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Optimized Test Solutions to Enable Low-Cost Optical Amplification

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presented by:

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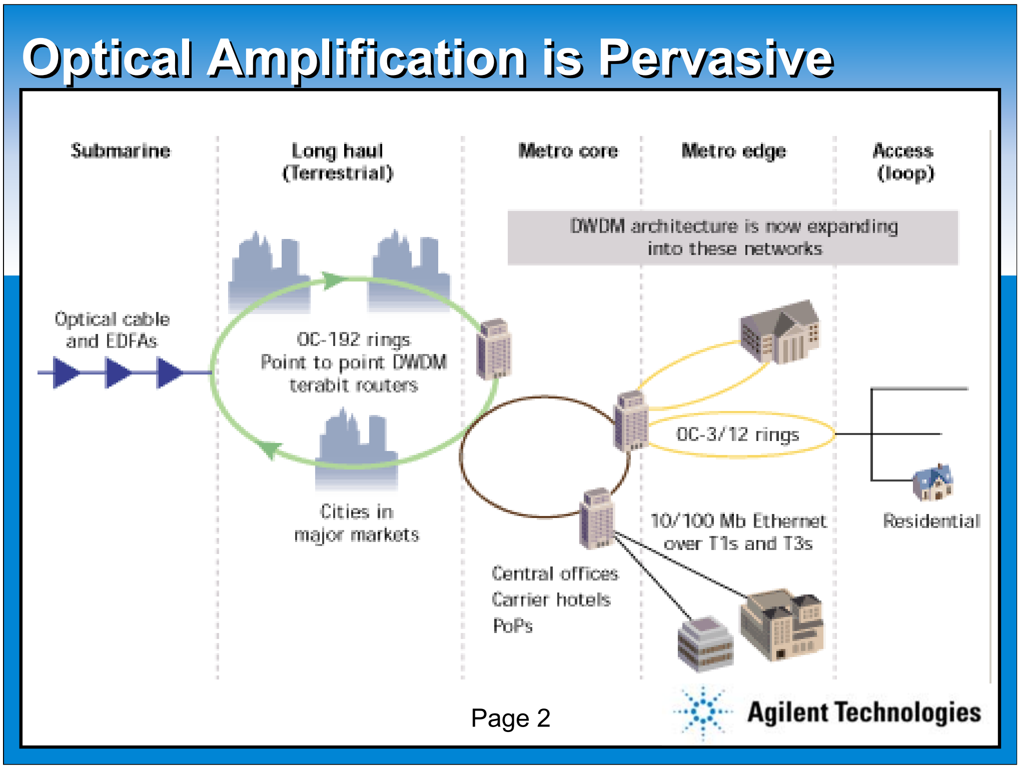

There is no component more ubiquitous in the fiber-optic network then the optical amplifier. The erbium-doped fiber amplifier (EDFA), along with dense wavelength-division multiplexing (DWDM), enabled high-capacity transmission in the submarine and long-haul terrestrial network. As depicted in this slide, the applications of optical amplifiers extend from submarine and long-haul terrestrial networks through the metropolitan (metro) networks. Metro application of optical amplifiers will become pervasive as DWDM expands into the metro networks. While the need for amplification to make up for fiber loss in metro is less significant because of the shorter lengths involved, the use of cross-connect switches and other signal routing devices require amplification to overcome insertion loss. Amplifiers in the metro segment will be required to carry fewer channels and in some cases, only a single channel. The reduced performance requirements open the door to lower-cost EDFA designs and alternative technologies such as the semiconductor optical amplifier (SOA) and the erbium-doped waveguide amplifier (EDWA).

Enabling Low-Cost Amplification

Topics

- Optical Amplifier Trends
- Technology of Optical Amplifiers
- Testing Optical Amplifiers
- Agilent Building Blocks and Systems for OA Test

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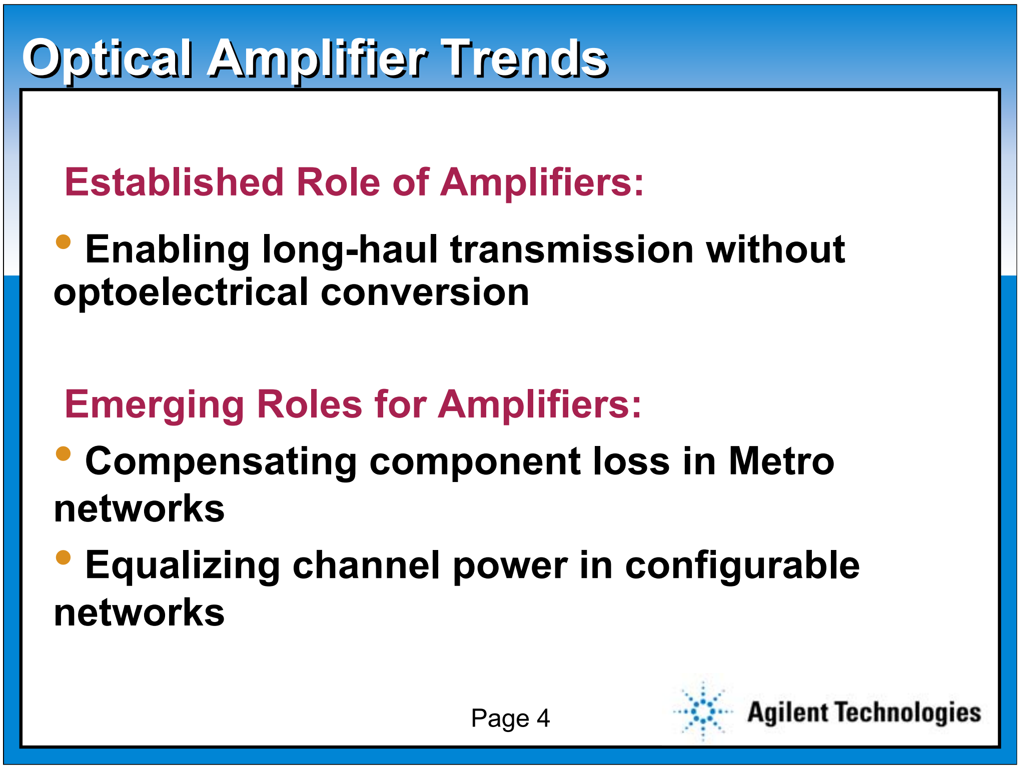

The types of optical amplifiers and their applications are becoming increasingly diverse in direct response to market demands and maturing technology.

Demand for increased transmission capacity can be addressed by higher bit rates, which can be supported with Raman amplification, and by new wavelength bands that can be made accessible by L-band EDFA, Raman, and alternatively doped fiber like the TDFA and SOA.

Increasingly capable and flexible metro networks particularly benefit from smaller and lower-cost amplifiers, which may be based on EDFA, EDWA and SOA technology.

Here we briefly consider the special features of these different amplifiers and discuss their test needs.

Optical Amplifier Trends

Established Amplifier Technology:

- Erbium-doped fiber amplifiers, (EDFA) for the C-Band (1530-1565nm)

Emerging and Growing Amplifier Technologies:

- L-Band EDFA (1565-1625 nm)
- Raman amplification
- Erbium-doped waveguide amplifier (EDWA)
- Semiconductor optical amplifier (SOA)
- Other doped-fiber amplifiers for new bands, e.g. thulium-doped fiber for S-Band (1460-1530 nm)

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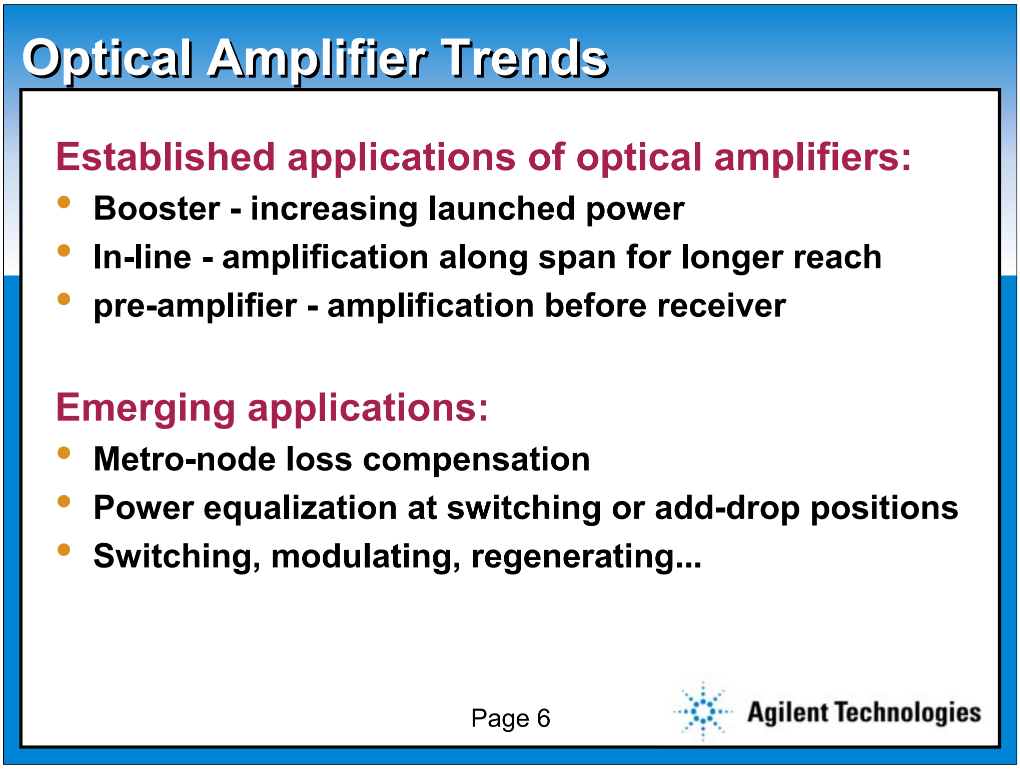

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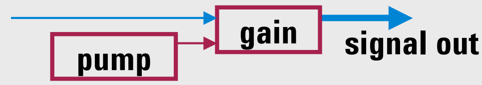
Optical Amplifier Technologies

Basic Principle



- The signal to be amplified is guided through a gain medium (like a fiber or waveguide)
- The gain medium is “pumped” by an appropriate energy source, such as laser light or electrical current, which enables the gain medium to generate light at the signal wavelength
- The signal stimulates the emission of identical light by the gain medium, thus increasing the light in the signal

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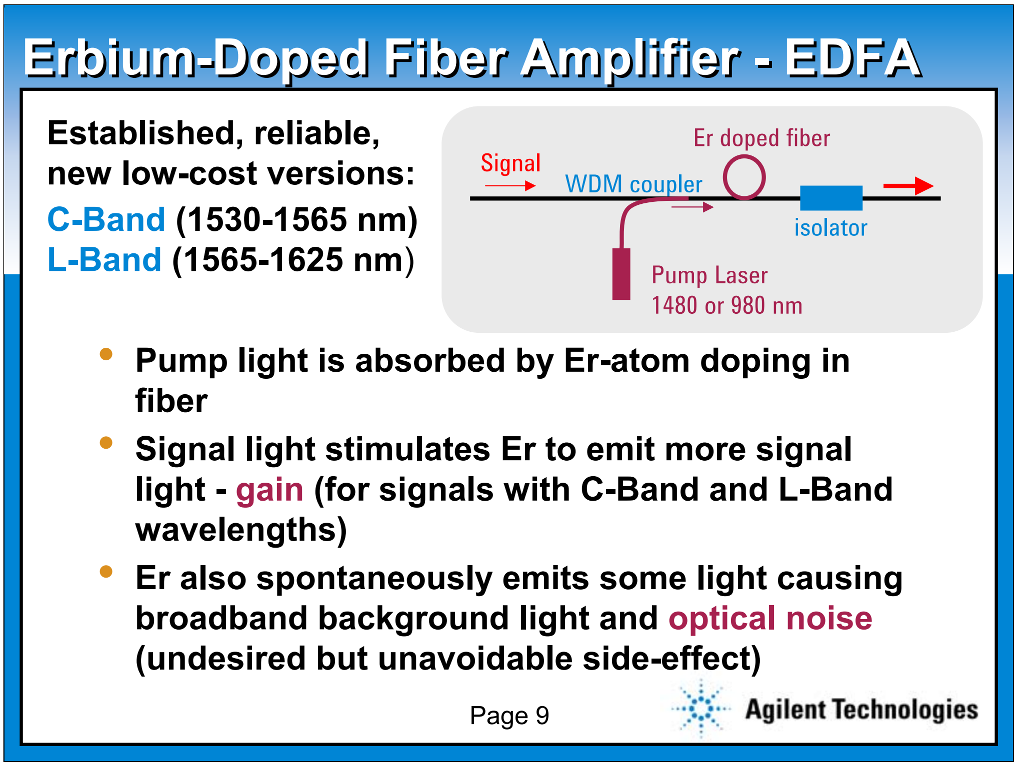


The EDFA is based on optical fiber which has a small concentration of erbium atoms in the core. Pumping is provided by coupling laser light of the appropriate wavelength into this erbium-doped fiber. The erbium absorbs the pump light and can then reemit the energy as light in the C-band and less strongly in the longer-wavelength L-band. Signal light is also coupled into the fiber. It stimulates the erbium to emit at exactly the same wavelength, thus amplifying the signal. Many wavelengths within the gain band can be simultaneously amplified!

