Defining Optical Modulation Index

An In-Depth Look at OMI

- How OMI is defined at a technical level
- Importance of OMI to optical system performance
- Measurement methods to save time and money

Intended for those interested in understanding OMI at a technical level, this whitepaper discusses the definition of OMI and its significant role in optimizing laser transmitter and optical system performance. In addition, both conventional and new methods of measuring OMI are compared, resulting in a more complete grasp of this important topic.

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Objectives

After reading this material, readers should have the ability to:

- **Explain what OMI is and how it is mathematically defined**
- **Discuss why OMI is extremely important to optimizing both downstream & upstream system performance, as well as laser transmitter maintenance**
- **Understand new ways of measuring OMI that save tremendous time & money compared to conventional methods**

You will learn a number of important relationships, applications, benefits, and methods for measuring and evaluating OMI and its impact on optical system performance.

Topic Outline

Defining OMI

Defining OMI

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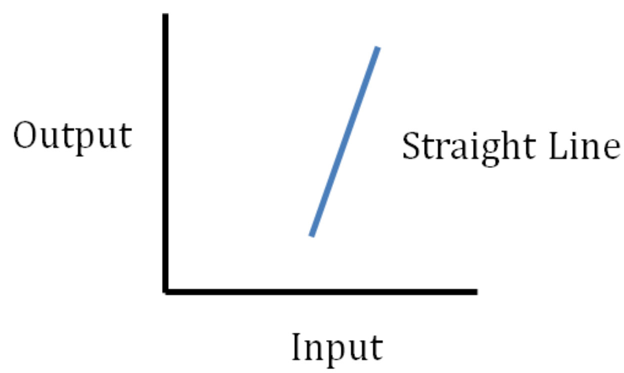
Linearity in Electronics

Before we can get into the idea of Optical Modulation Index (OMI), it is important to briefly discuss linearity because the performance of all lasers depends heavily on it. The definition of linearity in electronics is that the output varies in direct proportion to the input.

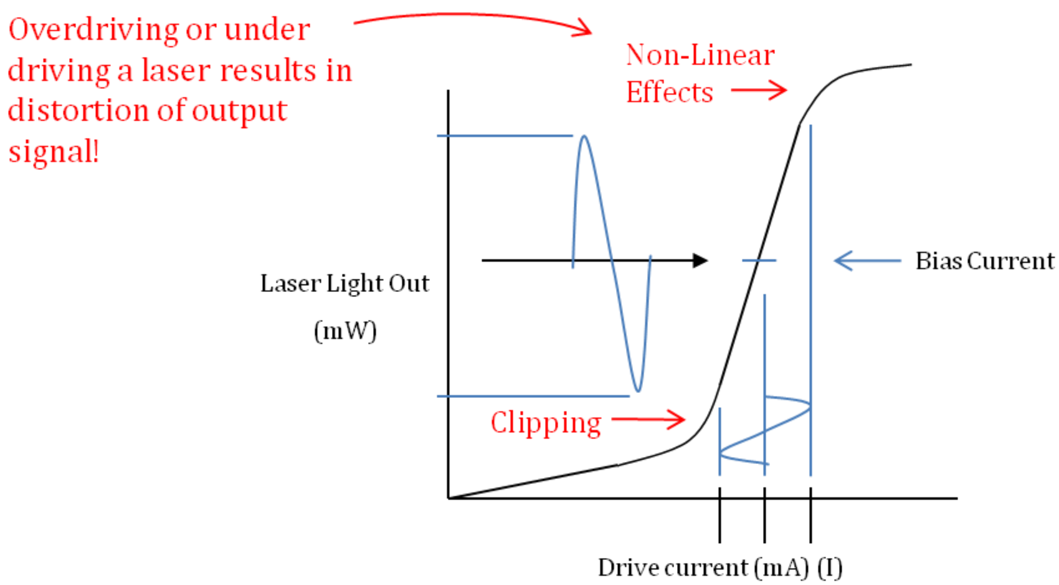


For example, if the input is current to a laser and the output is light, the light intensity output will be very linear (as shown by the straight line) and the light would represent the drive signal very well. In this case, the straight line would be a part of the transfer curve of the laser.

