FACTA UNIVERSITATIS (NIŠ)
Series: Electronics and Energetics vol. 11, No.2 (1998), 231-247

HYBRID FIBER–COAX CATV SYSTEMS: THE REVERSE PATH LASER SELECTION AND TESTING METHODOLOGIES

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Abstract. In this paper HFC architecture is described and transmission impairments in these networks are explained. Different types of reverse path lasers which are used in HFC systems are presented and their performance is tested. The different testing methodologies (BER and traditional method) and the results of measurements are discussed.

1. Introduction

The conversion of traditional all-coaxial based CATV distribution systems to hybrid fiber–coax (HFC) architectures has increased the transmission reach, extended the delivery system frequency bandwidth, and improved the quality and quantity of services delivered to the subscriber. In an HFC system, fiber–optic transmission systems transport services originating at the CATV headend to optical receivers (nodes) located in subscriber neighborhoods. Because the fiber may be deployed deeply into the network of subscribers, coaxial distribution from the nodes to the subscribers is necessary only over relatively short delivery spans and small cascades of RF amplifiers, greatly mitigating the signal degradation due to the bandwidth, noise, and distortion limitations inherent to the coaxial portion of the distribution system.

Recent deregulation of the telecommunications industry in the United States, and similar deregulation in much of Europe next year, has opened up a highly competitive market for the delivery of two way broadband communications services. These services include telephony, cable television (including

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Manuscript received August 2, 1998.

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high definition TV (HDTV), digital broadcast, and interactive video (pay–per–view, video–on–demand, video conferencing, shop– or bank–at–home, etc.)), personal communications services (PCS, including paging, messaging, and cellular/PCS phone service), and data transmission Internet access, data and cable modems, local and wide area networks (LAN/WAN)).

Communication from the subscriber back to the service provider's headend is accomplished over the reverse path sub–low band, completing the two way communication link. Contemporary HFC architecture is asymmetric; the forward path broadcast band extends from $40 \sim 50$ MHz to $750 \sim 860$ MHz, while the reverse (or return) path is limited to the band from 5 MHz to $30 \sim 40$ MHz. The coaxial distribution portion of the system carries this bi–directional traffic simultaneously to and from the subscriber. Diplex filters in the coaxial amplifiers and in the node separate the forward path broadcast traffic from the return path traffic, and the reverse path signals modulate a laser transmitter in the node for optical transport back to the headend.

Prior to the use of the reverse path for the return transportation of subscriber–generated communications, the return band was utilized primarily for system status monitoring and limited analog video transport (such as for remote video monitoring from the headend location). The status monitoring function typically uses FSK–modulated RF carriers to transport information about various monitored functions in the coaxial distribution system and the node back to the headend. With the growing deployment of two way interactive services, the demands upon the limited reverse path frequency band increase dramatically, and bandwidth efficient, complex digital modulation schemes (QPSK, 16– and 64–QAM, OFDM, CDMA, etc.) are being discussed deployed to handle the required information capacity.

As the demands upon the reverse path increase, selection, performance, and optimization of the laser used to transmit these signals becomes critical to achieving satisfactory system performance. Low cost, uncooled, unisolated Fabry–Perot laser diodes have been deployed extensively in the past when the system throughput demands were minimal. These devices are used extensively by the telecom industry in digital transmitter applications, and the tremendous volume makes these lasers available at attractive, commodity prices.

Until quite recently, little was known about the factors that were relevant to the successful deployment of lasers used to transport digitally–modulated carriers in the reverse path. Traditional analog transmitter characterization measures carrier–to–noise and second and third order intermodulation distortion products when lasers are loaded with two to six analog AM video carriers. We began to question the utility of these measurements when applied to the determination of relevant performance parameters for the transport of complex digital modulation formats. By their nature, these digital modulation formats are dynamic and "bursty" by nature, as opposed to the quasi–static nature of AM video carriers.

