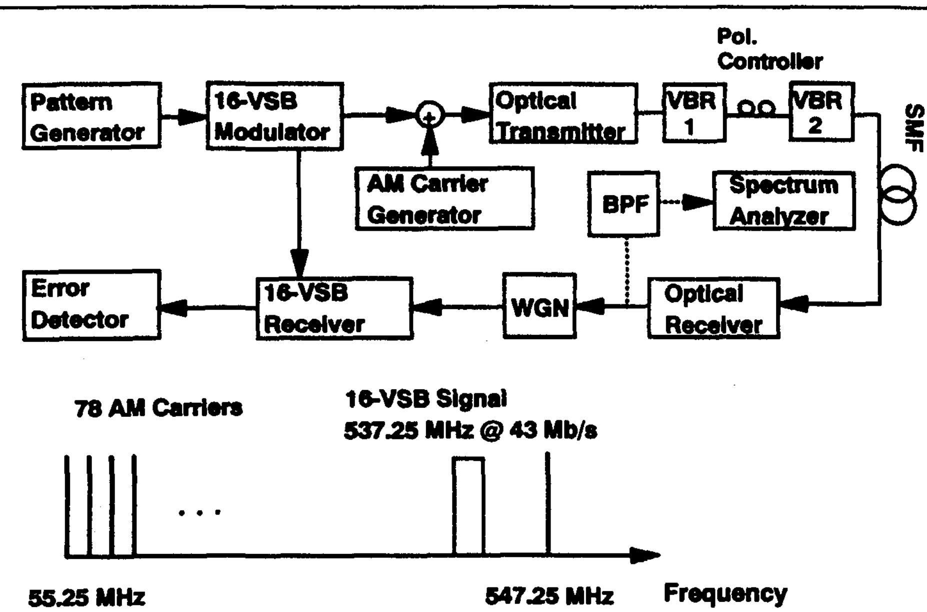


Fig. 1. The experimental setup and the frequency allocation spectrum.

## 4. RESULTS AND DISCUSSIONS

### 4.1. Directly-Modulated DFB laser Transmitters

The DM-DFB laser transmitter is the most widely used (> 80%) laser transmitter to transport the AM/digital video signals from the headend to the subscriber. The DM-DFB laser transmitter, which operated at wavelength of 1317 nm, had an optical power of 7 mW and low relative-intensity-noise (RIN ≅-159 dBc/Hz). Fig. 2 shows the

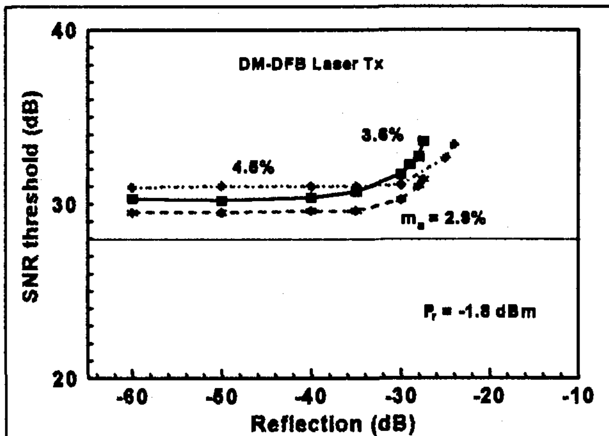


Fig. 2. The SNR threshold as a function of the reflection level for a DM-DFB laser transmitter with AM modulation indices of 2.9%, 3.6%, and 4.5% per channel using CW carriers from a Matrix generator.

SNR threshold as a function of the reflection level for the DM-DFB laser transmitter-based video lightwave system with AM modulation indices of 2.9%, 3.6%, and 4.5% per channel using CW carriers from a Matrix generator. The measured analog CNR was 48 dB at an AM modulation index of 3.6% per channel with the CSO and CTB distortions less than -65 dBc. With no WGN added, the received 16-VSB SNR was 40 dB. At a low reflection level (< -50 dB), the 16-VSB SNR threshold is increased by 2.4 dB from the reference SNR threshold level of 28 dB (the back to back case) for an AM modulation index of 3.6% per channel. Thus, one has a 9.6 dB operating margin to threshold at low reflection level, which is the difference between the received 16-VSB SNR and the SNR threshold. The 16-VSB SNR threshold is rapidly increased at reflection levels greater than -40 dB. At reflection levels greater than -27.5 dB, the R-S FEC was overwhelmed and the measured BER was greater than $3 \cdot 10^{-6}$ even with no added WGN. This means that the 16-VSB SNR threshold is higher than the received 16-VSB SNR, and thus the 16-VSB modem would not operate with the DM-DFB laser transmitter in this case. On the other hand, if one keeps low reflection levels and increase the AM modulation index to 4.5% per channel, the 16-VSB SNR operating margin is reduced to 8.8 dB, representing occurrence of additional errors due to increased clipping-induced impulse noise.[3]