**** Helpful Terminology: Transfer Curve ****

The plot of output vs. input for a device or system

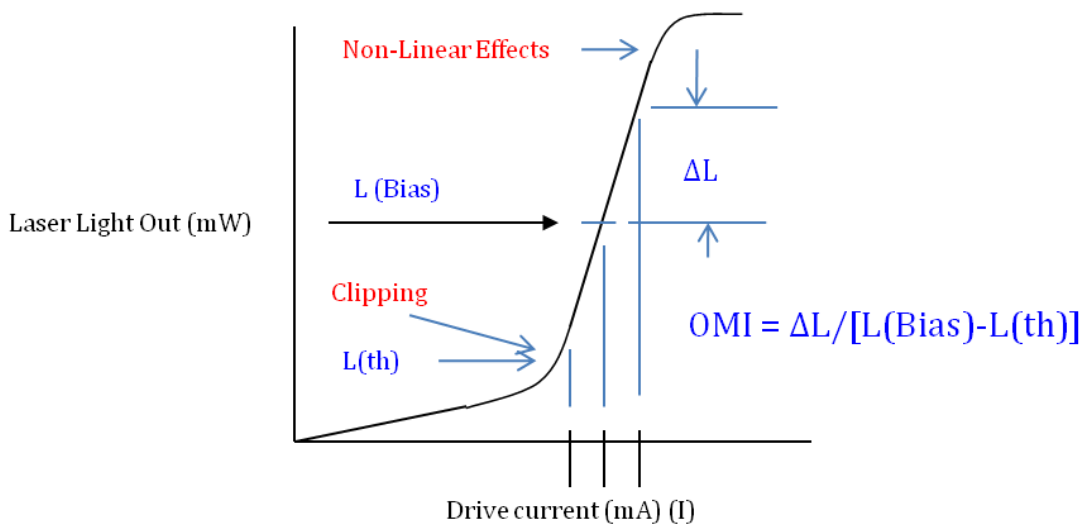
Devices Are Linear For Only A Portion of the Curve



The linear portion of the laser curve defines the transfer function between drive current and light output. With the laser bias current level established, the AC drive current around the bias causes the light output to change according to the linear portion of the laser curve. The slope of the curve determines the amplification of drive current to light output.

If the laser is overdriven, non-linear effects or clipping will introduce distortions. If the laser is under driven, noise will dominate and cause issues.

Defining OMI Using a Linear Curve



The light output goes through four performance stages as drive current is increased. The first is prior to the clipping region (before lasing) when the light output reacts as an (Light Emitting Diode) or LED. The second is the transition region as the light output goes from being an LED to being a laser (L threshold). This is the clipping region shown on the graph. The third area on the curve is the linear region where the light output varies around the bias point with current modulation and has good distortion characteristics. The fourth is the area where non-linear effects begin to take over due to over modulating and overheating of the laser. The non-linear effects region is where distortions become larger and the laser signal deteriorates.

Optical Modulation Index or OMI can be defined from the laser characteristic curve with either light output or current input. **The OMI is the Change in Light out or (ΔL) divided by the difference of the Optical bias point (L), minus the optical threshold or L (th).** Please note that clipping can occur at the threshold point and nonlinear effects can degrade CSO/CTB performance at the upper end of the curve due to overdriving the laser.

What Is Optical Modulation Index?

In a laser-based system, the **OMI (m) is a measure of how much the modulation signal affects the light output**, and is measured in %.

OMI is used to set and verify the optimum operating point (light or current bias) that provides the best tradeoff between noise (under-modulation) and distortions (over-modulation). OMI is simple to define but often quite difficult to achieve. It is measured in % per channel (peak) or total % (RMS) for all channels.

The ultimate goal is to set up the optical transmitter so that you achieve the highest modulation levels or power without creating unacceptable distortions. Typical OMI values depend on the type of laser being used. DFB lasers are the preferred lasers today because of their spectral purity, linearity and excellent power output levels. The typical DFB composite OMI is in the range of 19 to 22%.

As laser technology improves, the OMI percentages are expected to increase due to better linearity of the lasers.

Per Channel vs Composite RMS OMI

- **Per Channel OMI (m)** is a <u>peak</u> value expressed in % per channel

- **Total OMI m(T)** can be a peak value expressed in % total (not typically expressed as peak or total)

    - Defined as $m(T) = \sqrt{m^2 \cdot N}$; with N= number of channels

A very important fact to remember about OMI is that single channel OMI is expressed as a peak OMI value. Total OMI can also be expressed as a peak value. Total OMI is defined as the square root of the per channel OMI (m) squared times the number of channels.