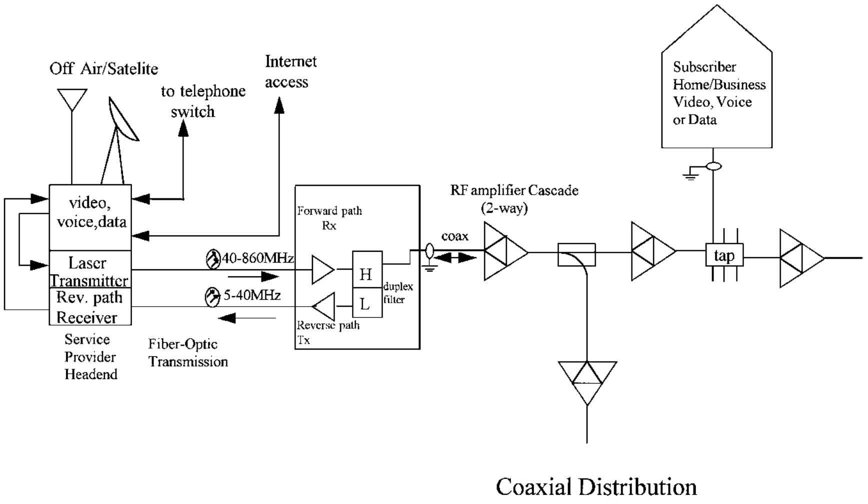

Figure 1. Hybrid fiber–coax system.

Our investigations lead to the discovery that new testing methods are currently being developed to measure the laser characteristics that are important and relevant to the transport of digital modulation on RF carriers (1). The input signal level dynamic range over which a given level of probability of error (bit error rate, or BER) can be maintained while the laser is loaded with simulated digital modulation is one example of the new testing methodologies being developed and discussed.

2. Laser devices for the return path

2.1 Laser diodes

Semiconductor injection laser diodes (ILDs) are the devices of choice for optical communications in the return path, due to the combination of relatively low cost and inherent performance parameters that make these devices suitable for efficient optical transport. Injection lasers operate via stimulated emission from the recombination of injected carriers that occurs within an optical cavity in the laser's crystal structure. This cavity provides for the feedback of photons. This process results in several key advantages [2]:

1) Relatively high optical output (up to several milliwatts) due to the amplifying effect of stimulated emission.

2) Narrow optical linewidths (typically less than 10 $10^{-10}m$) due to the high "Q" of the optical cavity. Narrow linewidths mitigate the effect of chromatic dispersion that occurs in transmission through optical fiber.

]item 3) Modulation bandwidths that extend into microwave frequencies (> 1 GHz).

4) Good spatial and temporal coherence which facilitates efficient coupling to, and operation within, the single–mode fibers that are deployed for optical transport in HFC systems.

Fiber–optic based systems used for transport of broadband communications services typically utilize two wavelength windows corresponding to inherent properties associated with optical fiber. Chromatic dispersion is at a minimum in the 1310 nanometer wavelength window, and optical attenuation is minimized in the 1550 nanometer window. Except when requirements call for lower attenuation for certain longerhaul applications (60–80 kilometers, or more), or where wavelength–division multiplexing (WDM) is used to share multiple wavelength information channels on a single fiber, the $1550nm$ window is rarely used for return path applications. Total optical link budgets in the return path rarely exceed 10 dB including both fiber and passive attenuation (splitter) loss, and for these distances, the minimum dispersion window at $1310nm$ is the better choice, primarily due to the cost effectiveness of devices in this window.

Unisolated Fabry–Perot lasers have been widely deployed for return path applications due to cost effectiveness and performance that was adequate for status monitoring and limited analog video transport. As digital deployment begins to extend in the return path in order to carry an increased volume of two–way services, distributed feedback lasers have been considered as a means of insuring that present and future demands upon the return link are met. Isolated DFB lasers are typically five or more times as expensive as unisolated FP lasers, and in a system consisting of hundreds of optical nodes, the questions of which is the most suitable device, and what are the relevant performance parameters for digital transport, become extremely important due to the significant economic impact of the device selection.

2.1 Device characteristics and options

The typical power spectrum of the Fabry–Perot laser exhibits multiple longitudinal modes. The relative amplitude of these longitudinal modes is a function of the gain spectrum of the laser, which varies with bias current, temperature, and optical backreflections into the cavity. Because this gain spectrum is typically much wider than the mode spacing, and the Fabry–Perot cavity provides feedback which is essentially consist for all longitudinal modes, the resulting mode discrimination is poor [2]. In a dispersive media (fiber), multiple modes (or wavelengths) have different propagation velocities resulting in degraded signal transmission integrity. In addition, the optical power in each wavelength varies greatly from one mode to the next, and varies with the gain function of the laser. Power fluctuates greatly in each mode as the gain function changes, but the integrated output power of the laser remains relatively constant. This modal noise (discussed later) is absent in a single frequency laser.

