Characterization of Return Path Optical Transmitters for Enhanced Digitally Modulated Carrier Transmission Performance

John J. Kenny, Ph.D.
Principal Engineer

Antec Technology Center
Atlanta, Georgia

Abstract

Noise loading is becoming an accepted way to characterize the noise and intermodulation performance of return path active components. This paper focuses on understanding how over-driven optical transmitters degrade digitally modulated carriers. Analysis and experimental findings have uncovered several factors which influence the performance reverse path optical transmitters used for transmitting digitally modulated carriers.

BACKGROUND

Noise loading is becoming accepted as way to characterize the noise and intermodulation performance of return path active components[1]. The basis for this stems from the primarily digital transmission use of the return path and the fact that the power spectral density of digital signals resembles the power spectral density of a band of noise. In a situation where the upstream payload consists of many, similar level, digitally modulated carriers, the probability distribution function (pdf) for the amplitude of the composite signal approaches the gaussian distribution associated with thermal noise.

Noise loading, as applied to return path active components, provides guidance to the system operator in the choice of appropriate nominal operating signal levels within the dynamic range of each component. Multiple digitally modulated carriers may then be carried and allow significant tolerance in their levels. Selection of the nominal level may also take into account, and provide headroom for, unaccounted for signals such as high level ingress.

There is a long history of noise loading of frequency division multiplexed telephony coaxial cable and microwave transmission systems. Analysis of the resulting noise and distortion characteristics derived from noise loading those systems produced the thermal noise, second order intermodulation distortion and third order intermodulation behaviors as a function of RF drive level[2].

Attempting to analyze return path amplifier and laser distortion characteristics by those methods immediately shows that when the intermodulation distortion exceeds the thermal noise by just a few dB, the device is severely distorted and the intermodulation noise can not be characterized by second and/or third order intermodulation.

QPSK and QAM signals are characterized by their signal states in the "phase plane", sometimes referred to as a constellation diagram. Noise loading is a scalar measurement. It is related to how much a signaling state of a digital signal is spread, but it will not indicate the direction of that spreading and how close that spreading comes to the decision thresholds in the demodulator. This was the motivation for experimentally investigating the distortion of a signaling state when the laser is over driven.

DISTORTION MECHANISMS

There are several basic impairments in QPSK and QAM transmission that may be viewed with a phase plane or constellation diagram. The usual situation includes some or all of the following properties in the phase plane.

If a laser only experiences tone-like intermodulation products when noise loaded or stressed with high level CW interferences, the signal states would be smeared symmetrically about their undistorted locations.

If there is only compression when the laser is overloaded, the signal states will be moved radially towards the center of the constellation diagram.

The transmitted carrier can undergo a phase shift and cause a rotation of the signal state. For instance, this could occur if an over driven laser experienced excessive chirp as it clipped the RF. Chirp in conjunction with fiber dispersion can result in a carrier phase rotation.

In a laser transmitter the laser diode DC current, I_{DC}, is set by a power control loop and the AC modulating current is superimposed from an RF path. These functions are shown in the block diagram, Fig. 1.

Normal level RF carriers will have peak currents less than I_{DC} - I_{th} (see the L-I characteristic in Fig. 2) so the laser diode current is in a range such that the laser always emits light. The output light is proportional to the laser diode current above threshold, i.e. P is proportional to I - I_{th}. The ratio of the peak of an RF carrier to I_{DC} - I_{th} is called the optical modulation index (omi).

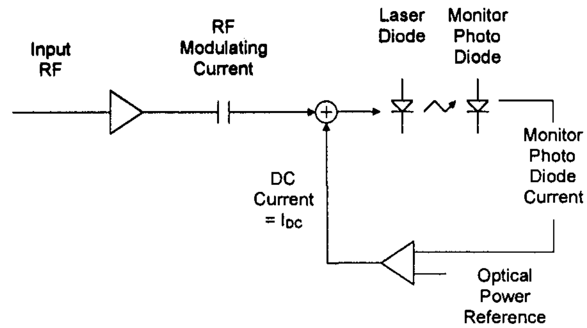

Figure 1 Return Path Optical Transmitter Block Diagram

When there is a modulating current comprised of a wanted digitally modulated carrier and a very high level out of channel signal (omi much greater than 100%), two distinct effects occur.

