RFoG the Path to the Future

Chapter 1

To me RFoG, or Cable PON is the path to the future for CATV operators. It offers an easy way to deploy fiber to the home in a non disruptive way. Lets look at its advantages:

1. Lower Cost, The price of fiber is lower than coax and the cost for electronics at the headend can be as low as $100. per customer and the expenses at the customers house, are not incurred until a customer is actually hooked up;
2. Fiber is actually run to the home, opening the door for many uses in the future;
3. Today's RFoG home devices, MicroNodes, NIU, NID, FID etc. have a bandwidth of 1 GHz but the fiber is good to 2, 3 or ? GHz and thus future bandwidth is assured;
4. All of your DOCSIS infrastructure remains the same, you have just attached the NODE to the side of the house;
5. The set-top boxes that you have already deployed remain the same and duplication of subscriber STB's is avoided;
6. All of the electronics are either at the headend or on the side of the customer's house with all of the increased reliability that this brings;
7. The cost of Outside Plant powering with all of its ancillary cost such as standby power supplies, battery maintenance and testing are eliminated;
8. Fiber is essentially immune to the elements, fiber does not get wet, temperature expansions do not cause splices and connectors to open;
9. Sweeping, CLI, and other normal HFC plant maintenance procedures are eliminated lower the cost of operation. Some systems with RFoG installed have reported that the cost of maintenance is lowered by as much as 90%;
10. Fiber is immune to ingress and CPD, which plague coax plants;

11. Because of RFoG's improved noise characteristics the full 5-42 MHz return path spectrum can be used for data. Todayçs RFoG systems can support DOCSIS 3.0 with bonding, but also the low noise floor enables 64-QAM upstream transmission, increasing return path bandwidth;
12. Passive optical network equipment consumes less than 80% the power required by the electronics in an HFC environment therefore making in a ñGreenò technology and Earth friendly;
13. Because the Passive Optical Network used by RFoG is identical to the networks used by (X)PON systems. A (X)PON system such as GPON or EPON can be overlaid on a RFoG network and used to provide bandwidth rich business network services.
14. RFoG is a 3 dimensional service in that service can be expanded through TDM (Time division Multiplexing), FDM (Frequency Division Multiplexing) and WDM (Wavelength Division Multiplexing;
15. Although not entirely true, but thanks to the extensive and effective marketing done by Verizon and others, people now believe that Fiber to the Home is the best service. With RFoG you can easily and cost effectively deploy FTTH;

When I hear of someone doing an upgrade, rebuild or extension, my first question is "are you running Fiber"? If they reply negatively, I then proceed to tell them that they are being very short sited and wasting a golden opportunity to move into the 21 century.

When I built my first cable systems back in the mid 1970çs, 20 channels was state of the art. I was building systems in rural Oklahoma and I can remember saying, ñwhy should I invest in 20 channel equipment, I cannot find enough channels to fill 12.ò Well, needless to say a few years later satellite delivered channels became available and soon I was struggling for bandwidth and rebuilding. I have never forgotten that lesson and today we are looking at much the same scenario, the ability to build for the future.

Much of the deployment of RFoG has and is in rural systems. Systems that had never upgrade past 550 MHz and are now going to FTTH with 1 GHz bandwidth and an easy path to mare if needed.

The major MSO's have been slow to embrace RFoG, mainly because they have billions of dollars invested in their HFC network and have only rolled out RFoG in Greenfield applications.

So maybe for the first time in cables history Main Street is leapfrogging Wall Street.

Cable TV has never been a static industry, from the 3 channel systems in the early 50's to the 5 channels systems in the mid 50's to the first 12 channel tube systems. Then in the early 60s it was transistors, first from AMECO and CAS/CO (both claim to have been first) to the first 20 channel, single octave equipment in the mid 1960's to the first push-pull equipment that used the midband in the later sixties. In the late 60's 2 companies were striving to perfect multichannel broadband 12 GHz microwave. Well Hugh's won and who can even remember Laser Link. The 70's brought the first mass produced hybrid amplifier chips from TRW and 36 channels.