The distributed–feedback laser improves mode selectivity by making the feedback in the optical cavity frequency dependent, so that the loss is different for different longitudinal modes. Unlike the feedback in the Fabry–Perot laser which is localized at the cavity facets (mirrors at each end of the cavity), feedback in the DFB laser is distributed thoughout the cavity length. A Bragg diffraction grating is formed along the laser cavity and supports coherent coupling of the backward– and forward–propagating waves only at selected wavelengths. Mode–suppression ratios of greater than 1000 (30 dB) are readily obtained, and the resulting power spectrum is essentially single–mode, or single frequency [3].

Two options, external to the laser diode itself, may be added to the base device to extend its operational envelope: optical isolation, and temperature stabilization. Optical isolation decouples the laser from reflections in the fiber either from discrete sources (connectors, splices, fiber defects, and interfaces to other optical devices and components) or distributed fiber reflections such as Rayleigh backscattering. Reflections back into the laser an alter the gain conditions in the cavity, resulting in increased noise, mode hopping, and linewidth broadening. Isolation may be achieved through anti–reflection coatings, controlled decoupling (physical separation) of the laser from the fiber, or by addition of one or more stages of optical isolation, either internally or externally. The most effective decoupling is achieved with optical isolators, but they can add significantly to the cost of the packaged laser. Isolated FP lasers, for example, are a factor of two or more times more expensive than unisolated devices.

Return path lasers must operate typically over significant temperature ranges. Optical receivers located underground operate in a relatively static temperature environment, but most nodes are located in pedestals (small enclosures at ground level) or are strand-mounted (suspended above ground on cables between utility poles). In the latter case, year–round temperature extremes an vary from –40 to 85 Celsius. Temperature variation can have significant effect upon laser performance, from inducing mode hopping and wavelength shifts to changes in differential quantum efficiency and threshold current. The laser diode may be mounted on a thermal–electric cooler module (TEC, or Peltier cell) to maintain a constant temperature over wide external variations; however, the current required to operate the cooler may be as high as one ampere or more, and the laser module packaging to include the TEC adds significantly to the cost. It is generally thought that the cost and power requirements of a cooled laser are prohibitive in a node application.

2.3 Laser performance

Traditional characterization of lasers measured carrier–to–noise ratio and composite second– and third–order intermodulation performance for a static loading of CW video carriers over a fixed optical link budget. This methodology, while providing a fixed point of reference for direct comparisons between lasers, provides almost no information about the dynamic characteristics of the devices. The lightly loaded, quasi–static return path of the past is being replaced with an information channel that will carry complex digital modulation that is dynamic and bursty in nature. New testing paradigms are necessary to provide better correlation between laboratory measurements and field performance.

Dynamic range may be defined as the input signal level range over which a laser can maintain a fixed level of C/N+IMN (carrier–to–noise+intermodulation noise) performance (1). At low signal levels, the laser is lightly loaded and the measurement is dominated by the intrinsic noise source in the optical link. In typical optical link budgets encountered in the return path, the dominant noise contribution to overall link performance is due to the laser noise, including RIN and mode partition noise. As the input signal level increases, intermodulation distortion products or noise increase and dominate the measurement.

When the peak input signal current exceeds the bias current level above threshold, the laser truncates, or clips the signal waveform and intermodulation performance degrades significantly. Bit–error–rate performance of the link degrades steeply when the intermodulation noise approaches the minimum signal–to–noise requirements of the particular digital modulation format being transmitted.

Maximum input signal level to the return laser must be planned carefully by the system operator so that the dynamic headroom is not exceeded under present and future system deployment. Consideration must be given for number and types of modulation, required C/N+IMN, and headroom to be allowed for the transmission impairments that will be discussed.

Measurements have been performed on a number of lasers, including unisolated, isolated, and decoupled FP lasers, and isolated DFB devices. Superior noise performance may be attributed to effective isolation, but in terms of linearity and dynamic range, the DFB lasers were not found to be superior to the FP lasers in these measurements. The inherent quality of the individual device, rather than device type, appears to be more important in the selection of lasers for the return path.

3. Transmission impairments

3.1 Rayleigh backscattering and spurious noise

When optical fiber is fabricated, small variations in density and composition of the glass lattice are permanently formed as the glass cools. These discontinuities are small compared to the wavelength of light, and result in fluctuations in the refractive index of the fiber. Transmitted light is reflected and refracted at the sites of these discontinuities, and the resulting perturbations are the dominant intrinsic optical loss mechanism in the fiber.