However the prevailing use of OMI is expressed (not as total) but as the composite or RMS value of the total OMI. So the peak total OMI divided by the square root of 2 will yield the composite (μ) or RMS value. The **FOS 1000A OMI instrument** (which will be discussed later in the presentation) yields the composite or RMS value of OMI.

- **Composite OMI (μ)** is an <u>RMS</u> value expressed in %. It is defined as $\mu = \sqrt{m^2 \cdot N/2}$, using peak value m.

    - <u>**Example:**</u> N=79 and m = 3.5%

      $\mu = \sqrt{m^2 \cdot N/2} = \sqrt{0.035^2 \cdot 79/2} = 0.22$ or 22% RMS (or 22% composite)

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**** Helpful Note ****

Peak per channel OMI should always be available from the transmitter manufacturer

Section 2

OMI and System Performance

Noise In Laser Systems

- **Internal Sources (to the laser)**
    - Relative intensity noise

- **External Sources (to the laser)**
    - Ingress noise
    - Amplifier/laser drive noise
    - Receiver noise

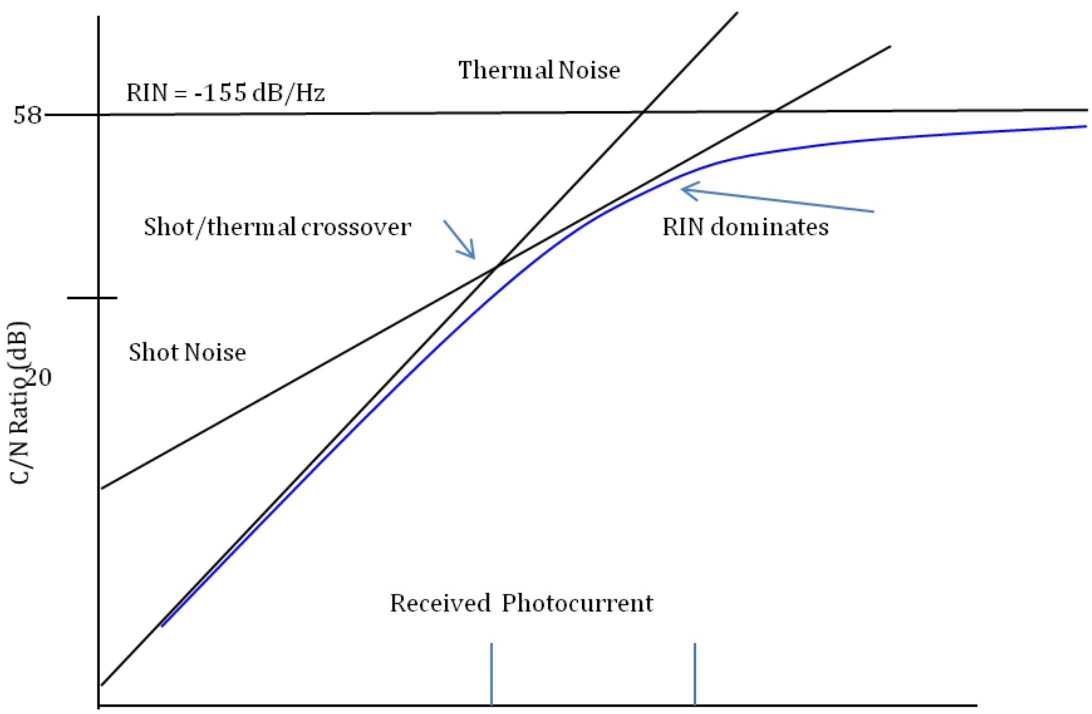
So now that we understand OMI, how does using OMI to set up a transmitter impact the system performance?

The laser operating point and modulation current levels are extremely important factors in the performance of a laser transmitter in the system. However, all noises associated with the laser and the receiver must be taken into account when determining C/N performance of the system.

- The primary noise internal to the laser is the **Relative Intensity Noise** or **RIN**. RIN is a measure of the instability of laser power for a variety of reasons including cavity fluctuations. The noises external to the laser arise primarily from laser drive electronics and receiver noise including thermal and shot noise.