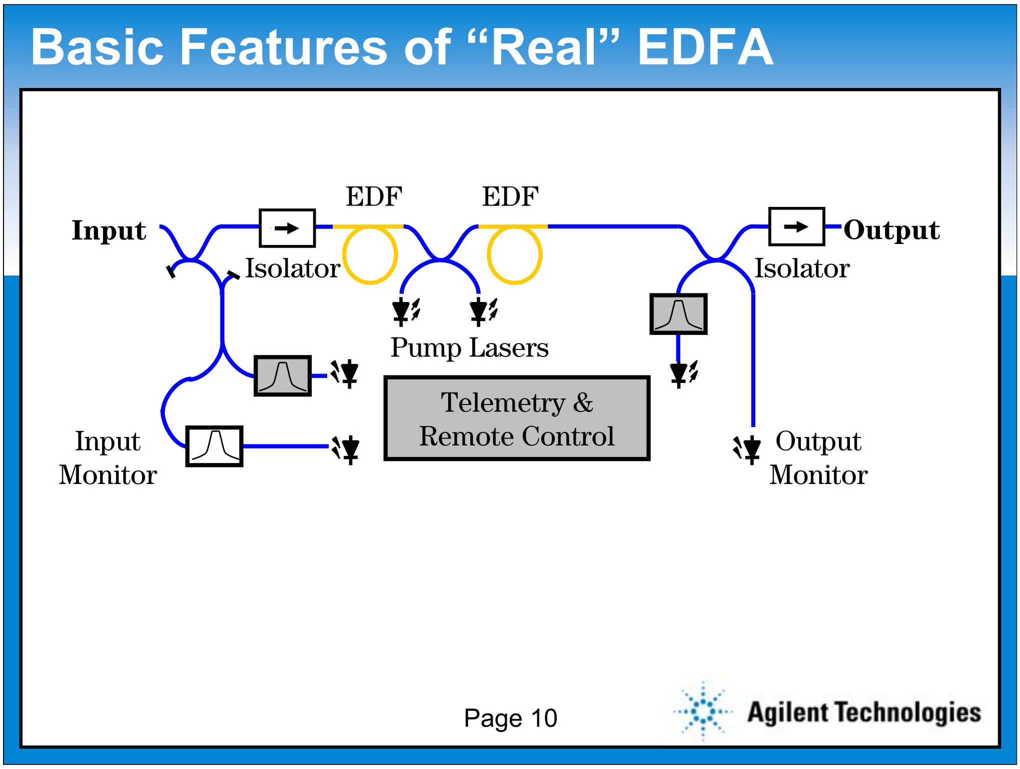
As the erbium can also emit light without stimulation from a signal, the amplifier also produces broadband spontaneous emission that is not related to the signals but is also further amplified. This amplified spontaneous emission (ASE) mixes with the signal causing noise.

The figure shown is a very basic schema for an amplifier and a complete EDFA may exhibit considerably higher complexity.

Isolators are included to avoid the amplification of reflected light and the possibility of a resonant cavity.

Tap couplers with photodiodes are included to monitor the input, output, and reflected optical power levels. This information can be used as feedback for adjusting the pump laser power and initiating an automatic pump shutdown if the output fiber is broken or disconnected.

There may be two or more stages of amplification, with additional functionality between the stages, such as gain flattening or dispersion compensation.



A more typical amplifier as shown in this slide. Isolators are included to avoid the amplification of reflected light and the possibility of a resonant cavity.

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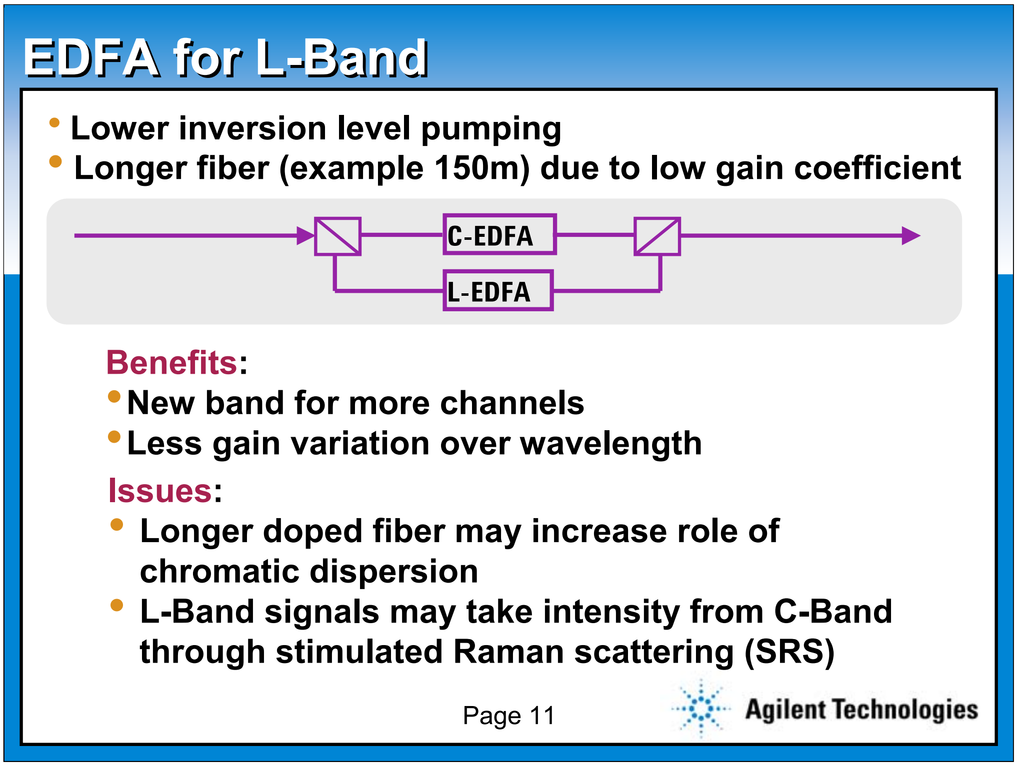

Additional DWDM channels can be added to a network by adding L-band amplification to a transmission line. The C-band and L-band signals can travel together in the optical fiber and most components. At the amplification points, the two bands of signals need to be split, sent to the respective amplifier, and then recombined. Note that it would disturb the operation of the L-EDFA if the C-band signals were allowed to enter it.

There is less structure in the gain curve in the L-band, so that gain flattening is more easily achieved.

There can be a complication in adding L-band channels to a system already operating in the C-band because power can be transferred from the short-wavelength channels to the long-wavelength ones by the Raman effect (discussed later). This is usually most significant when the difference between the two signal wavelengths is close to 100nm. This may discourage extending the L-band channels beyond about 1620nm.

Doped Fiber for New Bands

- **Other dopants than Er can be used, that emit light at other wavelengths: still emerging**
- **Important examples:**
  - **Thulium "TDFA" can be used to provide gain in the S-Band (1460-1530nm)**
  - **Praseodymium "PDFA" can be used for gain in the O-Band (1260-1360 nm)**
- **Other host glasses besides conventional silica fiber also influence the positions, widths and efficiencies of emission bands for the dopants**

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Just as the modified EDFA has been developed for the L-band, doped-fiber amplifiers with other dopant materials offer the possibility of amplification in other wavelength regions.

An important example uses thulium-doped fiber for the S-band, from about 1460-1520nm, depending on the type of host glass and the method of pumping. This offers the possibility to add channels on both the short- and long-wavelength sides of the standard C-band. This would for example avoid the complication of the new channels removing power from the existing channels due to the Raman effect, as can occur by adding L-band channels.

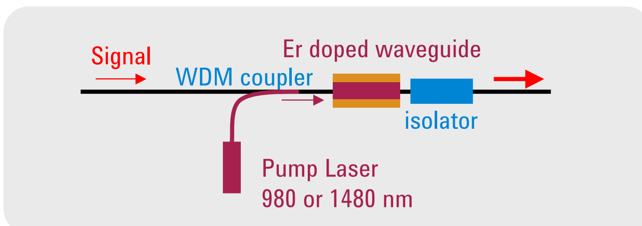
Another interesting material is praseodymium-doped fiber, which can be used for amplification in the 1310nm window of silica fiber.

A complication in developing these amplifiers, compared to the EDFA, is that new host glasses need to be developed. It has been difficult to find glasses combining good dopant concentration and gain properties with good properties for stability and connectibility (splicing).

Erbium-Doped Waveguide Amplifier

EDWA

- Same principle as EDFA but using doped planar waveguide (C-Band now; later also L-Band)
- Can also be integrated with conventional waveguide components like couplers/splitters.
- Very attractive for parallel arrays of amplifiers



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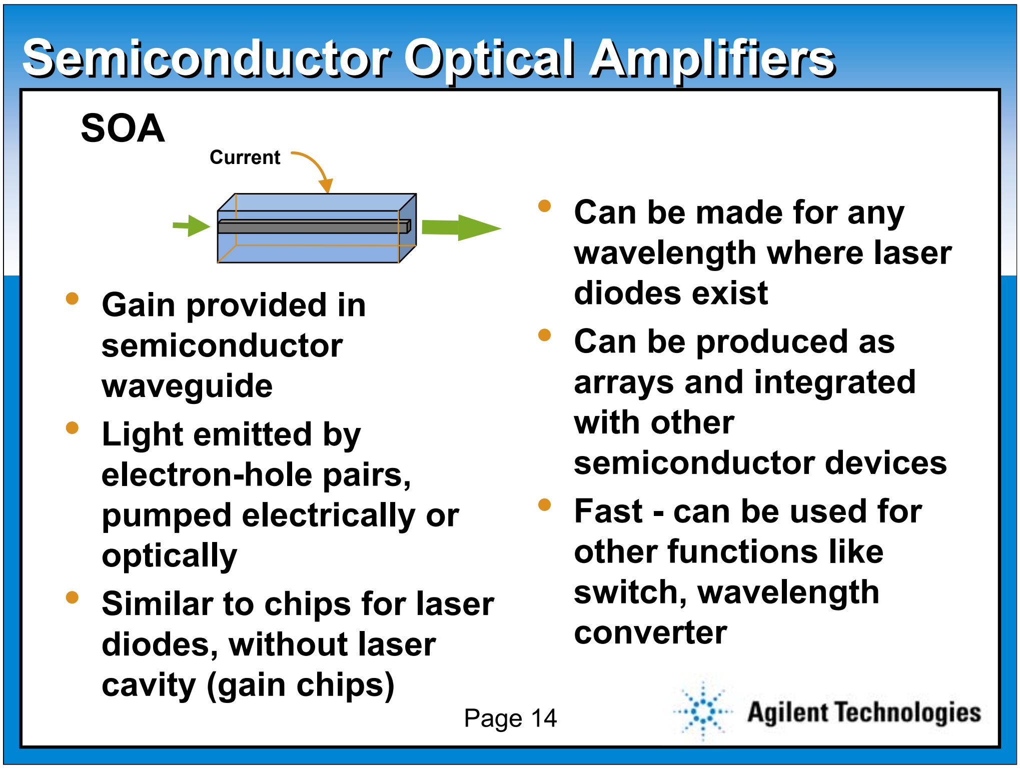
An amplifier with similar behavior to an EDFA can be achieved by doping a planar waveguide, instead of fiber, with Er. These generally use shorter gain paths with higher dopant concentrations than are typical for an EDFA. Both this concentration and the different host material can lead to different gain spectra and different transient (timing) behavior.