Rayleigh scattering can occur in any direction, but the light that is reflected back to the laser (backscatter) can re–enter the laser's cavity (especially if the front facet of the diode not decoupled or isolated from the fiber) and affect the cavity gain conditions. Mode hopping or excess noise (spurious noise) can be generated under these conditions. For single component glass, Rayleigh scattering may be calculated as [2]:

$$\gamma_R = \frac{8\pi^3}{3\lambda^4} n^8 p^2 \beta_c K T_F, \tag{1}$$

where

γ_R Rayleigh scattering coefficient
λ optical wavelength
n refractive index of the medium
p average photoelastic coefficient
β_c isothermal compressibility at a fictive temperature T_F defined as the temperature at which glass can reach thermal equilibrium
K Boltzmann's constant

The Rayleigh scattering coefficient is related to the transmission loss factor of the fiber $\mathcal{L}$:

$$\mathcal{L} = \exp(-\gamma_R L), \tag{2}$$

where L is the length of the fiber.

Together with the previous equation, this expression shows that the transmission loss in the fiber is a strong function of optical wavelength. Rayleigh scattering is significantly reduced for longer wavelength.

3.2 Mode partition noise

Semiconductor laser mode partition noise (LMPN) can impair the performance of high–speed digital communication links and analog optical systems [4]. LMPN can be significant for multimode lasers operating near the fiber dispersion minimum. LMPN is the tendency of optical power to distribute itself between different optical modes of a laser in such a way that the power in individual modes fluctuates but the total power in all modes is relatively steady. The relative intensity noise (RIN), which is related to the optical power at each wavelength, also varies greatly between modes. Below 500 MHz, the RIN of the dominant mode can be 30 dB higher than the total integrated RIN, due to noise cancellation between modes [3]. Fabry–Perot lasers are subject to mode partitioning because different optical modes compete for the same gain. DFB lasers exhibit much less of a problem with LMPN due to much better mode suppression. Partitioning becomes a problem when dispersive propagation delays cause the fluctuations in the powers of individual modes to become separated in time, so that at a given time the fluctuations of the various modes no longer cancel one another and excess noise is generated.

3.3 Noise funneling

Coaxial distribution from the fiber–optic receiver (node) located in subscriber neighborhoods to the subscriber is typically configured in a tree–and–branch architecture. A typical node may serve several hundred to several thousand subscribers. Cascades (serial connection) of r.f. coaxial amplifiers branch out from the node in multiple directions. Amplifiers with multiple outputs serve "feeder" cascades off of these main branch lines. Return path signals from many subscribers return to the node through all of these amplifiers. Additionally, the combined thermal noise from all of the active devices, and noise and signal intrusion from ingress, "funnel" back to the node and are combined at the input to the return transmitter (5).

The noise floor at the return transmitter is therefore a function of the number of actives in the return path feeding into the node, and limits the achievable signal–to–noise ratio and dynamic range of the transmitter. Additionally, the amount of interfering signals and noise from ingress can reduce the dynamic "headroom" (i.e., the margin between maximum desired signal level and the level which causes signal clipping) of the return path laser.

3.4 Laser clipping, intermodulation noise and dynamic range

Laser clipping occurs when the optical modulation index (OMI) of the laser is too high. OMI is the ratio of the peak to the average optical output, and is set in the transmitter by adjusting the amplitude of the r.f. modulating signal. When the peak modulating current exceeds the d.c. bias current level above threshold, the optical output is clipped (Fig. 2). When clipping takes place, two effects occur: the laser is turned off for part of the negative excursion of the high level modulation, resulting in an amplitude compression of the wanted signal, and intermodulation noise and products are generated and some may fall into the channel, producing interference.

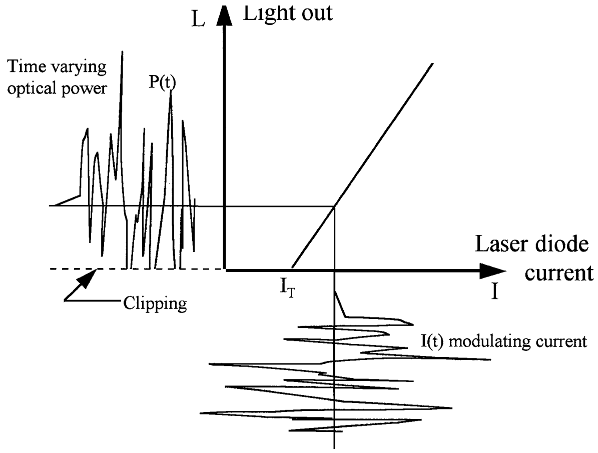

Figure 2. Laser clipping.