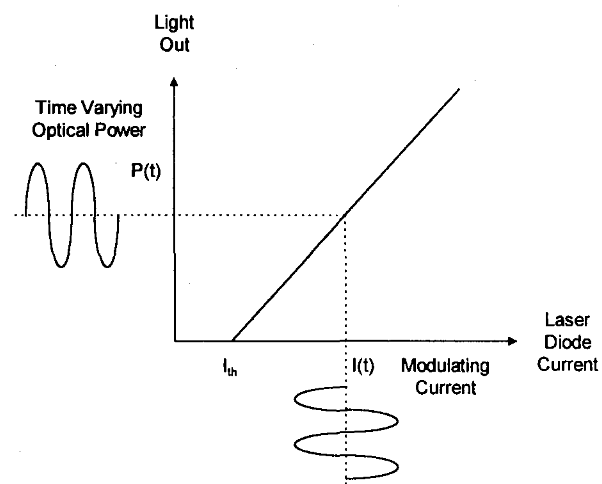

Figure 2 Laser L-I Characteristic

1. Intermodulation products are generated and some may fall into the channel producing interference.
2. The laser is turned off for part of the negative excursion of the high level interference, resulting in an amplitude compression of the wanted signal.

Generally both occur, but it is worthwhile to consider them individually.

At first one might say that in the limit of extremely high omi, the laser would be turned off for half of the time, resulting in a 6 dB RF level drop of the wanted signal. This is usually not the case. The power control loop maintains constant average output optical power. This results in a further reduction of the laser's duty cycle, as shown in Fig. 3.

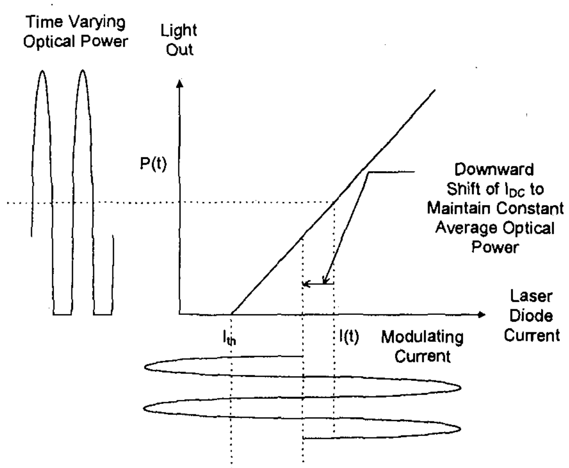

Figure 3 Laser Light Output When the OMI is Greater than 100%

EXPERIMENTAL WORK

An apparatus arrangement as shown in Fig. 4 was assembled. It permitted the flexibility to do both noise load testing and signal constellation distortion measurements.

Noise load testing

Three lasers were characterized for Carrier to Noise plus Intermodulation Noise [C/(N+IMN)] vs. RF drive level in a manner similar to that used in reference 1. Here, however, a 42 MHz band of noise was notched by using a T7 channel deletion filter. A CW carrier around 9 MHz was placed within the notch as shown in Fig 5. The level of that carrier was set to equal the noise power missing from the notch. The motivations for inserting the carrier were to provide a reference level and to estimate the potential for digital signal degradation. The noise generator and spectrum analyzer options of Fig. 4 were used.