These devices can be used to make more compact amplifiers and production may be more easily automated. It is also attractive technology for making arrays of multiple amplifiers on a single substrate. Amplification can also be combined with other planar waveguide components for advanced devices.

EDWA are currently available for the C-band. EDWA for the L-band can also be expected, but are likely to require longer waveguides, as is also true of the L-band fiber EDFA. Other dopant materials should also be possible in waveguides to address other wavelength regions.

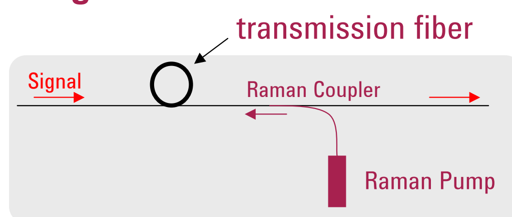


While the EDFA is currently the prevalent amplifier type and Raman is emerging to provide better performance, the semiconductor optical amplifier (SOA) continues to progress as a potentially more compact and lower cost alternative. The SOA also has applications in optical switching and as a non-linear device in applications such as wavelength conversion. The SOA may also be applied in the 1310-nm window where doped-fiber amplifiers have not proven to be viable.

The simplest construction of an SOA is a semiconductor laser, operated below threshold, with low facet reflectivity. Such a device can be compact is size, have low power consumption and can readily be integrated with other optical components.

Raman amplification

- **Special Raman Amplifier Features:**
- **No fiber doping required - transmission fiber can be amplifying fiber!**
- **Weak effect - long lengths >10 km, high pump power >20-30 dBm**
- **Amplified λ-band shifts with pump-wavelength: with right pump, any wavelength!**



The properties of the Raman effect give special properties to the amplifiers. No doping is required and amplification is even possible in normal transmission fiber. The effect is weak, so it is necessary to use high pump power and long fiber to reach significant gain.

Typically, about 500mW pump power is required to achieve 10dB gain in standard single-mode fiber.

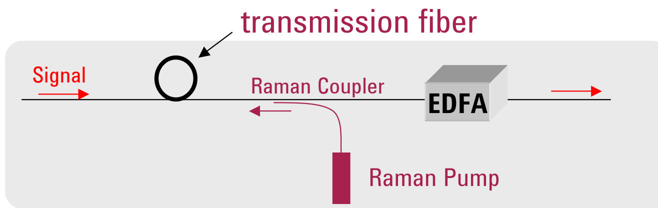
Raman amplifiers can be made for any wavelength region because the gain wavelengths shift together with the pump wavelength. Also, by pumping at multiple wavelengths, gain can be achieved over very broad bands and the flatness of the gain spectrum can be adjusted with the relative pump powers.

The ability to put amplification in long lengths of transmission fiber makes "distributed" Raman amplification possible and is one of the most important benefits. This can be combined with EDFA amplifiers for a "hybrid" system. It is also possible to make amplifier modules that contain the fiber as a "discrete" device as is common with the EDFA.

Raman amplification

Configurations:

- **Amplifying fiber included in box, "discrete" amplifier,**
- **Amplifying fiber is transmission fiber, "distributed" amplifier,**
- **Distributed Raman pre-amp. combined with EDFA, "hybrid" amplification**



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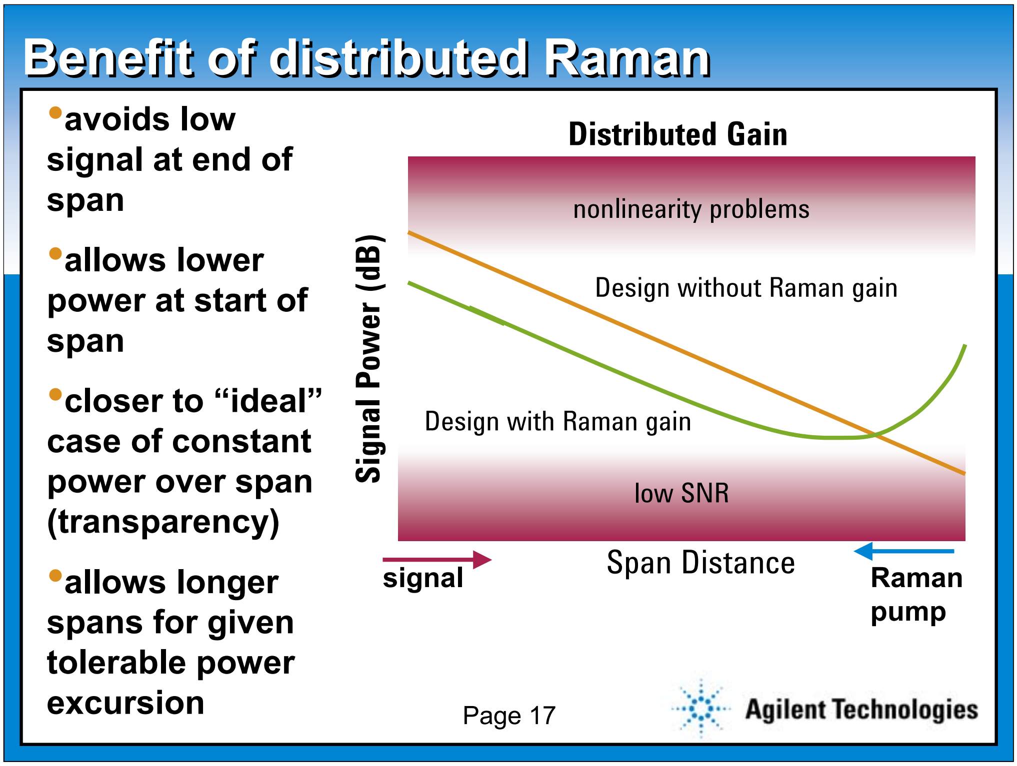
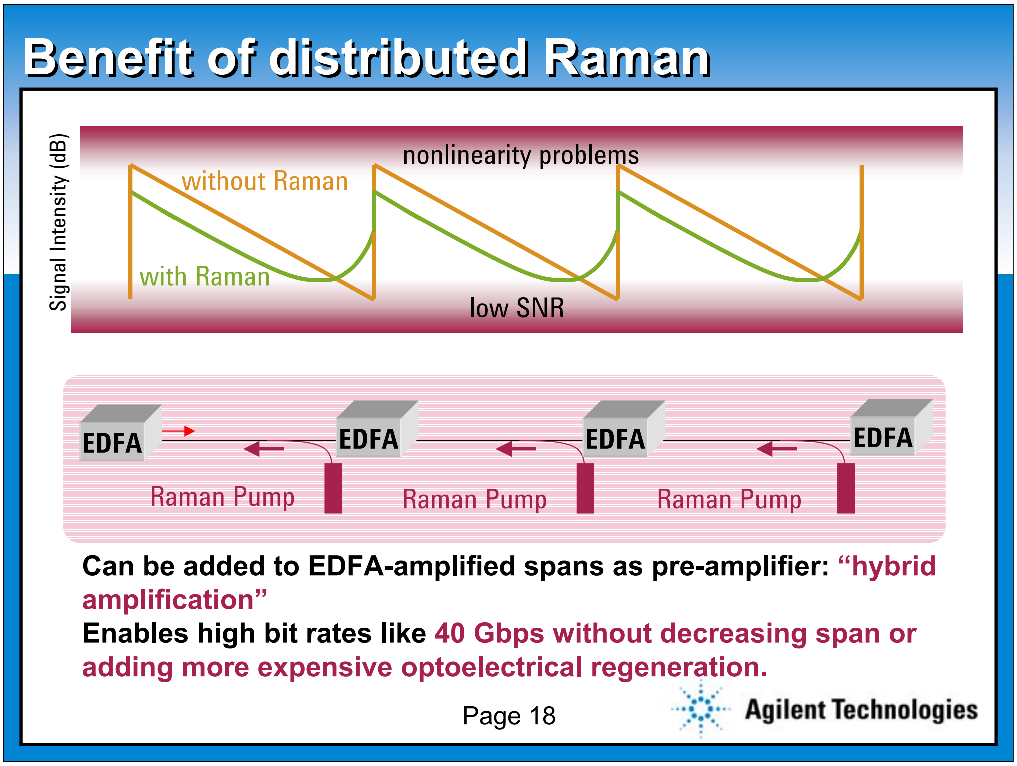


One important advantage of Raman amplification is the capability to “distribute” the gain over a long distance in the transmission fiber.

The difference between maximum and minimum intensity in a span can be reduced without reducing the span length, avoiding problems with too high and too low intensity. Using lower launch intensities avoids nonlinearity. The noise properties of distributed amplification is also better than if all of the gain is made at one point.

This helps achieve long distances with a series of amplified spans without expensive optoelectrical regeneration and enables high bit rates like 40 Gbps.

It is possible to combine the benefits of moderate distributed Raman gain with the more efficient power conversion of the EDFA in a hybrid amplification system. This system will have better noise performance, allowing longer spans, than a similar system with only EDFA.



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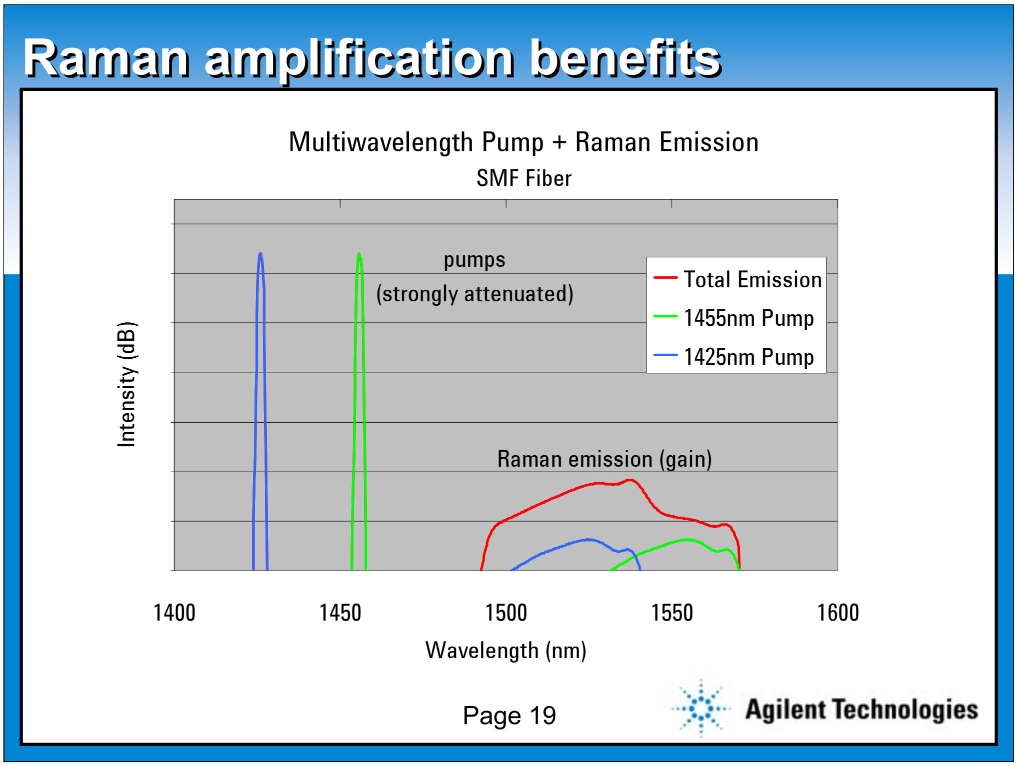

The wavelength band for amplification can be freely determined by choosing the pump wavelength. This is major difference to EDFAs, where the erbium determines the band. New bands, like S-band are possible!