Intermodulation noise is a significant performance degradation due to occasional laser "clipping". When clipping is rare, the clipping distortion may be treated as a Poisson pulse train asymptotically. Knowing this, a generalized Gaussian distribution model can be created, which is the sum of a Gaussian distribution with a probability of no clipping occurrence and a non–Gaussian part with a probability of clipping occurrence. This model, applied to QAM signals with small OMI, or a small number of AM channels, gives good correlation between experimental and analytical results. It is shown that BER performance of an M–ary QAM system can be significantly degraded due to the clipping noise distortion generated by occasional laser clipping (6).

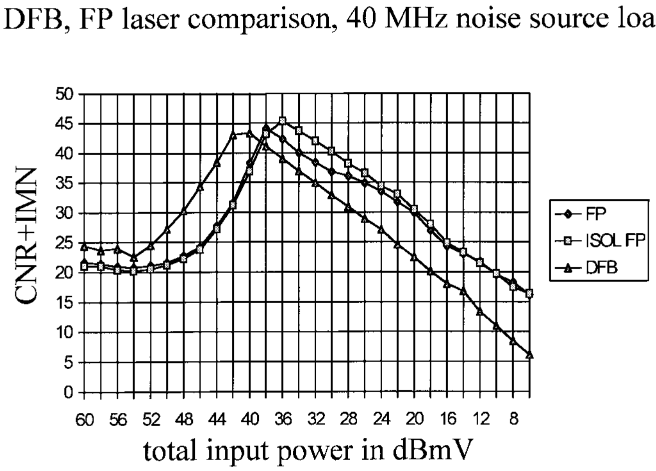

Figure 3. Laser dynamic range comparison.

The dynamic range of the laser is defined as the input signal range over which a fixed level of carrier–to–noise + intermodulation noise (C/N+IMN) is maintained. For small input signal levels, the noise floor of the optical link is set by the intrinsic noise sources in the optical link: laser RIN, mode partition noise, spurious noise, receiver shot noise and thermal noise.

When return path lasers (FP or DFB) are loaded with discrete analog (CW) channels and their signal amplitude approaches or is sufficient to cause clipping, intermodulation products are produced. These discrete IMN products can be measured as CSO (composite second order) and CTB (composite triple beat) distortion, and they define the upper limits to dynamic range of the laser.

Today, return path loading is moving toward bursty, digital traffic and new methods of testing and specifications are required. Investigations into new test methodologies indicate that Gaussian noise loading provides identical results to QAM and QPSK signal loading (1). We used noise loading to measure C/N+IMN and characterize dynamic range for several different lasers. Fig. 3 shows the dynamic range of three different lasers (isolated FP, FP, DFB) measured under conditions of simulated digital loading, with the reference channel (carrier) amplitude varying with along with the simulated digital signal level. In Fig. 4, the reference carrier amplitude was held constant as the simulated digital signal level was varied.

An alternative method to measure the dynamic range of these lasers is to load them with simulated or actual QPSK and QAM digital signals and measure BER (bit error rate) as a function of total input signal level (1). Reported results show that the type of signal used to load the laser, other than the actual digital channel used to measure BER, has no measurable influence on the BER performance. Also, the differences in dynamic ranges for different type of lasers are less apparent when tested with this method. Dynamic range is very important because it gives the user information on how to set up these transmitters to operate properly, given minimum required C/N+IMN and expected signal loading on the return path link.

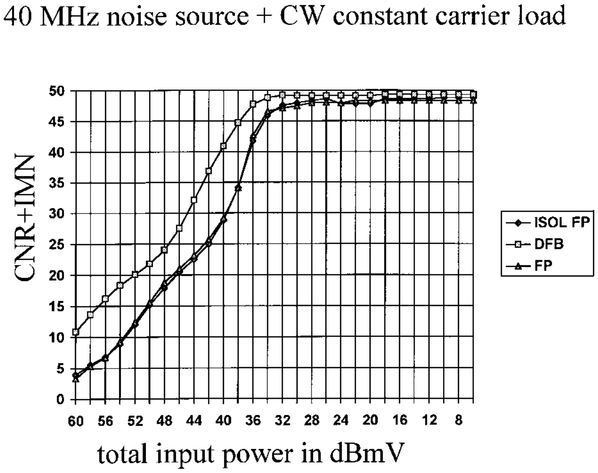

Figure 4. Laser dynamic range, CW fixed level.