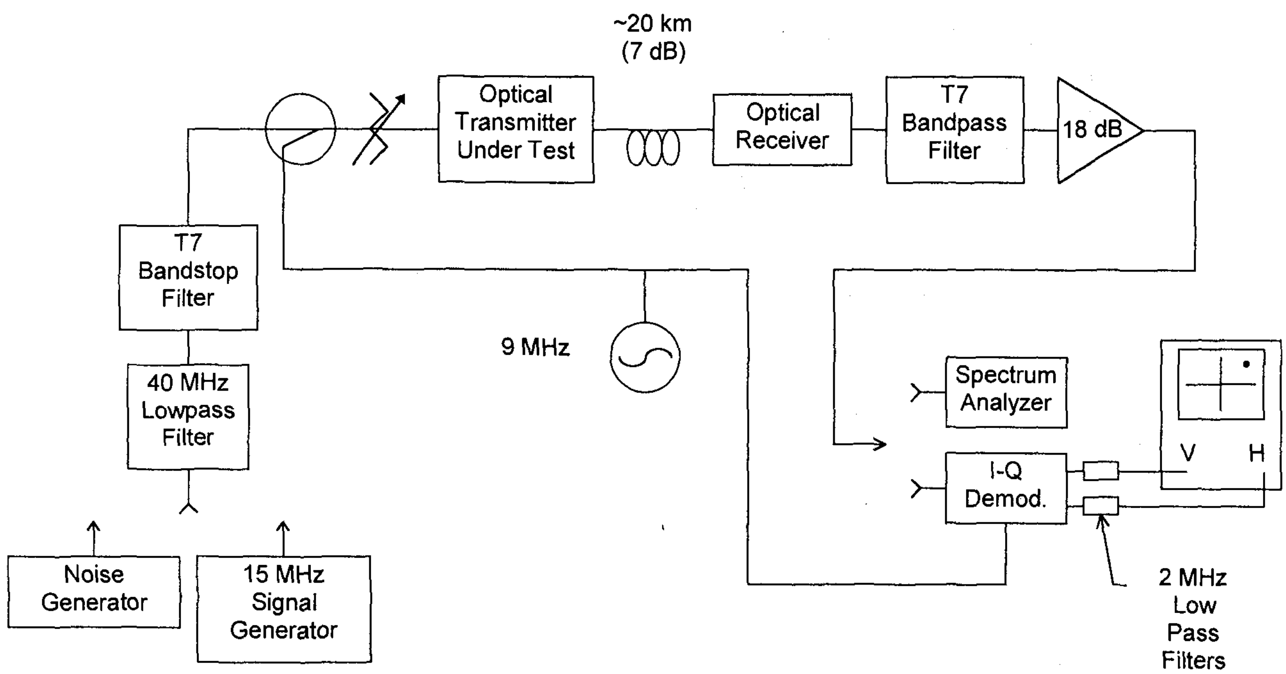

Figure 4 Experimental Test Set Up

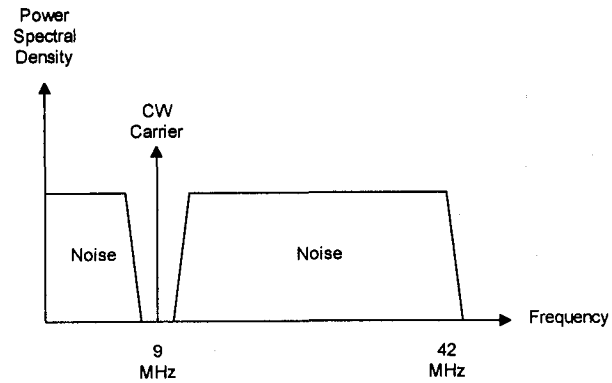

Figure 5 Notched Noise Plus CW Carrier

The three lasers (all isolated and uncooled) characterized were:

Laser	Type	Output Power
1	DFB	+4 dBm
2	DFB	+1 dBm
3	FP	0 dBm

The test results follow in Figures 6, 7 and 8. To the left of the peak C/(N+IMN), C/(N+IMN) is dominated by relative intensity noise, shot noise, optical receiver front end noise and double rayleigh backscatter noise. To the right of the peak, C/(N+IMN) is dominated by noise-like intermodulation distortion. To the left of the peak, lasers 1 and 2, both DFBs, improve C/N at a rate of about 4 dB per 3 dB increase in RF drive. This occurs because, as the RF drive to the laser is increased, not only is the received RF increased relative to various noise sources, but also the laser wavelength chirps more and the double rayleigh backscatter noise is reduced. Laser 3, a Fabry-Perot type, improves at a rate of 1 dB per 1 dB increase in RF drive.