The mid 70's brought satellites and the first satellite delivered signals. Would you believe that the firs dishes were required by the FCC to be 10 meters (33feet), had to be licensed by the FCC and cost between $1-200,000.00 For that you got HBO and a little later WTCG, the original name of WTBS.

Next came 60 channel systems and then Cable started its love affair with fiber with the advent of the HFC (Hybrid Fiber Coax) system. At first nodes were deployed to serve 500 to 1000 homes, then it was 500 homes then 250 and now it is as small as 50 homes per node.

Fiber all the way to the home is the next logical step and RFoG makes it easy, affordable and deployable today. Any new build, extensions, or bandwidth upgrades in selected areas, RFoG should be the 1st consideration If you have areas that have severe problems with ingress, or radiation, think RFoG.

I remember a high rise condo project we had in Oceanside California. This building had every paging transmitter in North San Diego County on the roof and we could not keep in from picking up outside interference. I could not even sell it so I finally donated it to a local soccer club. A major CATV Brokerõs son was on the team and the Broker was able to convince the local cable company to donate $5,000 to the soccer club and get the cable system as a bonus. A fiber to the home RFoG solution would have been a miracle in that system.

There are beneficial offshoots to RFoG. One of these is an RF/optical tap that will allow you to feed customers 1-5000 feet from you distribution lines using fiber between the cable plant and the home. Once the signal is back to the cable plant it is handled as a normal customers signal. (More in Chapter XX)

There are new RF2F (RF to Fiber) hardened transmitters you can begin to deploy fiber at any point in your system, even if you are fiber poor from your headend. Using this equipment you can roll out RFoG fiber to new builds or Greenfields when you need to without reengineering your entire plant. Some people instantly think that the noise would immediately preclude this option, but in normal cases this is not true. We will talk more about this in Chapter XX.

Opportunities abound, I am aware of a number of builds and planned builds into areas that:

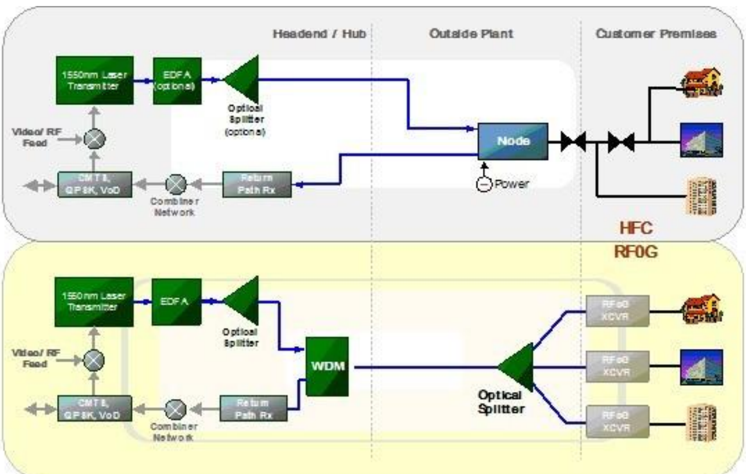
1. Were always considered uneconomical to build;
2. Were previously built out with cable and then abandoned;
3. Areas now underserved by major cable companies (overbuild)
4. New developments and subdivisions where the developer wants ñFiber to the Homeò and the local cable company cannot or will not comply with the requirement; I some cases FTTH adds $10-15000 to the sale price of the home.

As an industry and especially the entrepreneurial side of the industry, we need to THINK FIBER and we can prosper though out the 21st century.

System Basics

Chapter 2

For those of you that have a basic understanding of what a RFoG systems consists of this chapter will be redundant but for those who are new, a basic understand as a base to build on is imperative.



Graphic Alloptic

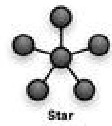
Many people, when first trying to understand a RFoG system try to make to make it too complex. A RFoG system is simply a HFC system where the node has been moved to the side of the house and the coax portion of the HF**C** is the RG-6 inside the home.

As any Cable Technician call tell you , the fiber portion of the HFC network is much less prone to outage than the Coax portion. The Coax is subject to temperature related splice and connector failures, power related outages both from lack of power and from voltage transients, water ingress into the connectors or amplifiers and stress related failures of the outer sheath and of course cuts and breaks caused by tree limbs, oversized trucks and backhoes. Fiber is of course effected by tree limbs, oversized trucks and backhoes but is basically immune from the rest.