3.5 Ingress

Ingress is the intrusion of unwanted RF signals and noise into the coaxial distribution system. The interference arises from a number of sources: wireless transmissions (amateur and CB radio, particularly), hum and corona discharge from AC power distribution systems, radio frequency interference and electrical noise from automobile ignitions, electrical and electronic switching, and household appliances.

Ingress may be conducted into the coaxial system wherever there is a breach in the r.f. shielding, such as through loose, corroded, or faulty r.f. connectors, damaged cable, or poor quality drop passives. The service provider can mitigate ingress in the outside plant by proper installation and maintenance of the distribution system, but studies have shown that the primary point of intrusion is in the drop cables entering into the subscribers homes, and in the homes themselves. Filtering at the point of entry into the subscriber's home has been shown to greatly mitigate ingress.

The spectral distribution of ingress generally flows a $1/f$ law, with the highest concentration of noise in the portion of the return path between 5 and 15 MHz. The temporal distribution of the ingress generally takes the form of impulsive or burst noise lasting less than 100 microseconds, with most events lasting less than 10 microseconds. Ingress from discrete r.f. carriers such as amateur or CB radio transmissions are present for longer time periods [7,8,9].

Ingress, conducted and amplified from the coaxial distribution system back to the node, causes unwanted additional signal and noise loading to the return path laser. The intruding signals can be of sufficient magnitude to cause compression in the r.f. amplifiers and clipping in the laser. This results in an increase in intermodulation distortion and noise which significantly reduces the dynamic range of the return path system. In particular, intermodulation noise induced from laser clipping has been shown to be the primary cause of bit–errors in the optical transmission of digital information [6].

4. Testing methodologies

4.1 Traditional/dynamic range

Traditional CATV analog transmitter performance characterization loads the laser with CW carriers and measures the signal degradations (CNR CSO, and CTB) that are important factors for analog video quality. Typically these tests are performed at a fixed OMI, in other words, the input signal level is fixed in order to achieve some desired level of CNR or distortion performance for a given optical test link. An important extension of this traditional methodology is to measure CNR and distortions over a wide input signal range, in a manner analogous to digital loading tests for (C/N+IMN dynamic range measurements. At high input levels, the intermodulation distortion products are measured, rather than the intermodulation noise floor. Fig. 5 shows the basic test system. The return path transmitter is loaded with CW carriers and drives an appropriate optical link budget (which may consist of fiber and passive attenuation). The r.f. output from the test system receiver feeds a spectrum analyzer for signal analysis. An r.f. amplifier may be required between the receiver and analyzer in order to raise the test link noise floor above that of the analyzer, for more accurate measurements.

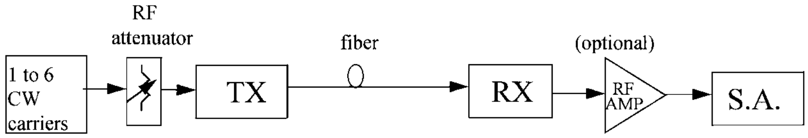

Figure 5. Basic performance measurement system.

The laser performance is dependent upon the level and the number of the channels loading the transmitter. We compared three different lasers: FP, isolated FP, and isolated DFB over temperature. The dynamic range was found to be similar for these three lasers using this test methodology. No significant difference was found which would differentiate one laser from another in terms of input dynamic range and linearity. These results apply only to the samples that we evaluated. More devices remain to be fully characterized; reported test results from other researchers have shown differences among lasers.

4.2 Spurious noise or carrier–to–interference test

Spurious noise is generated by the interaction of the laser with backreflections from the fiber that re–enter the laser cavity. This noise is suppressed under conditions of modulation, and is seen as a significant rise in the laser noise floor (20∼30 dB) when modulation is removed. Spurious noise is important in HFC applications where several return path transmitters are feeding a common link. Because of the bursty nature of the digital traffic, constant modulation on a given transmitter cannot be guaranteed, and spurious noise may be produced, raising the noise floor and degrading the signal performance and headroom in a multi–transmitter system.