Multiple pump wavelengths can be used for wider bands and the intensities can be adjusted for gain flatness! The gain bands of each pump wavelength simply add together!

Thus it is common to pump Raman amplifiers with more than one wavelength.

Raman amplification benefits

- Gain band moves with the pump wavelength: new bands and broad bands can be amplified
- WDM pump can broaden amplification band
- Pump intensities can be adjusted to flatten gain

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Testing Optical Amplifiers

Basic Issues

Device properties depend on input optical power
- Select and adjust source power

Device properties depend on input wavelength distribution
- Select and adjust wavelength
- Multichannel source for multichannel OA test

Devices emit light over a broad wavelength range
- Measure output spectrally: need OSA

Devices have time-dependent properties
- Control and measure transients
- Consider effects of source modulation

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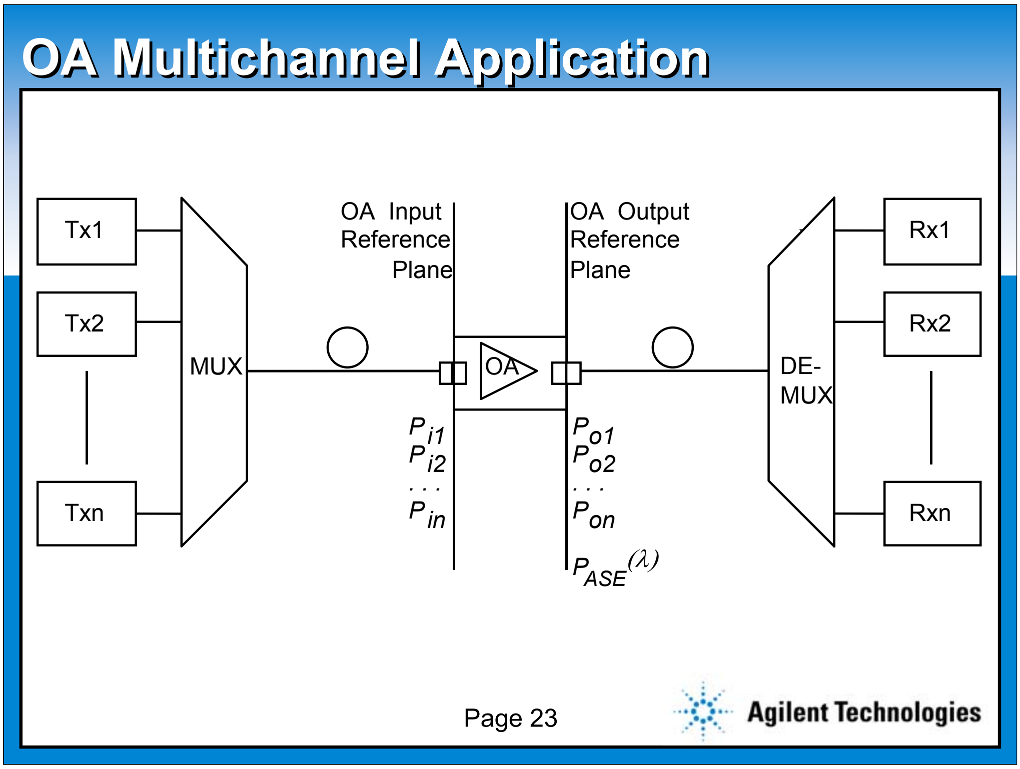
Despite the variety of amplifier types, the most important properties are common to all of them and most of the basic issues and methods for testing are the same. Now we will discuss the common test needs and also some issues that are specific to individual amplifier types.

An important point is that the essential parameters of an amplifier depend on the input power and on the distribution of signals over wavelength. Therefore it is necessary to choose the right sources with the right flexibility.

Also, since amplifiers emit their own light over a broad wavelength range and are often used to amplify multiple signals, the output generally needs to be analyzed spectrally.



The IEC has defined gain and noise figure parameters for the general case of an optical amplifier used in a multichannel (WDM) applications. A typical configuration of an OA in a multichannel application is shown inthis slide. At the transmitting side n signals, coming from n optical transmitters, T_{x1}, T_{x2}, . . . T_{xn}, each with a unique wavelength, λ_1, λ_2, . . . λ_n, respectively, are combined by an optical multiplexer (OM). At the receiving side the n signals at λ_1, λ_2, . . . λ_n, are separated with an optical demultiplexer (OD) and routed to separate optical receivers, R_{x1}, R_{x2}, . . . R_{xn}, respectively. To characterize the OA in this multi-channel application an input reference plane and an output reference plane are defined at the OA input and output ports, respectively.

At the input reference plane, n input signals at the n wavelengths are considered, each with a unique power level, P_{i1}, P_{i2}, . . . P_{in}, respectively. At the output reference plane, n output signals at the n wavelengths, resulting from the optical amplification of the corresponding n input signals, are considered, each with power level P_{o1}, P_{o2}, . . . P_{on}, respectively. Moreover, the amplified spontaneous emission (ASE) with a noise power spectral density, $P_{ASE}(\lambda)$, is also to be considered at the OA output port.

International Standards for Optical Amplifiers

OA standards are addressed by the IEC*

- IEC 61290-series addresses test methods
- IEC 61291-series addresses parameter definitions
- IEC 61292-series are technical reports on a variety of subjects including:
  - Amplifier component parameters
  - Theoretical background for noise figure
  - Classification of OA types
  - Optical safety

* http://iectest.iec.ch/

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Much of the work for standardization of optical amplifiers and their test methods is done within the International Electrotechnical Commission.

Test methods have been published for gain and optical power measurements based on the use of an optical spectrum analyzer, an electrical spectrum analyzer, and an optical power meter. Documents defining test methods for noise figure parameters based on an optical spectrum analyzer and on an electrical spectrum analyzer are nearly ready for publication.

Drafts nearing publication in the series IEC 61290-10-x also address the special needs of multi-channel amplifiers.

Current information on IEC documents can be found on the IEC website: www.iec.ch

International Standards for Optical Amplifiers

IEC Test Procedures

- **IEC 61290-1-series:** Gain parameters
- **IEC 61290-2-series:** Optical power parameters
- **IEC 61290-3-series:** Noise figure parameters
- **IEC 61290-5-series:** Reflectance parameters
- **IEC 61290-10-series:** Multichannel gain and noise figure parameters
- **IEC 61290-11-series:** Polarization Mode Dispersion

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Key Parameters

- Gain
- Channel gain
- Small-signal gain
- Noise figure
- Signal-spontaneous noise figure
- Multichannel gain tilt
- Multichannel gain variation (flatness)
- Gain ripple
- PDG
- PMD

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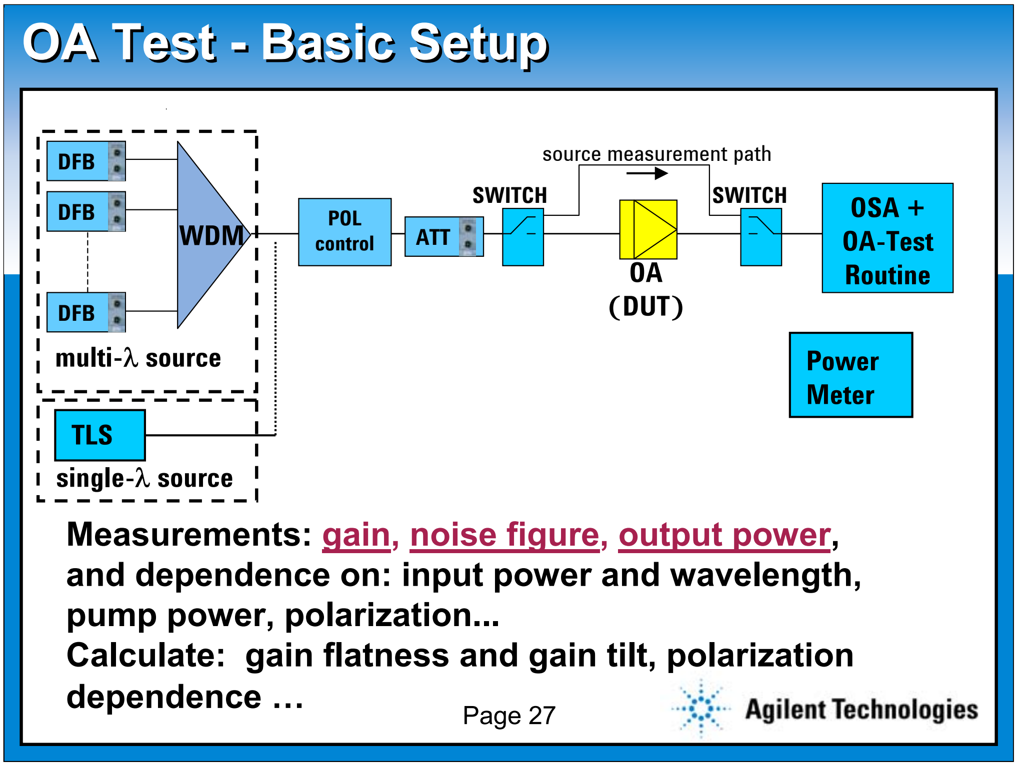
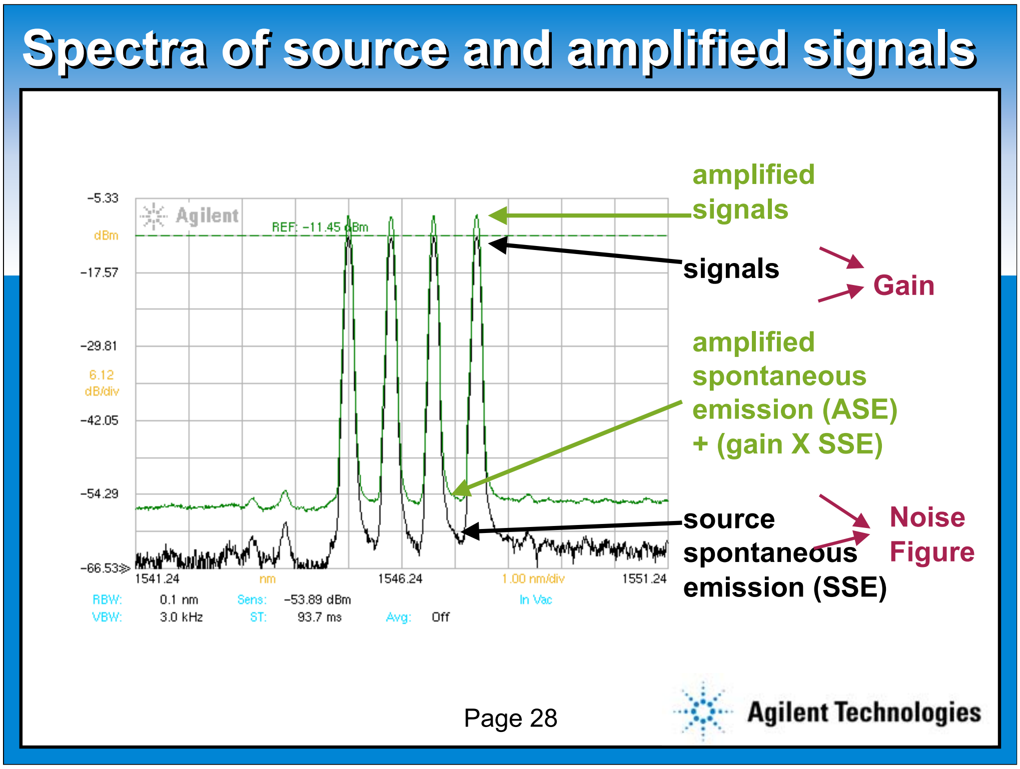


The illustration depicts a basic setup that can be used to measure the major parameters of any optical amplifier, including: gain, output power and noise figure. Generally, their dependence on input power, wavelength, polarization and other factors needs to be determined over the relevant ranges. Some of the parameters indicated for specification by international standards are obtained by analyzing these dependences.