System Performance

The graph below describes the limiting factors in a typical fiber optic system. At the receiver, the thermal noise dominates at low input light levels. At the crossover point, or medium input light levels, shot noise becomes dominant. Both are detector or receiver limitations.



However, in all cases the laser Relative Intensity Noise (RIN) of the laser source limits the overall system performance as the input current to the detector increases (higher light levels). The best operating point for the receiver is at or slightly beyond where the RIN begins to dominate. At this point the system performance hits a point of diminishing returns as shown by the composite curve. For detector current this is typically at around 0 dBm or 1 milliamp detector photo current.

Carrier Power

Carrier power in multi-channel optical systems is defined as one half the square of the optical modulation index (m) times the optical power (P or IR).

$$C\ (\text{Power}) = \tfrac{1}{2}(m\ IR)^2$$

In order to generate the highest carrier power possible, the OMI (a squared term) must be maximized along with the optical power.

As described earlier, the key is setting the OMI to achieve the highest optical power without distortions.

Carrier-To-Noise Ratio (CNR)

Ultimately, in analog or mixed analog and digital systems, we are trying to optimize Carrier to Noise ratio to achieve superior system performance. Carrier to noise ratio is defined as the carrier power divided by the sum of all the major noises in the optical system:

$$CNR = (m \cdot IR)^2 / [2B\{2q(Ir+Id) + (IR^2 \cdot RIN) + N\}]$$

m = OMI

IR = Detector Current

B = Video Bandwidth

2q(Ir+Id) = Shot noise

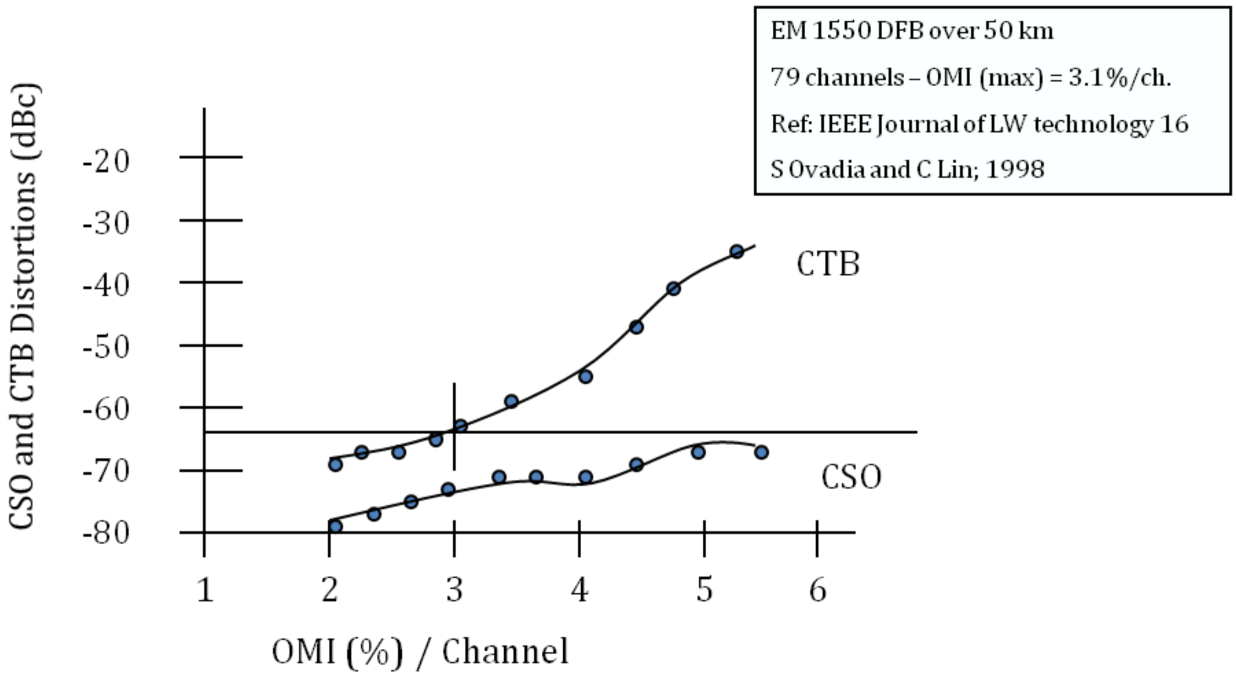
N = Receiver noise equivalent current (thermal noise)

RIN = Relative Intensity Noise

Optimized OMI has a major impact on CNR. In multiple carrier systems, optimizing the CNR means maximizing optical power and maximizing OMI without impacting distortions and noise sources. Both the optical power and OMI are squared terms and set the carrier side of the equation.