Fig. 3 shows the 16-VSB SNR threshold as

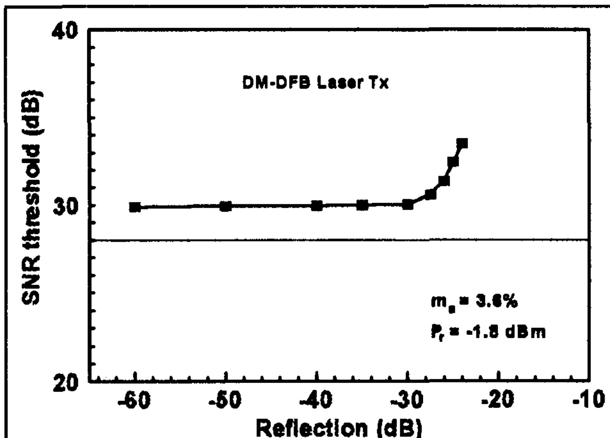


Fig. 3. The 16-VSB SNR threshold as a function of the reflection level with the same AM modulation index as in Fig. 2, but using a 50%/50% mixture of AM CATV video signals and CW carriers.

a function of the reflection level with the same 3.6% AM modulation index as in Fig. 2, but using a 50%/50% mixture of AM CATV video signals and CW carriers from a Matrix generator. Notice that the 16-VSB SNR threshold is reduced by 0.5 dB compared with the results in Fig. 3 at low reflection levels, and no 16-VSB operating margin for optical reflections greater than -24 dB compared to -27.5 dB (Fig. 2). Changing the AM modulation index per channel for the DFB laser transmitter-based lightwave system at a reflection level of -60 dB causes no significant degradation in the observed 16-VSB SNR threshold as shown in Fig. 4. In contrast, the SNR threshold is rapidly degraded when only CW carriers from a Matrix generator are used (Fig.4). Thus, when using a 50%/50% mixture of

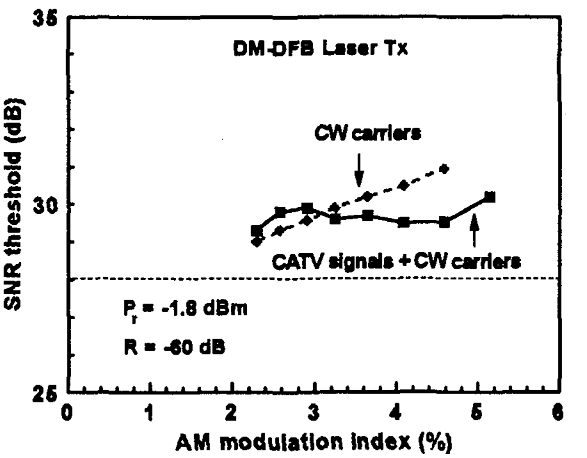


Fig.4. The 16-VSB SNR threshold as a function of the AM modulation index per channel for a DM-DFB laser transmitter using a 50%/50% mixture of AM CATV video signals and CW carriers.

AM CATV video signals and CW video carriers from a Matrix generator, the reflection tolerance is increased by up to 10 dB compared with CW video carriers. In practice, reflection levels less than -35 dB are required for robust transmission of only the 16-VSB signals. However, the AM CATV signals require reflection levels less than -50 dB in such a system.[6]

## 4.2 Externally-Modulated Laser Transmitters

The EM-YAG laser transmitter (λ=1319 nm) has two output ports with 20 mW at each port, and a very low RIN (RIN≈-170 dB/Hz).[6] The EM-DFB laser transmitter, which is an attractive alternative to the directly-modulated (DM) DFB laser

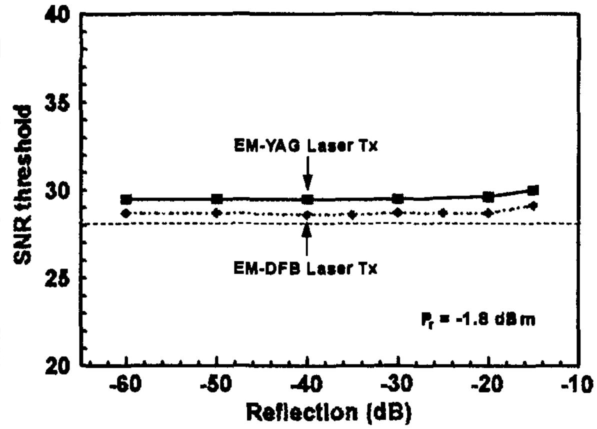


Fig. 5. 16-VSB SNR threshold as a function of the reflection level for the EM-YAG laser transmitter and the EM-DFB laser transmitter.