The equipment setup for spurious noise (also called carrier–to–interference) is the same as the traditional setup for measuring carrier–to–noise. The return path laser is signal loaded to a given level of OMI that would typically be used in a field installation. If CW signals are used, for example, the laser is loaded with several video channels and the OMI is adjusted until the desired link CNR is achieved. The spectrum analyzer reference level is adjusted to the peaks of the carriers, then the carriers are turned off and the analyzer is set to peak hold on the displayed noise floor, at which time the spurious noise is observed to accumulate. After at least one minute (necessary to achieve repeatable results within a few dB), the difference between the reference level and the highest spurious noise peak is measured as C/I.

Spurious noise was measured for all lasers in this test; isolated lasers performed the best as effected, due to the isolation from backscatter. The isolated FP laser, which used a two–stage isolator for minimum performance, achieved the best spurious noise numbers at better than 50 dB over temperature.

4.3 Digital signal loading simulation/intermodulation noise

Noise loading is becoming accepted as a way to simulate digital signal loading, and to characterize the combined effects of noise and intermodulation on the performance of return path active components. In the situation where the upstream payload consists of many, similar level, digitally modulated carriers, the probability distribution function (pdf) for the amplitude of the composite modulating signal approaches the Gaussian distribution associated with thermal noise [10].

In tests that we performed, we built a 40 MHz noise source and combined it with one CW carrier at 150 MHz (Fig. 6). (Our test transmitter platform, used to evaluate the various lasers, was flat to within 1 dB from 5 MHz to 250 MHz.) In the first experiment, we measured the CNR of the single 150 MHz, consist level carrier as the signal level of the noise source was varied. This simulates traffic with constant CW carriers and variable digital loading. The result is one view of the dynamic range of the laser, presented in Fig. 4. A second experiment simulated digital loading on the reverse path as a function of total signal levels. The level of the carrier was changed in step with the level of the noise source. This dynamic range is plotted in Fig. 3. DFB, isolated FP, and FP lasers were compared using these two methods and the results are that both FP lasers have almost the same dynamic range for this kind of loading. The DFB laser has similar dynamic range, with the difference that it requires more RF input to achieve the time C/N+IMN performance. Performance differences in these tests are probably due to individual characteristics of the particular devices selected, and should not be attributed to the device type, such as DFB or FP laser.

4.4 Bit–Error–Rate

Considering the changing role of the return path, the results from traditional testing do not allow us to evaluate how well these lasers will perform when utilized for digital communications (cable modems, internet access, etc.). BER testing using real digital modems, over input dynamic range with simulated or actual digital loading, is a more suitable methodology to determine the conditions and limits under which the transported digitally–modulated signal will still have acceptable performance. Also, the nature of these digital signals is that they are not continuous. Digital communications are transmitted in bursts typically at random times and at indeterminate duty cycles. In the future additional tests will be developed to more accurately model and predict the performance of these systems.

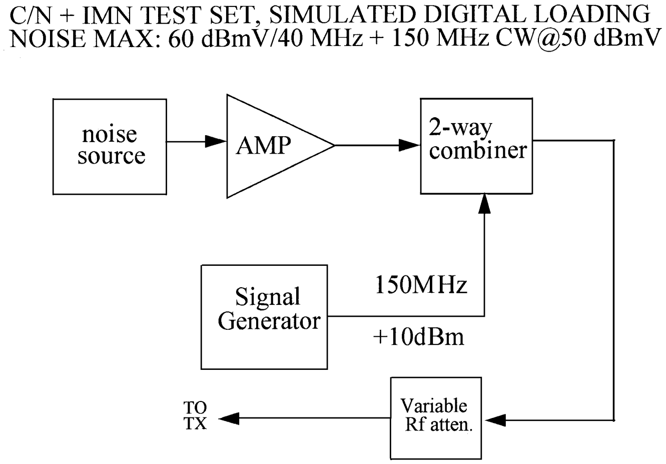

Figure 6. C/N+IMN test with simulated digital loading.

To perform a BER test, digital QPSK or QAM–modulated signals are used. The test set up is presented in Fig. 7. The goal of this test is to determine the dynamic range of the system measuring the BER The operating levels of the signal load are recorded and BER is measured as a function of signal level. Dynamic range is defined as the range of input signal levels over which a fixed BER is maintained The Multiple Carrier Signal Source (MCSS) from Hewlett–Packard is used in the described test because of its capability to generate digital signals in various formats that are identical to a real source. However, it is not able to perform the BER measurements. To do this, at least one modem pair of the desired digital modulation type and speed is needed as well as a BER test and measurement device [11].