In all cases, optimum system performance is achieved when OMI is maximized with acceptable distortions.

Example:
Distortions and OMI on Sample System



For this example taken from the IEEE Journal of LW Technology, the OMI % per channel provides best performance at 3.1% while maintaining CTB at less than –62 dBc. The total OMI for the 79 channels is 19.5% where m= √(79 x m²/2)

Section 3

Measuring and Setting OMI

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Sources Of Errors in Existing OMI Settings

Laser Manufacturer Variables:

- Use of un-modulated carriers to set OMI
- Use of specific numbers of channels
- Normal instrument tolerances

Transmitter Manufacturer Variables:

- Driver circuit linearity, temperature dependent errors
- Use of un-modulated carriers
- Variations in front panel setups & test point circuits
- Normal instrument tolerances
- OMI sometimes not available

There are many variables that can affect the OMI setting of a particular laser and thus the laser transmitter. The specified RF drive levels provided by manufacturers are typical levels for all transmitters with the same model number. The OMI will move around accordingly as circuit variables change the RF drive level. Variables can include driver circuit tolerances, test point inaccuracies, instrument tolerances, and the use of un-modulated carriers. They can all affect the RF drive level.

A direct measurement of OMI provides a way to eliminate the variables in the RF to optical transfer function by looking directly at the optical signal and adjusting the RF level to obtain the correct OMI. When setting the optimal OMI with RF drive level, all of the variables or inaccuracies are taken into account. So it becomes a relatively easy task to optimize the laser.

How And Why To Use OMI

Benefits of Setting Proper OMI:

- Maximize Carrier-to-Noise
- Minimize CSO and CTB distortions
- Optimize system performance

Useful for System Setup, Periodic Maintenance, & Troubleshooting:

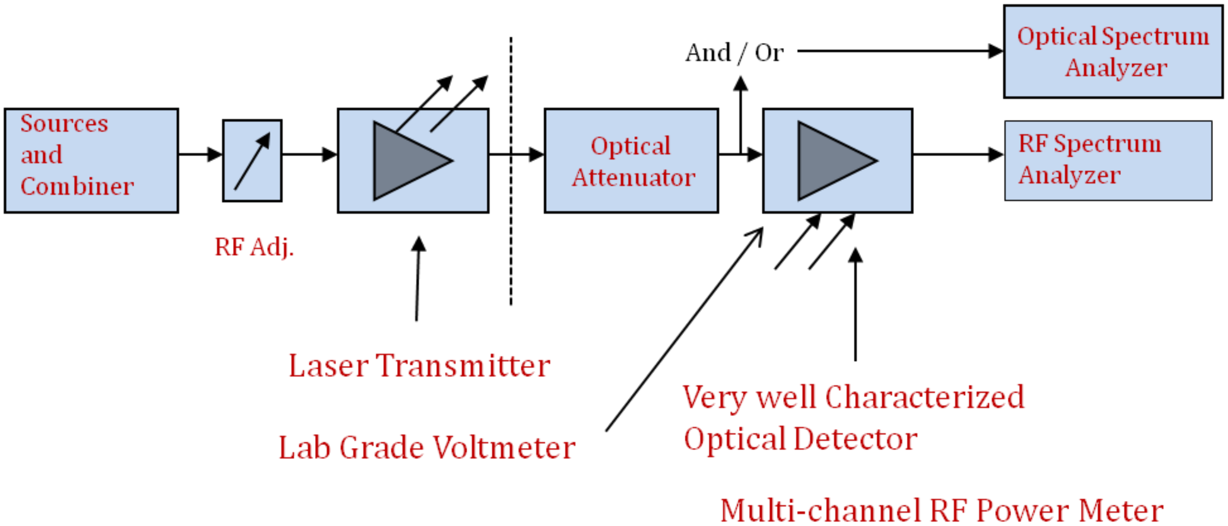
- Ensure new laser transmitters are setup & running at optimal levels
- Periodic review of laser transmitter OMI to ensure best performance
- Detect decreased performance of laser transmitters prior to failure
- Network troubleshooting