The **source** must be able to provide enough input power to reach the limits of the amplifier. For amplifiers used with a single channel, a single-wavelength source, like a tunable laser can be used. For amplifiers used in a multi-channel application, it is usually necessary to measure with a similar set of wavelengths as required by the application. An **attenuator** can be used to control the input source over a range of power. Wavelength-flat attenuation, provided by the Agilent 8157x-series modules, greatly assists multi-wavelength testing.

An optical spectrum analyzer, **OSA**, is used to measure both the input signals and the output of the amplifier. Switches or reconnection can be used to change between the two types of measurements. A reference power meter permits calibration of the difference between signal power at the OSA and at the amplifier input and output, as well as calibration of the absolute power for the OSA which is important for accurate noise figure measurements.

Details for calibration are described in the Agilent application note “Measuring Dependence of Optical Amplifiers on Input Power Using an Attenuator”, publication number 5988-5260EN.



This figure shows measured spectra for the unamplified and the amplified signals from a distributed Raman amplifier. This illustrates the primary measurement needs for gain, power and noise figure.

The power of the signals must be measured accurately, and especially with good relative accuracy for gain calculation. This requires an OSA with very good fidelity (linearity) to accurately compare very different power levels.

It is also important to accurately measure the spontaneous emission for determination of noise figure. This requires an OSA with good dynamic range and sensitivity. This is an absolute power measurement and is best performed by calibrating the OSA together with a reference power meter. It is also important that the noise equivalent bandwidth of the OSA is calibrated, since the measured intensity of the broadband light depends directly on the bandwidth.

The most flexible method for measuring amplified spontaneous emission (ASE), which can be used with all amplifier types, is called interpolation with source subtraction (ISS) and depends on spectral-resolution to separate the signals from the ASE. As can be seen, this depends not only on the 3-dB bandwidth, called the resolution bandwidth, but on the spectral resolution 30-40dB down, called the dynamic range. The filtering of the Agilent 8614x-series OSA permits accurate ASE measurement down to a channel spacing of 100GHz.

Choosing test sources

Criteria:

- **Single or multi-wavelength (based on the application)**
- **Wavelengths or wavelength range**
- **Required input power**
- **Gain stability**
- **If multichannel, how many lasers?**

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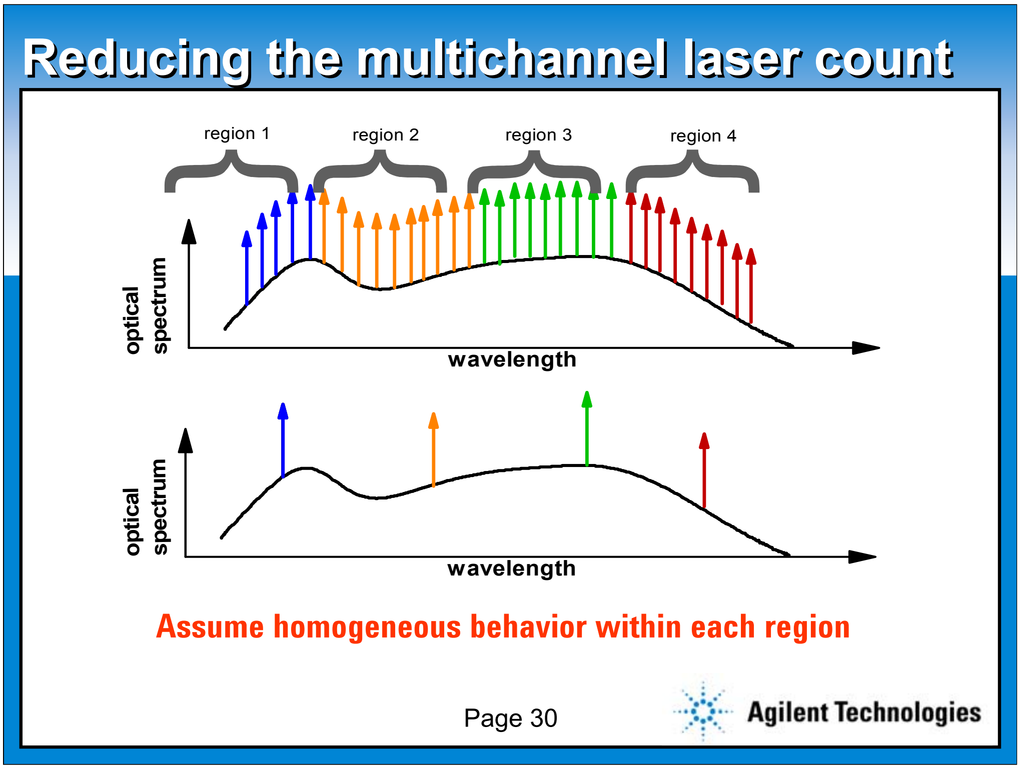
An important amplifier test system consideration is the type of input signal source which must provide:

- Enough power
- Stability in wavelength and power for accurate gain measurements
- The required wavelength range

If the amplifier is for single-channel applications, it can be tested with a single laser source. The flexibility and 10dBm power of the compact Agilent 81689B tunable laser make this a good choice.

For multi-channel applications, the amplifier usually needs to be tested with a multiple wavelength source such as a set of DFB lasers. Today's DFBs, like the Agilent 81662A and 81663A modules, offer the high power and stability needed for accurate measurements over the necessary wavelength ranges. Low source spontaneous emission permits accurate noise figure measurement with the ISS method.

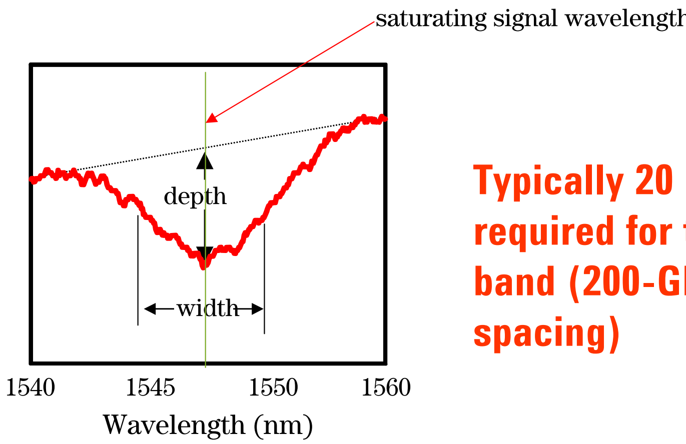
The number of test channels must be chosen based on the details of the amplifier and its application. If the necessary input power is concentrated in too few channels, the gain at these wavelengths can be reduced by "spectral hole burning", SHB, below the gain level when the power is distributed over more channels. One approach is to test with the same number of channels as will be transmitted in the network. However, studies of SHB linewidth in EDFAs indicate that test channel spacing usually need not be less than 100 GHz and sufficient testing can often be reached with about 16 channels per band. It is therefore possible to use a reduced set of test wavelengths for amplifiers that will be used with many channels. Different doped-fiber materials, amplifier technologies, and gain-flattening features may influence the choice of test channel count.



Setting the power level of a reduced set of lasers to replicate the effect of a larger set is based upon the homogeneous model. As shown is here, the spectrum is divided into regions. The regions may be unequal in width and all the signals within each region are simulated by one larger signal in each region. However, when spectral hole burning (SHB) plays a role, the saturation wavelength is approximated as a weighted average of the ensemble of closely spaced channel powers.

Spectral Hole Burning (SHB)

Limits the Reduction in Test Lasers



Typically 20 lasers required for the C-band (200-GHz spacing)

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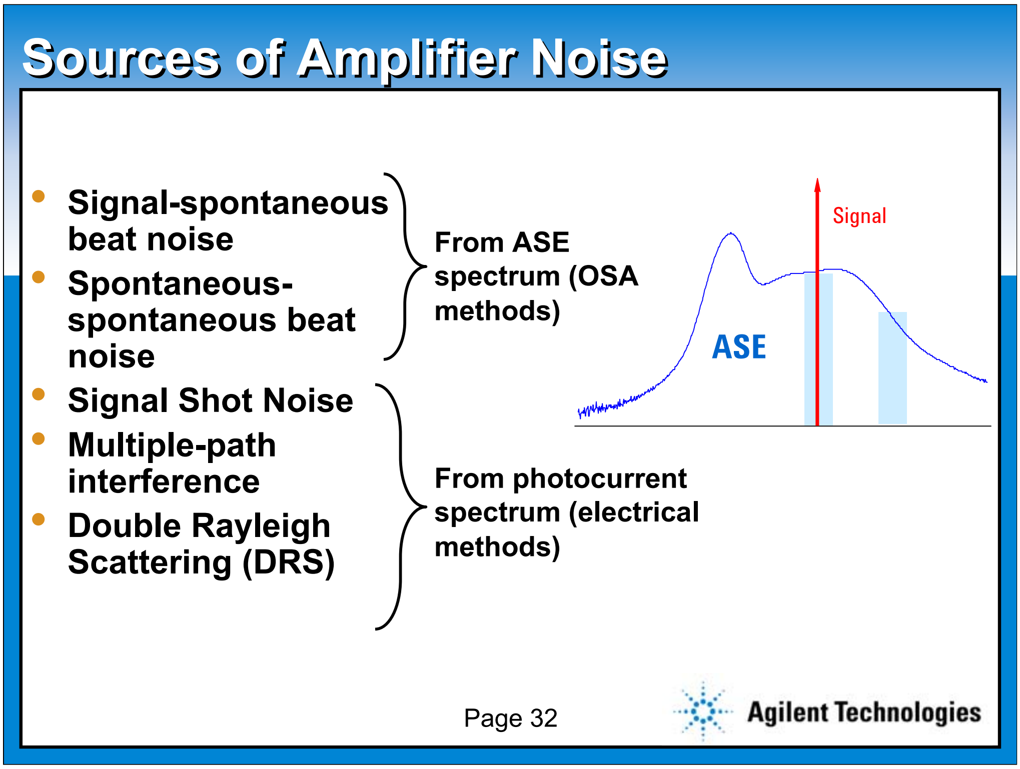
The reduction in the number of lasers is limited by spectral hole burning (SHB). As shown , SHB is a wavelength-localized depression in gain that is signal power dependent. SHB reduces the average ion population contributing to gain locally in excess of the global reduction. For an amplifier that is to be used in a WDM environment, it is essential that the gain and noise figure that are measured include the SHB effect. If the spacing of the test lasers is too wide, the measured gain will be higher than actually encountered in the WDM system. The gain depression has a width, called the spectral hole width, that is in the order if 3 to 8 nm. For good accuracy, the lasers must be positioned in wavelength so that their spacing is less than the spectral hole width.