transmitter, operated at 1554 nm and incorporated an Er-doped optical fiber amplifier with a 20 mW output optical power and a low RIN (RIN ≈ -162 dB/Hz).[7]
Figure 5 shows the 16-VSB SNR threshold as a function of the reflection level for the EM-YAG laser transmitter (AM modulation index of 3.1%) and the EM-DFB laser transmitter (AM modulation index of 3.2%). The analog CNR was 48 dB with the CSO and CTB distortions less than -65 dBc. The received 16-VSB SNR was 40 dB. The 16-VSB SNR threshold had a reflection-indepedent 1.5 dB penalty due to impulse noise and a 10.5 dB operating margin using the EM-YAG laser transmitter. Similarly, the 16-VSB SNR threshold had a reflection-indepedent 0.8 dB penalty due to impulse noise with a 11.2 dB operating margin at low optical reflections using the EM-DFB laser transmitter. However, at a high reflection level (> -20 dB), the operating margin is reduced by about 2 dB for this hybrid system.

The optical transport results can be explained as follows:[7] Interferometric intensity noise (IIN) is generated from two sources, namely, multiple discrete optical reflections between the two VBRs, and from the fiber's Rayleigh backscattering interacting with those reflections. The EM-YAG laser transmitter and the EM-DFB laser transmitter have a narrow linewidth (≤ 1 MHz) and a very low IIN ($RIN_t$ < -160 dB/Hz at R = -15 dB) so the observed 16-VSB SNR threshold is reflection-independent. In contrast, the DM-DFB laser transmitter has a relatively broad modulated linewidth (> 1 GHz), and therefore has significantly higher IIN ($RIN_t$ = -130 dB at R = -15 dB). Thus, large amount of optical reflections (> -40 dB) degrade the digital channel further.[5]

## 5. SUMMARY

In conclusion, the performance characteristics of the 16-VSB cable modem was measured in a hybrid AM/16-VSB lightwave video transmission system using three different laser transmitters with the 16-VSB signal 6 dB below the AM carriers. The hybrid video lightwave transmission system-based EM-YAG laser transmitter or EM-DFB laser transmitter had ≤ 1.5 dB penalty due to impulse noise with a reflection-indepedent operating margin ≥ 9.1 dB for the 16-VSB signal even at high reflection levels (≥ -20 dB). In contrast, the hybrid video lightwave system-based DM-DFB laser transmitter showed a 2.4 dB penalty due to impulse noise with a 9.6 dB operating margin at low reflection levels for the 16-VSB signal. From the measurement using a 50%/50% mixture of AM CATV video signals and CW video carriers from a Matrix generator, it is observed that the reflection tolerance is increased by up to 10 dB when actual modulated video signals are transmitted instead of CW carriers. In practice, reflection levels less than -35 dB are required for robust transmission of only the 16-VSB signals. However, the AM CATV signals in such a system require reflection levels less than -50 dB.

## 6. REFERENCES:


1. K. Maeda, H. Nakata, and K. Fujito, "Analysis of BER of 16QAM Signal in AM/16QAM Hybrid Optical Transmission System", Electronics Letters 29, 640 (1993).

2. Q. Shi, "Performance Limits on M-QAM Transmission in Hybrid Multichannel AM/QAM Multichannel Fiber Optic Systems", IEEE Photonics Technology Letters 5, 1452 (1993).

3. Shlomo Ovadia, L. Eskildsen, Chinlon Lin, and W. T. Anderson, "Bit-error-rate Impairment in Hybrid Multichannel AM/16-QAM Video Lightwave Transmission System", IEEE Photonics Technology Letters 6, 869 (1994).

4. Ron Lee, "High Data Rate VSB Modem for Cable Applications Including HDTV: Description and Performance", NCTA Technical Papers, 274 (1994).

5. H. Samueli, L. Montreuil, W. H. Paik, and R. Lee, "QAM vs. VSB, Which is the Best Modulation", Communications Engineering and Design 12, 47 (1994).

6. Shlomo Ovadia, L. Eskildsen, Chinlon Lin, and W. T. Anderson, "Multiple Optical Reflections in Hybrid AM/16-QAM Multichannel Video Lightwave Transmission System", IEEE Photonics Technology Letters 6, 1261 (1994).

7. Shlomo Ovadia, Chinlon Lin, and W. T. Anderson, "Hybrid AM/QAM Video Lightwave Systems: Performance of Different Laser Transmitters in the Presence of Optical Reflections", ICC, Seattle, Washington, June 18-22, 1995.