Properly setting OMI facilities and simplifies optimal system performance by maximizing C/N and minimizing distortions. If the correct (composite) OMI is set and recorded for a particular transmitter, it will never change. This recorded OMI can be used for the life of the unit to keep the system at peak and to detect performance degradation or laser failure before it impacts the customer. If you add or subtract channels, it is a simple RF level change to adjust the OMI to its composite set point.

Measuring OMI - Traditional Approach

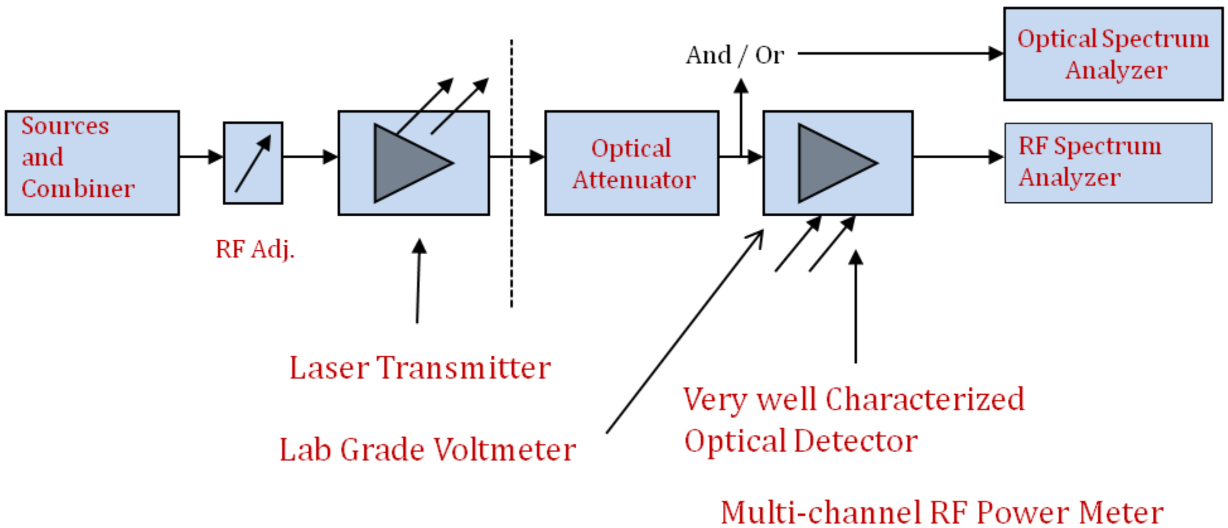
Measuring OMI using traditional processes has been a difficult task, as it requires both a significant amount of money and time:

- **The equipment list is long and very costly, often as much as $30k or more**
- **The process is time consuming (up to 1.5 hours per transmitter), as each adjustment and calculation is done manually and must be repeated each time any single variable changes**
- **Task typically requires a senior level engineer or technician, familiar with the equipment and process**



A typical setup for laser transmitter OMI measurement and alignment is shown above.
Note: *Everything to the right of the dotted line is required to set OMI*