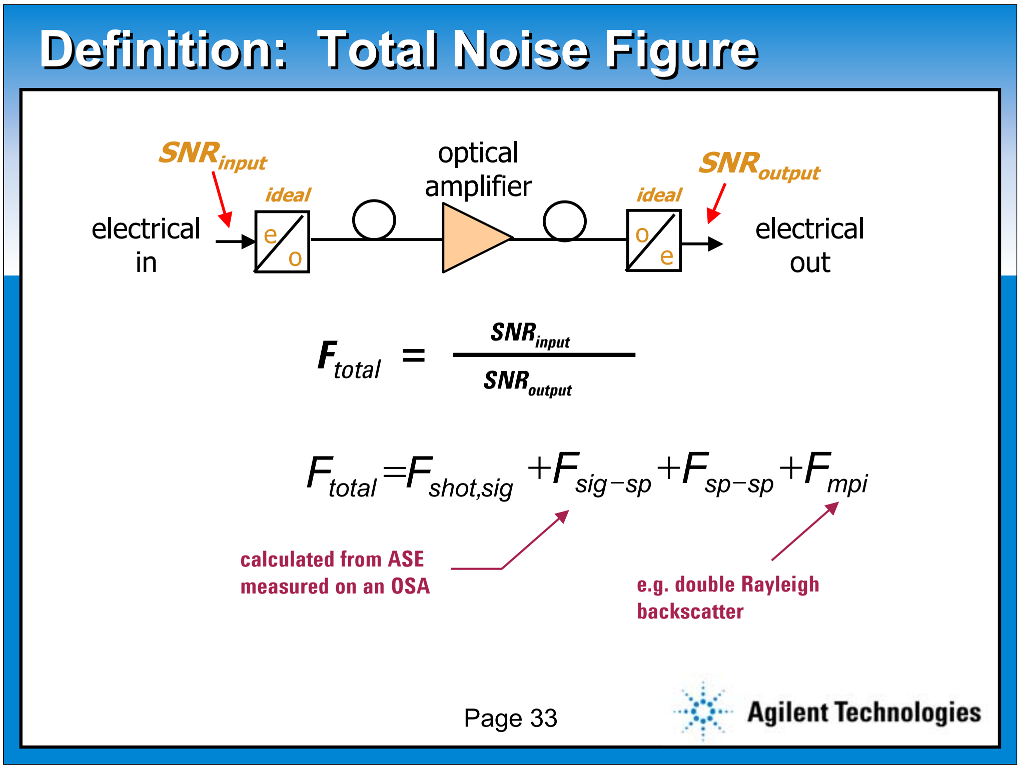
There are several possible sources of noise in the signal from an amplifier. Signal shot noise and signal RIN are amplified but not caused by the amplifier. For electrically detected noise measurements, the signal RIN must be minimized.

Signal-spontaneous beat noise is the dominant contributing factor to the amplifier noise figure, especially for the EDFA. This is caused by the mixing of the signal with the ASE at nearby wavelengths. Beat noise is caused over the frequency range corresponding to the difference between the optical frequency of the signal and that of the ASE, which is very broad. Similarly, beat noise can be caused by beating of the ASE with itself but this effect can be minimized by filtering ASE either at the amplifier or, more commonly, at the detector. Wavelength demultiplexing ca also accomplishes this, preventing the full bandwidth of ASE from reaching the receiver.

ASE can be measured directly by optical means and a formula exists to calculate NF from this measurement. This is the most common way to measure NF in an EDFA and is often the also best choice for other amplifiers.

Other contributing factors to noise figure, like pump RIN, multiple-path interference (MPI), and a special kind of MPI due to double Rayleigh scattering are only detectable on the signal wavelength itself and are not usually resolved optically. Instead these are measured electrically.

The method of noise figure measurement can therefore depend on the type and details of the amplifier. For instance, double Rayleigh scattering can be important in high-gain Raman amplifiers because of the long gain fiber. This can require electrical measurement. When signal-spontaneous beat noise is dominant, optical measurements are most common.



A side effect of providing gain is that an amplifier always degrades the signal-to-noise ratio of a signal. That is, the noise increases more than the signal intensity. The noise figure characterizes this degradation and is defined in terms of the measurable noise on the electrically detected signal.

Often called *total noise figure*, the basic definition of optical noise figure is defined in electrical quantities as shown in Figure 11 [4][5]. It is explicitly defined as:

The decrease of the signal-to-noise ratio (SNR), at the output of an optical detector with unitary quantum efficiency, due to the propagation of a shot-noise-limited signal through the OA, expressed in dB.

Noise factor is the linear representation of noise figure and is related to noise figure as follows:

Noise figure (NF) = 10log(F) where F is the noise factor

The noise factor as shown in Figure 11 may be broken down into multiple contributions as indicated is Figure 12. Each of these contributions can be expressed by a partial noise factor [6]:

a) Signal shot noise factor, Fshot,sig , from shot noise from amplified input signal;

b) Signal-spontaneous noise factor, Fsig-sp , from signal beating with ASE;

c) Spontaneous-spontaneous noise factor, Fsp-sp , from ASE beating with itself;

d) Noise factor from multiple path interference (MPI), Fmpi .

Shot and Signal-Spontaneous Noise

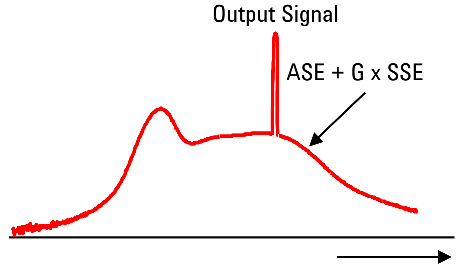
Contributions to noise can be calculated from optical powers

ASE spectral power density in W / Hz

$$F_{sig\text{-}sp} = \frac{\rho_{ase}}{G\, h\, \nu_{sig}}$$

Optical frequency in Hz

$$F_{shot,sig} = \frac{1}{G}$$



F = “noise factor”
NF = “noise figure”=10 log (F)

The challenge: separate the ASE from the strong signal and source spontaneous emission (SSE)

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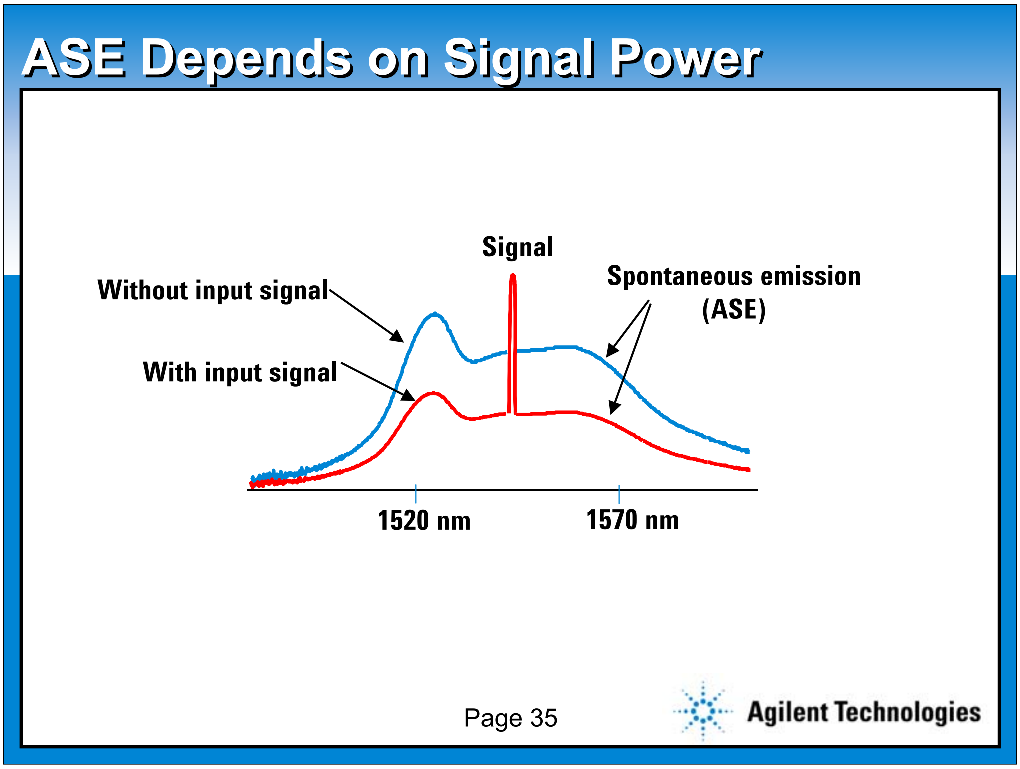
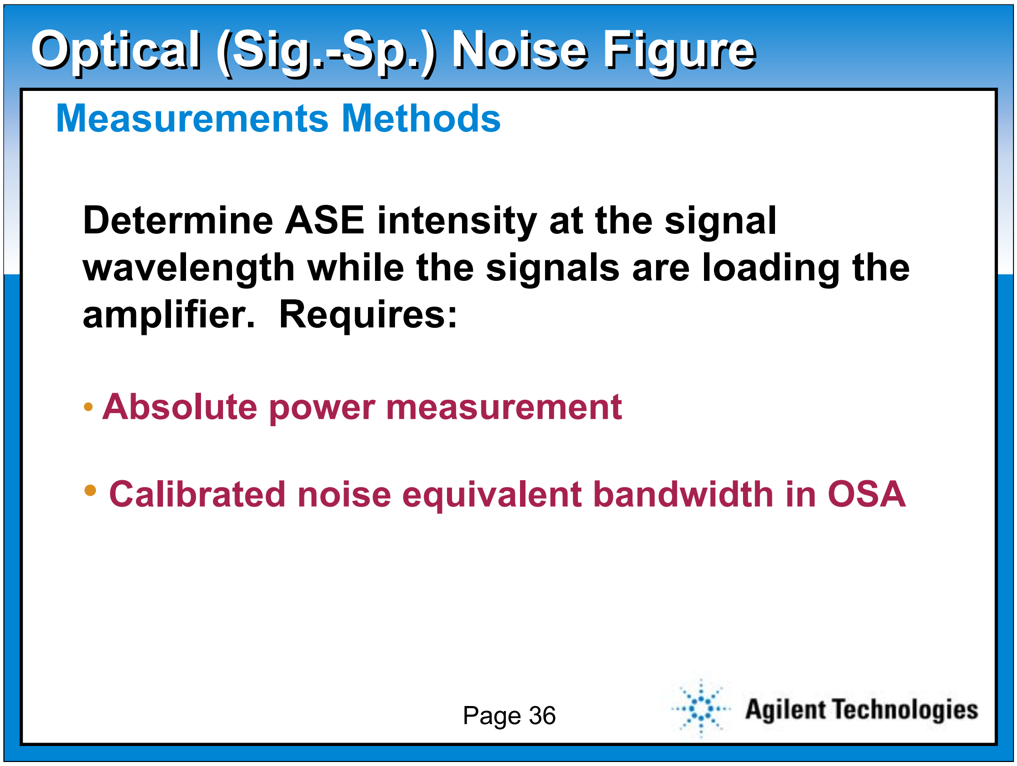
As signal-spontaneous noise often dominates the noise figure, and the noise figure can be calculated from a measurement of the ASE power density, it is usually possible and convenient to determine NF from an optical spectrum measurement rather than an electrical noise measurement.