The behavior of lasers 1 and 3 for RF drive levels to the right of the C/(N+IMN) peak show rapid decrease of C/(N+IMN) with increasing RF drive and are generally similar to those reported in reference 1. Laser 2, although it exhibits a smaller dynamic range than laser 1, degrades more gradually as the RF drive increases.

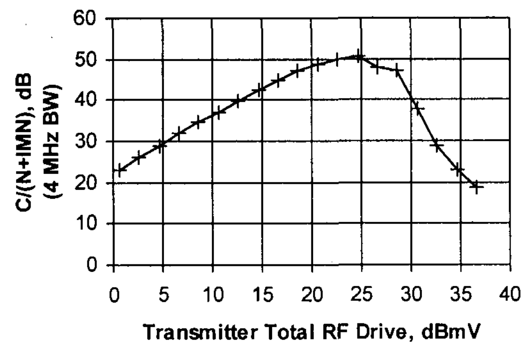

Figure 6 Laser 1
+4 dBm, Isolated, Uncooled DFB

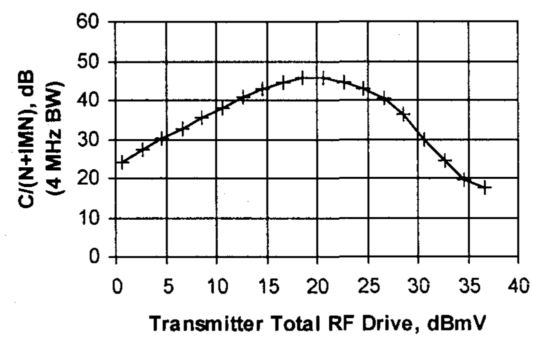

Figure 7 Laser 2
+1 dBm, Isolated, Uncooled DFB

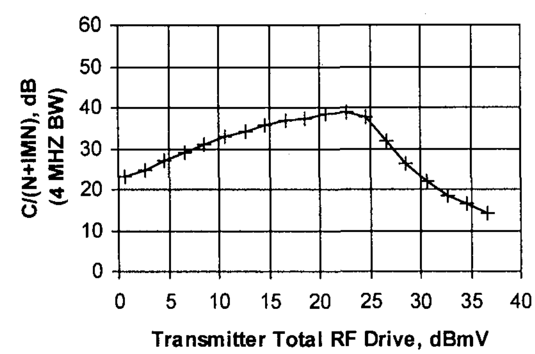

Figure 8 Laser 3
0 dBm, Isolated, Uncooled FP

Signal constellation distortion

The other configuration of Fig. 4 uses an I-Q demodulator to view the signal constellation in a manner similar to the CW Tester™ reported by Prodan[3]. It displays the location of one signaling state on an oscilloscope. It simulates the continuous transmission of the upper right hand quadrant state of QPSK or the upper right hand quadrant corner state of a QAM signal.

The frequency of the wanted carrier to be demodulated is 9 MHz. In addition there is either the notched noise as shown in Fig. 5 or a high level ~15 MHz, 100% modulated carrier, 15 dB higher in level than the wanted carrier. The exact frequency was intentionally chosen so that there were no noticeable beat products within the ±2 MHz bandwidth of the demodulator.

The signal constellation diagram is shown in Fig. 9. The signaling state is shown in the upper right quadrant. If it is being demodulated as a QPSK signal, then the decision thresholds are ideally coincident with the I and Q axes. If it is being demodulated as a 16 QAM signal, the decision thresholds are much closer. The digital signal will be correctly demodulated if the effects of noise, interference and distortion do not displace the signal state beyond the thresholds.