Measuring OMI - Traditional Approach



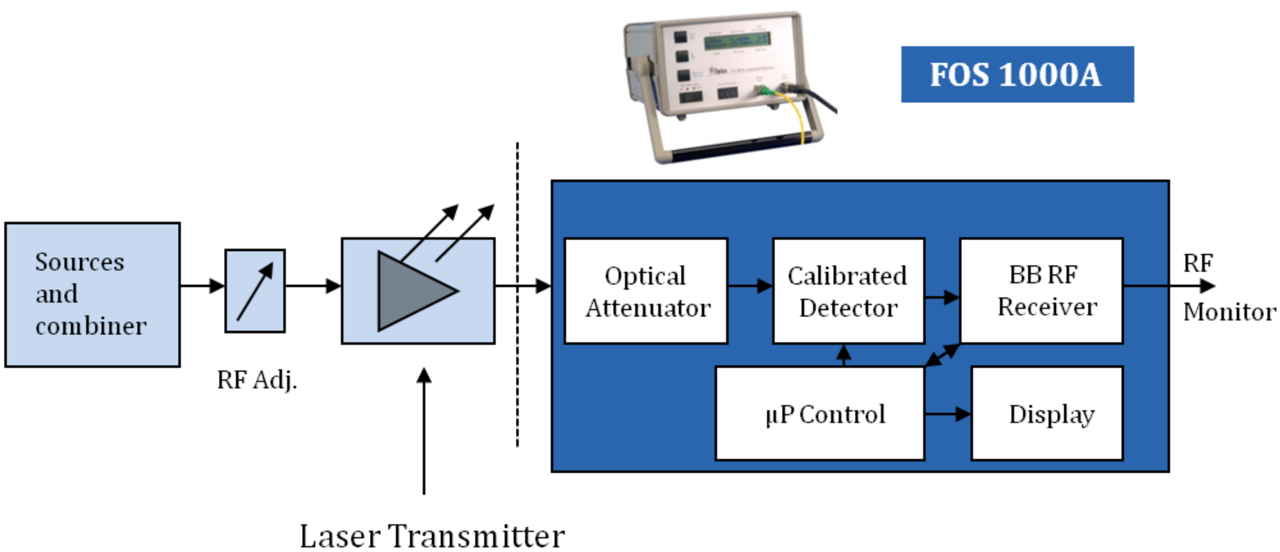
Knowledgeable technicians and very expensive test equipment are typical requirements for determining optimal OMI settings. An RF source with level adjustment capability, a very well characterized optical detector or optical spectrum analyzer, a laboratory grade voltmeter, a multi- carrier RF power meter, and an RF spectrum analyzer to optimize carrier to noise (C/N) are what is required to measure and set OMI.

In summary, the result is a cumbersome and inefficient way to measure and set OMI, as each time any variable in the circuit is changed via trial-and-error, a complete set of new measurements and calculations must be performed.

Measuring OMI - New Approach

Measuring OMI using the FOS 1000A instrument saves significant time and money:

- **Replaces list of traditional equipment with single instrument, for a total investment of less than $10k**
- **Measures proper OMI automatically while taking all variables into account, reducing typical time spent to less than 10 mins per transmitter**
- **Task can be performed by technicians of all levels**



A typical setup for laser transmitter OMI measurement with the FOS 1000A instrument.
Note: *FOS 1000A replaces all required equipment using the traditional method*

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Benefits Summary Using New Approach

In addition to cost and time savings achieved using the FOS 1000A OMI instrument, there are several important system benefits of setting proper OMI :

- **Pinpoints the laser optimal setting/point for a given loading**

- **Optimizes system performance**
    - **Best overall system performance**
    - **Maximum CNR**
    - **Minimum CSO & CTB distortions**
    - **Obtains the perfect balance to achieve peak performance**

With proper setting of OMI, the laser transmitter is optimized. With proper design of the system, the receiver performance is optimized. When this is accomplished, the system performs optimally and the perfect balance is attained for peak performance.

Additional OMI Facts & Related Information

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Facts About OMI

- **Laser OMI does not change, regardless of measurement location in the system**
- **Per channel OMI % times the number of channels never adds up to 100%.**
  - Example: 78 channels x 3% = 19% Total OMI; where $m = \sqrt{(N \times m^2/2)}$, N = channels.
- **Minor changes in the RF drive can produce major changes in OMI and system performance**
- **OMI is extremely important in both the setup and ongoing maintenance of multichannel CATV systems**

Explained further:

Once set, OMI does not change anywhere in the optical system, regardless of power level or measurement location. This is very helpful for network troubleshooting.

Per channel OMI times the number of channels never adds up to 100%. Statistically speaking, the laser would be hugely overdriven if loaded in this manner. Total OMI for all channels is typically less than 25%.

Once the total OMI is known for a particular laser transmitter, it will remain constant regardless of the number of channels on the system. The RF drive will be changed to attain the total OMI if channel numbers are reduced or added. This is very helpful for period maintenance and performance benchmarking.

Minor changes in RF drive level can produce major changes in OMI, so transmitters should be put on a scheduled maintenance program to verify OMI settings.