Using a constellation analyzer is another valuable testing approach to learn about the impairments to digital transmission. A constellation analyzer displays the location of the signaling states (phase and amplitude) of the particular digital modulation format. For example, QPSK is characterized by a four–quadrant constellation. By observing the constellation integrity as a function of various return path impairments, we can visually observe how robust the particular format is to each impairment [10]. The digital signal will be correctly demodulated if the effects of noise, interference and distortion do not displace the signal state beyond the thresholds between states. The results show that QPSK is extremely tolerant to clipping (more so than QAM). When the laser is clipping the QPSK signaling state is displaced diagonally toward the origin, rather than in a perpendicular direction toward the state thresholds. Bit–error–rate degradation is therefore predicted to remain relatively robust to laser clipping.

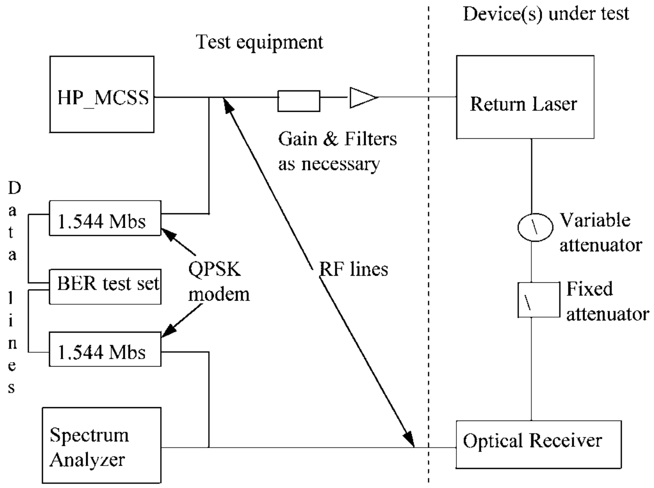

Figure 7. Bit–Error–Rate test.

5. Summary

The deployment of two–way services over HFC networks is placing new demands upon the return path system, and in particular, the laser transmitter. Complex, bursty, digital modulation is replacing the traditional signal loading of FSK status monitoring signals and one or a few analog video channels. Laser device and laser–related impairments are the dominant non–linearity in the reverse path. Traditional methods of limitter characterization reveal little about the laser performance necessary to transport data with acceptable bit–error–rates.

We have identified device types, features, and transmission impairments, and are continuing to evaluate various lasers and testing methodologies, in an effort to better predict and characterize the factors and performance necessary for effective and economic field deployment.

REFERENCES

1. O.J. Sniezko and T. Werner: *Return Path Active Components Test Methods and Performance Comparison.* SCTE Emerging Technologies Conference l997, pp. 263–294.
2. J.M. Senior: *Optical Fiber Communications.* Principles and Practice, Second edition, UK: Prentice Hall International, Ltd., 1992.
3. G.P. Agrawal and N.K. Dutta: *Long–Wavelength Semiconductor Lasers.* New York: Van Nostrand Reinhold, 1986.
4. R.H. Wentworth, G.E. Bodeep and T.E. Darcie: *Laser Mode Partition Noise in Lightwave Systems Using Dispersive Optical Fiber.* Journal of Lightwave Technology, vol. 10, no. 1, pp 84–87, Jan. 1992.
5. K.D. LaViolette and E.J. Schnettler: *Fiber in the HFC System.* Communications Technology, vol. 14, pp. 26–30, Feb. 1997.
6. Q. Shi: *Asymptotic Clipping Noise Distribution and Its Impact on M-ary QAM Transmission over Optical Fiber.* IEEE Transactions on Communications, vol. 43, no. 6, pp. 2077–2084, June 1995.
7. L.F. Bourdot and F.F. Boin: *Power Allocation Strategies for the Return Path.* 1997 NCTA Technical Papers, pp. 105–127.
8. D. Large and R. Bullinger: *A Proposed Method for Quantifying Upstream Ingressing Carriers.* l997 NCTA Technical Papers, pp. 128–141.
9. R.S. Prodan, Ph.D., M. Chelehmal, Ph.D., and T. Williams: *Results of Return Plant Testing.* 1997 NCTA Technical Papers, pp. 142–165.
10. J.J. Kenny, Ph.D.: *Characterizing Return Path Transmitters.* Communications Engineering & Design, pp. 26–32, May 1997.
11. D.T. Gall: *Industry Wide Benchmark for HFC Return Networks.* Time Warner Cable memo, July 1997.