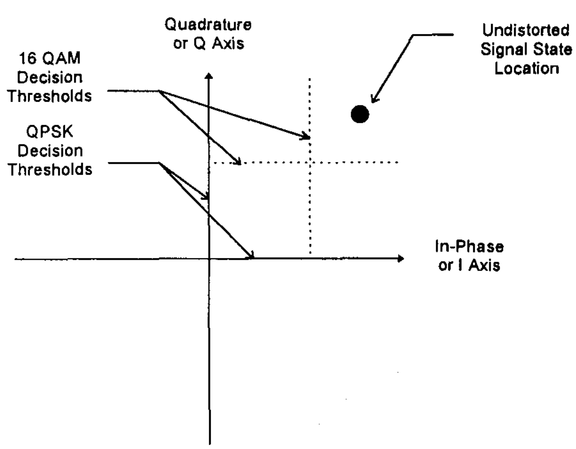

Figure 9 Signal Constellation Representation of a Signaling State Showing Decision Thresholds

When a laser is driven at low RF levels, the signaling state will be somewhat blurred, symmetrically about its intended location. The subject of interest here is what happens to the signal state when the laser is driven at very high levels. Lasers 1, 2 and 3 were driven at the level of the highest data point of Figs. 6, 7 and 8. The C/(N+IMN) was less than 20 dB in each case and dominated by intermodulation noise. An example oscilloscope photograph (Fig. 10) shows significant blurring of the signaling state. All three lasers exhibit an elliptically shaped distortion of the state with the major axis of the ellipse oriented along the diagonal line. This shows that the dominant distortions are noise-like intermodulation products and compression. No phase rotation is noticeable. The elongation of the signal state in the direction of the origin is a very favorable situation for QPSK.

The second test signal was comprised of a 9 MHz wanted carrier and a ~15 MHz, 100% modulated carrier, 15 dB higher in level. The 9 MHz carrier was set to the normal input level for these transmitters (+18 dBmV). For all three lasers, the effect of this out of channel signal is an almost identical, radial, compression of the wanted signal. An example measurement is shown in Fig. 11. The peak compression occurs at the peak of the modulated signal (6 dB above its carrier). When the level of the modulated signal is at its minimum, the signaling state is in its normal location. Further increases in the level of the CW carrier can reduce the wanted signal essentially to zero, as shown in Fig. 12.

LESSONS LEARNED

Several conclusions can be drawn from this work:

1. Signal constellation impairments during noise loading have shown no peculiar effects.

Both product generation and compressive effects are taken into account.

2. Type testing a return path optical transmitter using a constellation analyzer provides valuable insight into its capability for carrying digitally modulated carriers.

3. Smaller wavelength chirping of DFB lasers at lower RF drive levels increases the slope of the C/(N+IMD) characteristic curve.

4. Some laser types have “softer” degradation at high RF drives.

5. Lasers are extremely tolerant of QPSK transmission because laser distortions and QPSK distortion tolerance complement each other.