The use of the FOS 1000A instrument allows you to do this with ease, accuracy, and at a minimal investment.

CATV Analog/Digital System Example

A good example of a multichannel system could have 88 analog channels and 40 digital channels. The manufacturer reports that the single channel OMI (m) for this transmitter is 3.2%.

- Analog Channel Count: 88

  Digital Channel Count: 40 @ 6dB down

Using the equation we described earlier, we can calculate the composite OMI to be 22.4%.

- Calculate Composite OMI with m = 3.2

  40 digital channels 6dB down = 10 analog channels (power equivalent)

  Therefore the total channel count = 88+10 or 98

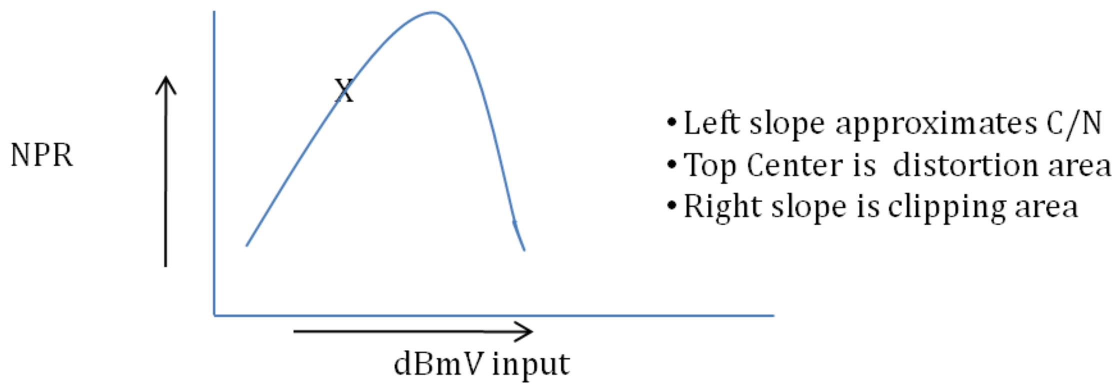
- $\mu = \sqrt{(m^2 x n/2)} = \sqrt{(.032^2 x 98/2)} = 0.224$ or 22.4%

- Set the laser to 22.4% composite OMI with the OMI Instrument and always keep it the same for any number of channels. Optimum performance is assured.

From this time forward, the composite OMI will always be set to 22.4%, regardless of the number of channels, more or less, and will never change. Knowing this value results in a great performance benchmarking and maintenance tool to ensure optimum laser transmitter performance.

Noise Power Ratio Curves

Noise Power Ratio (NPR) curves or tables are another way of describing the performance of laser systems.



“X “marks the optimum performance spot. The RF dBmV input level at this spot is directly associated with the transmitter OMI value.

A noise power ratio curve yields significant information on the performance of a laser based optical system. The left side of the curve is essentially the Carrier to Noise section of the curve. As the RF input to the laser is increased, the NPR is increased until it begins to distort (at the top of the curve). The right hand side of the curve shows the NPR rapidly declining due to clipping. The X is meant to determine an optimum operating point for the laser. Since RF input power determines the total OMI of the transmitter, the OMI for the optimum RF input is recorded and can be set back to that point regardless of the number or mix of channels.

All-Digital CATV & Multi-Channel Systems

Although digital channels require less power and thus lower Signal to Noise to obtain perfect video, as CATV systems move towards all digital transmission, OMI continues to be an important parameter for achieving peak performance.

Since OMI is a carrier power related function, the performance of the system will continue to be optimized by properly setting OMI.

Want More Information?

If you have specific questions in regards to the topic of OMI and/or the use of the FOS 1000A OMI instrument, please contact M2 Optics or an authorized partner for more information.

The staff at M2 Optics welcomes all inquiries and is available to schedule direct discussions, as well as live web-based presentations, in order to serve you better.

Contact Us Today!

About M2 Optics:

M2 Optics is a leading provider of unique, high value solutions for testing, monitoring, and optimizing fiber optic equipment and systems. As a result, many of the largest and most recognized Telecom, CATV, Networking, Government, Financial, and Research organizations around the world rely on our innovative products for the valuable benefits they provide.

To learn more about how M2 Optics can be a partner to your organization, contact us directly at **(919) 342-5619** or visit our website at www.m2optics.com

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