There are a few differences in the way that the RFoG fiber plant may be configured, as compared to a HFC fiber plant, but we will go over these in Chapter 3.

The other big difference is the fact that RFog plants use 1550 nm transmitters and most HFC plants use 1310 nm. There are a couple of reasons for this, the first is the lower attenuation of the fiber at 1550 nm but the big reason is that we can amplify the 1550 wavelength, with a device called an EDFA, (Erbium Doped Fiber Amplifier). We will go over both of these in latter chapters in the book

Types of Systems
Chapter 3



In todayꞌs RFoG world there are three different types of system architecture. The first is a adaptation of the traditional phone system PON architecture or sometimes called a star type system. (See figure 1) It is also sometimes referred to as a tree system although I think the star is more descriptive and much more presently used

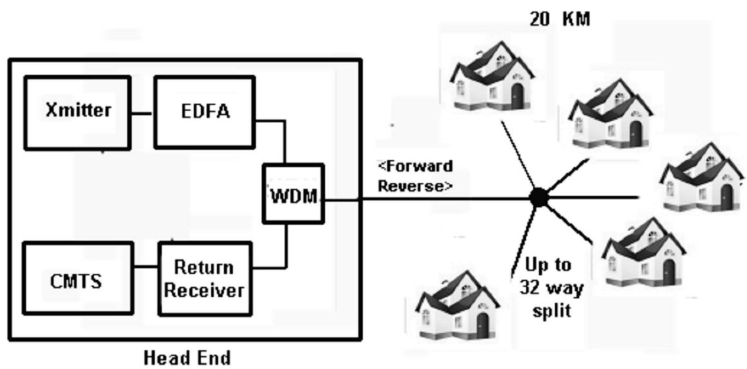


Figure 1

In this type of system signal on a single fiber is split up to 32 ways and then fed out to 32 homes. The splitter can be at the headend or located at some remote spot in the system.

This type of architecture works great in an urban area or an area with a heavy concentration of users and potential users.

Typical systems use a 32 way splitter with 32 drops radiating out from the splitter, which can be in a pedestal or on inline areal enclosure.

Lets look at the typical numbers in this type of system.

EDFA output	17 dBm
WDM Loss	-.75 dB
Fiber loss to Splitter	-2 dB
32 way splitter loss	-17.5 dB
Fiber Loss to house	-1 dB
SIGNAL LEVEL @ House	**-4.25 dBm**

Loss for the return signal	21.25 dB
Return Transmit level	1 dBm
Return Signal Level @ receiver	**-20.25 dBm**

We have seen a number of RFoG NIU units that only produce a return transmit level of -2 dBm so the actual receive level may be as low as -23.25 dBm.

In the PON world there is a movement to possibly using 64 way splits and I see that as a future option in RFoG. Today a return signal of -20 dBm is at the edge but with new technologies coming on line (See Chapter XX) this level will drop considerably maybe even down to -30 dBm.

If RFoG went to a 64 way split scenario then the return receive level would drop to approximately -24 dBm or -27 dBm worst case. This level with the new type of receivers should work great even with DOCSIS 3.0 and bonded channels.

In the Star or Tree type system you can also employ a version of a self healing optical ring by running 2 fibers to the splitter by different routes. By utilizing a switching and signal sensing circuits, a cut of either fiber line will not disrupt service..
(Figure 2)

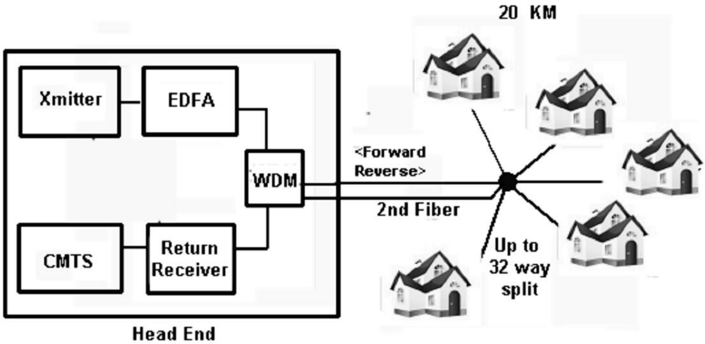
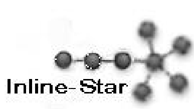