The requires the determination of the ASE intensity at the wavelength of the signal and the gain at this wavelength. The challenge of the measurement is to get an accurate value for the spontaneous emission at the wavelength of the usually much stronger signal.



The goal is to measure the ASE without interference from the signal light. However, if the signal light is turned off, the ASE changes. This is because the amplifier is now using less power for stimulated emission and has more power available for spontaneous emission. Hence, the ASE increases when the signal is turned off. Several methods have been developed to solve this problem.



The ISS method uses wavelength resolution to separate the signal from the ASE. The ASE is measured at wavelengths close to the signal and the value at the signal wavelength is found by interpolation. In this case, the contribution of spontaneous emission from the source which is also amplified, must be subtracted to find the true ASE.

Another method called time-domain extinction, TDE, uses time resolution to separate the ASE from the signal. The signal is turned off for a short time(usually modulated or pulsed) and the ASE is measured quickly before the amplifier changes the ASE level. This method was developed for the EDFA and relies on the relatively slow rate of change from the erbium. The method is not directly transferable to other types of amplifier, like the SOA which is usually much too fast. It can also be complicated by the control electronics of the amplifier, which may cause faster changes. The necessary modulation rate therefore depends on the details of the amplifier. TDE measurements are not sensitive to the noise level of the source, since this is also modulated out.

It is also possible to separate ASE from the signal using polarization, because ASE is mostly unpolarized. This is called the polarization extinction method. This is difficult to use for multi-channel testing or for amplifiers with polarization dependent gain, like some SOAs.

Optical (Sig.-Sp.) Noise Figure

Two commonly used methods:

Interpolation with Source Subtraction, ISS

- Measure background emission on either side of signals and interpolate to signal wavelength
- Subtract amplified source spontaneous emission
- Applicable to all amplifier types

Time-domain extinction, TDE

- Interrupt input signals and measure background ASE before the amplifier can adapt to the missing signal load.
- Square-wave source modulation at >50 kHz
- Applicable to EDFAs and other doped fiber types

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Applicability of Noise Figure Methods

	ISS $F_{sig-spon}$	TDE F_{sig-sp}	Electrical
EDFA	✓	✓	✓
EDWA	✓	✓	✓
SOA	✓		✓
Raman	✓		✓
Raman DRS		*	✓

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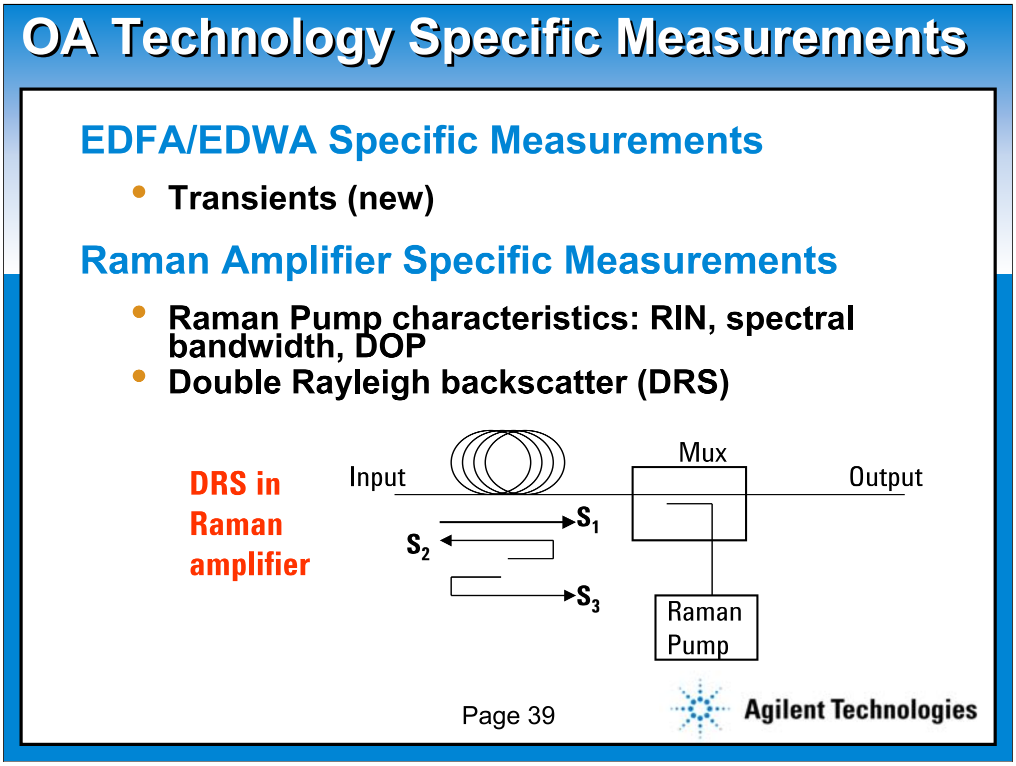


In addition to the standard measurements (Gain, NF, etc) already mentioned for optical amplifiers, there are additional tests that are applicable to a specific amplifier technology. These are illustrated above for Erbium amplifiers, SOAs and Raman.

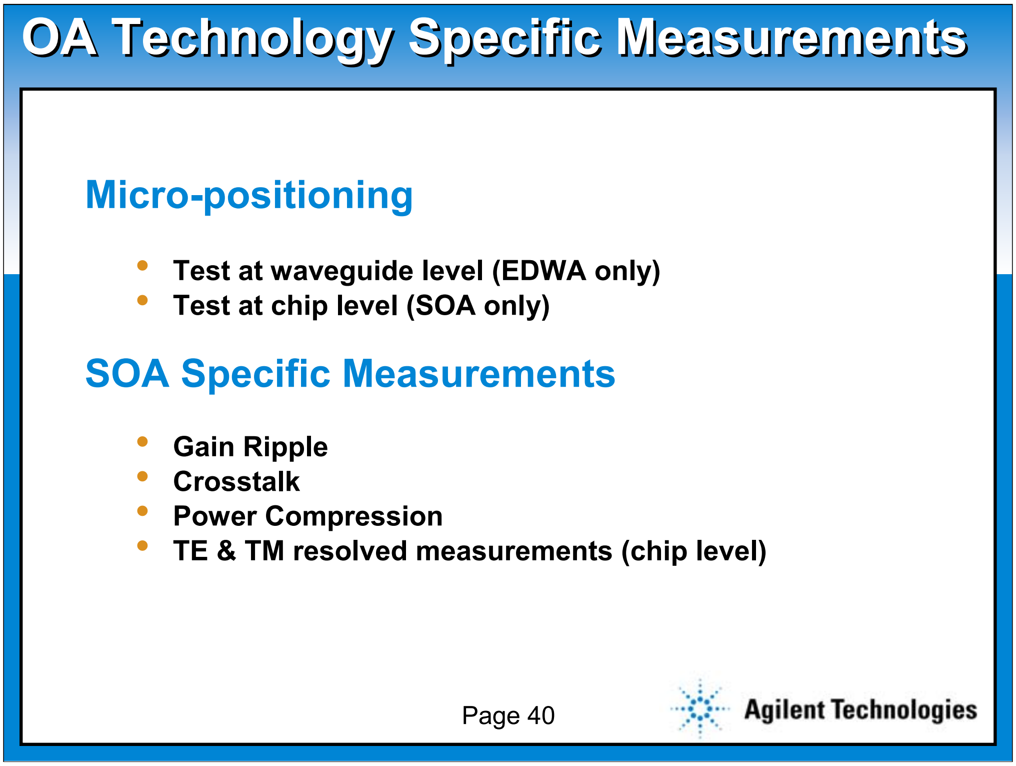
EDFA and EDWA Test

Transient measurements are important for Erbium based optical amplifiers that are to be used in an environment with a dynamic channel plan. As wavelengths are added and dropped from a given link, the remaining (or surviving) channels would normally change their gain. EDFAs designed for use in this environment will employ a transient suppression technique; usually achieved by varying the pump powers. The transients on the surviving channels must be captured and measured for maximum excursion(s) from the initial condition, the settling time and the error between the pre and post conditions.

Raman Amplifier Test

For most amplifiers, the dominant noise component is the signal-spontaneous noise mentioned earlier. In Raman amplifiers, the contributions to the noise due to multi-path interference (MPI) may also need to be included. This noise can become a significant contributor to NF when there is a doubly reflected signal in the gain region of the amplifier. MPI creates noise that is measurable via mixing of the incident signal with the doubly reflected signal, which is measurable via electrical methods

In a distributed Raman amplifier, the device manufactured is not really a complete amplifier: it lacks the single mode fiber that will be supplied by the user. In order to test the Raman pump as an amplifier, a reference spool of fiber must be added. Another approach would be to treat the Raman pump as the DUT and measure its characteristics.



Micro-positioning and OA Test

For both EDWAs and SOAs, it is desirable to test at the waveguide level(EDWA) or the chip level(SOA) prior to device packaging. In this way, costs may be reduced by finding defective devices prior to packaging.

SOA Test

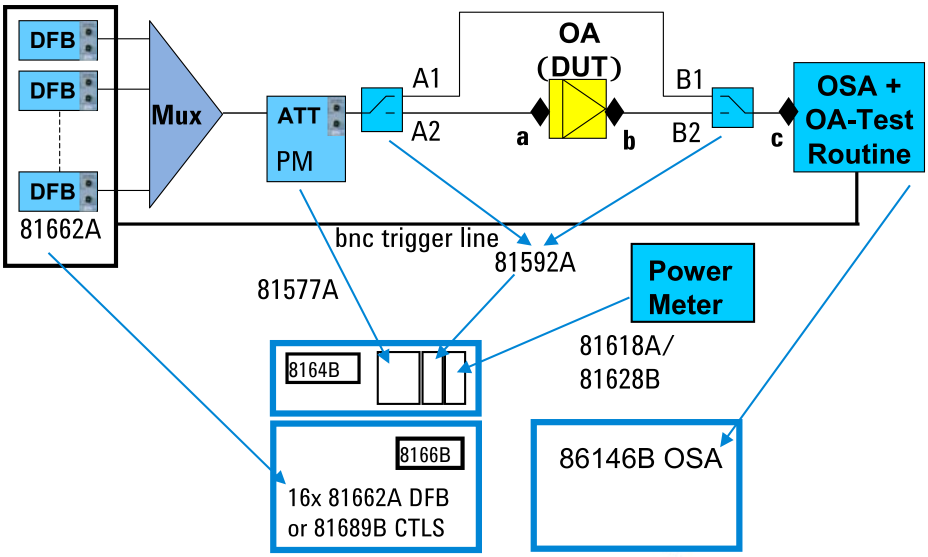
SOAs present additional test challenges. Gain ripple can be present due to etalons in the relatively small device (device lengths range from a few tenth's to a few millimeters). The ripple period of such a device in the 1550nm band can be smaller than the RBW of the OSA. Because of this TLS probe methods must be used in order to measure gain ripple.

As discussed earlier, suddenly removing an input signal from an optical amplifier will cause gain changes on the remaining channels. For Erbium amplifiers, this "gain recovery" is very slow relative to typical telecom modulation rates. The other wavelengths will be unaffected by the modulation on any other channel. For SOAs, the gain recovery can be very fast. This can cause the traffic on one wavelength to modulate the gain(s) of the of the other wavelengths, causing crosstalk..

Some SOAs are designed to behave as linear amplifiers below a certain operating threshold. That is, they have constant gain independent of input power. This constant gain will start to drop when the total power out of the amplifier is taken too high. This is gain compression.

Finally, when testing SOAs at the chip level, it is possible to define a TE and a TM state and measure certain SOA parameters relative to these axes.