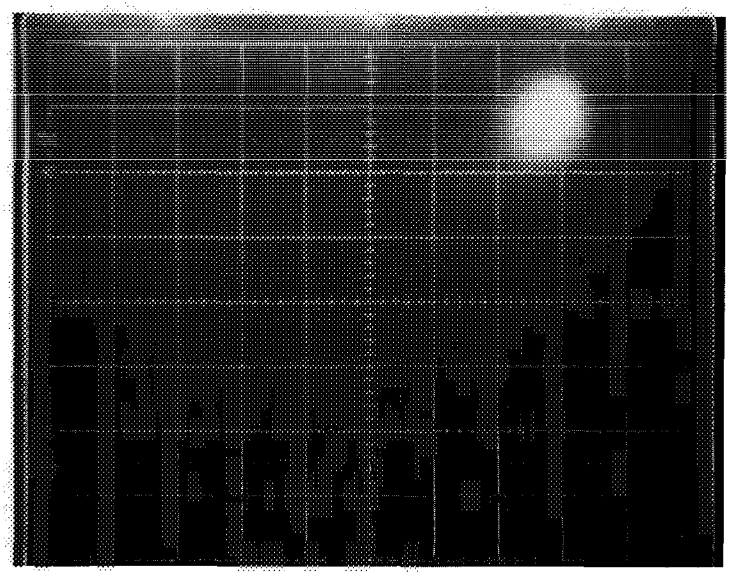

Figure 10 Signal State Spreading During Noise Load Testing at High Levels

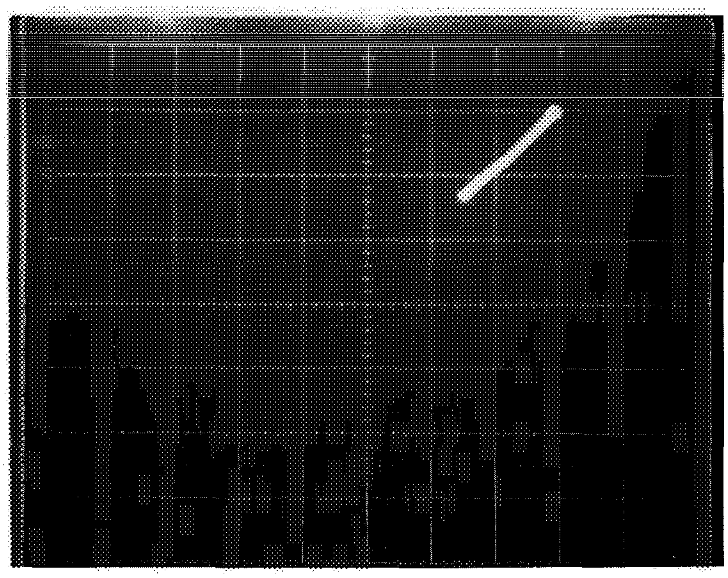

Figure 11 Signal State Compression in the Presence of a High Level 100% AM Modulated Carrier

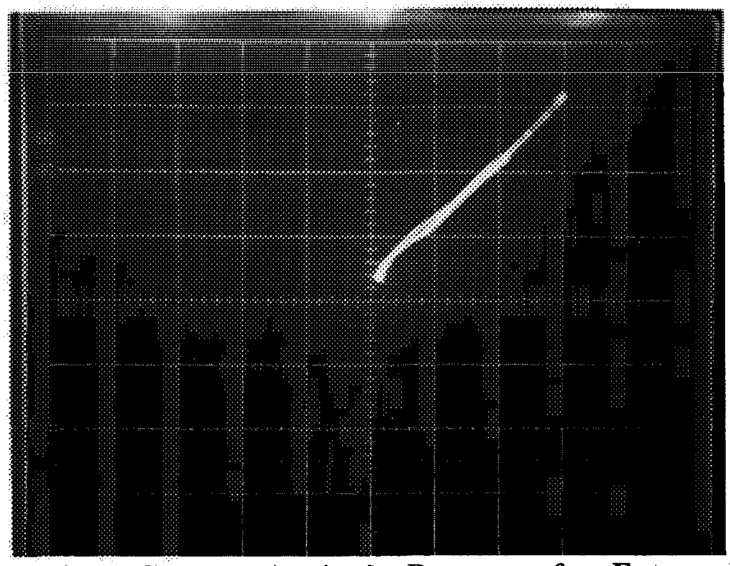

Figure 12 Signal State Compression in the Presence of an Extremely High Level 100% AM Modulated Carrier

ACKNOWLEDGMENTS

The author thanks Jim Farmer for his continuing support and the members of the SCTE Engineering Subcommittee addressing upstream transportation issues for their open and stimulating discussions. An advance copy of reference 1 sent to us by Oleh Sniezko provided valuable background information.

My thanks are also extended to James Street who expeditiously assembled the test facility and collected most of the data.

References

[1] O. Sniezko and T. Werner, "Return Path Active Components Test Methods and Performance Comparison," 1997 Conference on Emerging Technologies Proceedings Manual, January 8-10, 1997, Nashville, TN, pp. 263-294.

[2] Technical Personnel, American Telephone and Telegraph Company, Telecommunications Transmission Engineering, Volume 1 - Principles, 2nd edition, Western Electric Company, Winston-Salem, NC, 1977, pp. 450-453.

[3] R. S. Prodan, M. Chelehmal and T. Williams, "Analysis of Two-Way Cable System Transient Impairments," 1996 National Cable Television Association Technical Papers, pp. 65-78.