Basic Setup for Multichannel Test



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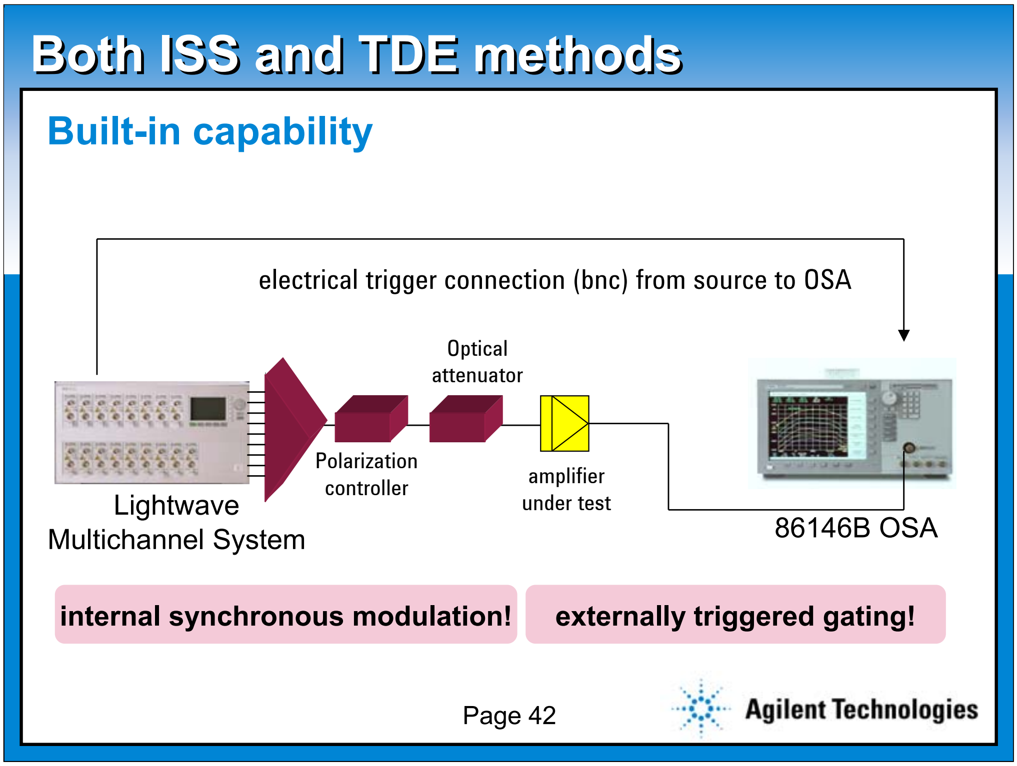


The two major noise figure measurement methods, ISS and TDE, can be realized easily with Agilent instruments.

The 86140 series OSA includes built-in software to measure gain and noise figure with ISS.

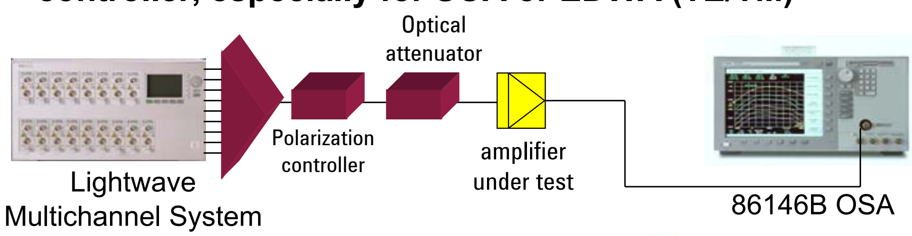
The new 86146B OSA also includes a similar routine using the TDE method. This works together with Agilent DFB and tunable laser modules.

For ISS they provide high stability and low SSE. For TDE they can be modulated directly and synchronously at up to 100KHz. Triggered by this modulation, the OSA detection can be internally gated to measure alternately signal and ASE intensities.

Note also that as shown here, a **polarization controller** is often added to a test system to measure the polarization dependence of gain or to test the amplifier with mixed polarization states at the input to properly simulate actual operating conditions.

Use of Polarization Control

- Improve reproducibility by averaging-out polarization dependence
- Measure polarization dependent gain by determining maximum and minimum powers while scanning input polarization states
- Measure at chosen polarization-states set by controller, especially for SOA or EDWA (TE/TM)



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Important Measurement Practices

- Calibration of path losses in setup
- Calibration of absolute power reading of OSA with reference power meter
- Reproducible and low-loss connections, path switching or splicing of DUT into test setup
- Connector Care and Cleaning (to avoid damage at high power and for reproducibility)

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Enabling Low-Cost Amplification

Topics

Optical Amplifier Trends

Technology of Optical Amplifiers

Testing Optical Amplifiers

Agilent Building Blocks and Systems for OA Test

Agilent's Building Blocks OA Test

Optical Spectrum Analyzer with built-in routines for OA-test: 86142B with ISS and 86146B with ISS and TDE

DFB Laser Modules: 81662A with 10mW and 81663A with 20mW, custom powers and wavelengths available

Tunable Laser Modules: 81689A and 81649A with 6dBm and 81689B with 10dBm

High Power Attenuators with 0.1dB wavelength flatness and optional power control feedback: 8157xA

Mainframes: 8166B, 8164B

Modular Switches: 8159xx

High Power - Sensor Module: 81630B up to 28dBm; Optical Head: 81628B up to 40dBm

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Important Specifications (Instruments)

86146B and 86142B OSA(example, C-band)

- scale fidelity: 0.05 dB
- pol. dep.: 0.05 dB
- Bandwidth accuracy: 3%

86130B High Power Sensor

- abs. power: 5%
- linearity: 0.05 dB
- pol. dep. 0.01 dB

81662A/81663A DFBs

- power stability 0.005 dB/0.003 dB
- power 10 dBm/13 dBm
- λ stability 3 pm/5 pm
- SMSR 45 dB/50 dB

8157xA Attenuator

- max power 33dBm
- spectral flatness 0.05 dB
- repeatability 0.01 dB

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Agilent's OA Test Systems

Agilent E2156A Optical Amplifier Test System

Measurements

- Gain
- Gain Flatness
- NF
- PDG (optional)
- Signal Input Power
- Signal Output Power
- Total Output Power
- ASE Power
- Transients (optional)

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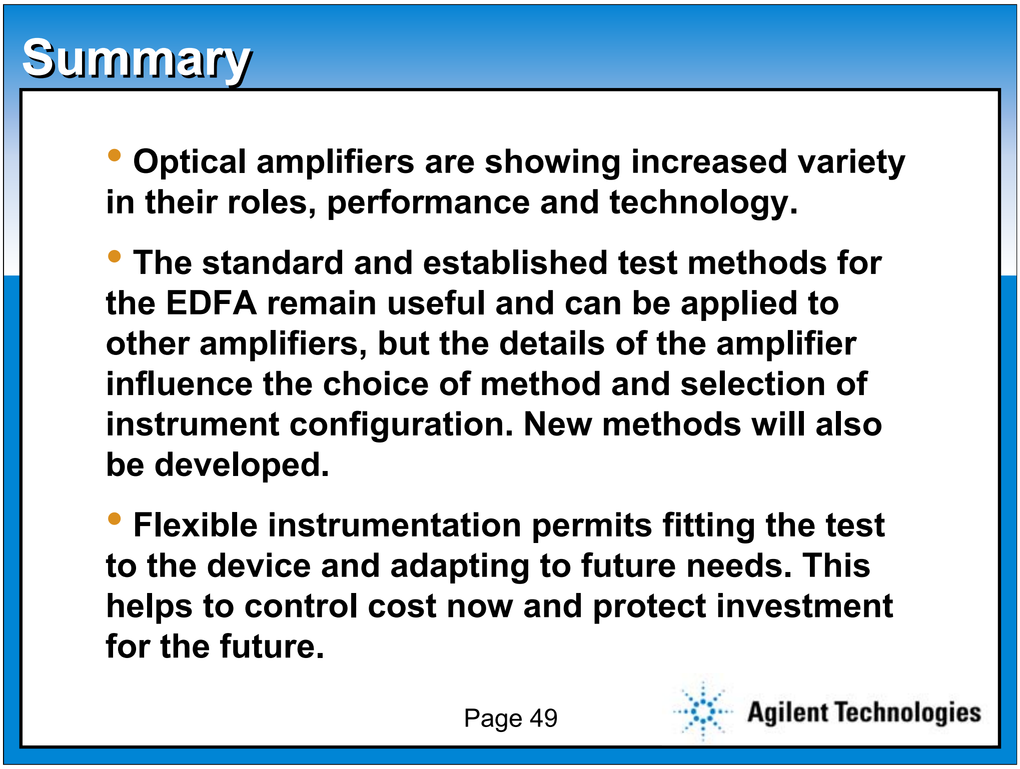
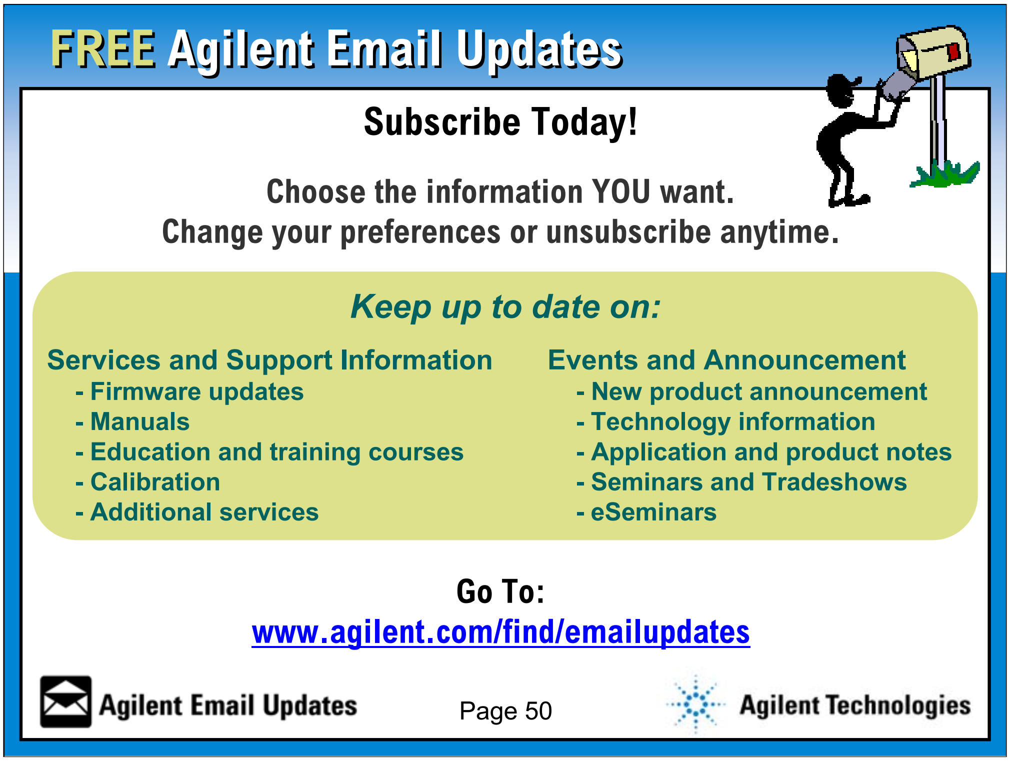


Summary

Optical amplifiers are showing increased variety in their roles, performance and technology.

The standard and established test methods for the EDFA remain useful and can be applied to other amplifiers but the details of the amplifier influence the choice of method and selection of instrument configuration. New methods will also be developed.

Flexible instrumentation permits fitting the test to the device and adapting to future needs. This helps to control cost now and protect investment for the future.



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