Figure 2

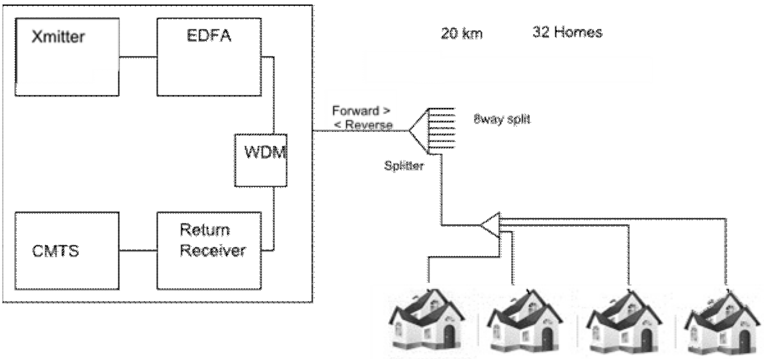
This is an option with this type of architecture that is not as easily done in a Line or Bus type of system and in many cases is impossible. Running a second fiber with the regular fiber will not achieve the desired results as a cut to one will most likely also cut the backup. A different route needs to be used.



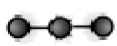
As an adaptation of the star and incorporating some of the aspects of an inline system, it sometimes makes sense to spread out the splitters. As a 32 way splitter can also be looked at as a 8 way splitter followed by 8, 4 way splits it is conceivable that we could put an 8 way and 1 four way in the first location and then have the other 7, 4 ways some distance from this point. As 1000 feet of fiber only has .076 dB of loss we could move the other 7, 4 way splitters closer to the subscribers homes and use less fiber.

EDFA output	17 dBm
WDM Loss	-.75 dB
Fiber loss to Splitter	-2 dB
8 way splitter loss	-10 dB
Fiber Loss to 4-way	-2 dB
4-way loss	-6.5 dB

SIGNAL LEVEL @ House	**-4.25 dBm**
Loss for the return signal	21.25 dB
Return Transmit level	1 dBm
Return Signal Level @ receiver	**-20.25 dBm**



This system closely emulates the inline system but gives more flexibility. In an real world example you would come out of the 8 way with a 12 count fiber, and at a convenient location you would terminate on of the 8 active fibers with a 4 way splitter. From this split location you would either run the drop or use 4 of the open fibers to continue the splitter outputs to a location closer the service location



The other type is an In-Line system. This system is the system used by Commscope in their BrightPath® system. It is very similar to a traditional coaxial cable system and uses descending value taps starting with a large value and decreasing to a splitter at the end of the line. This type of system also traditionally serves 32 homes. (Figure 3)

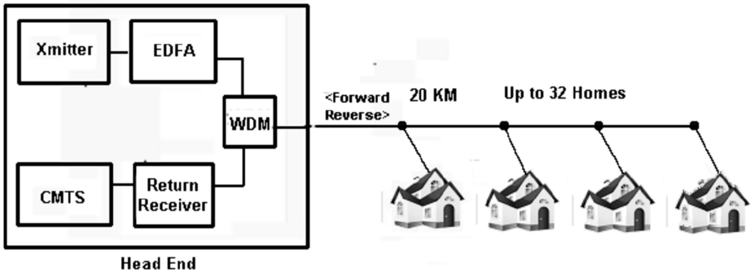


Figure 3

This type of system works best in rural or long spread out areas such as down a valley or a rural road.. Of course there is no reason why a mixture of both types of architecture cannot be used dependant on the specific needs of the area. Using both types of systems is something that most engineers do not even consider.

Lets look at the typical numbers in this type of system.

EDFA output	16 dBm
WDM Loss	.75 dBm
Fiber loss to First Tap	.5 dBm
First Tap loss	17 dB
Fiber Loss to house	-1.dBm
SIGNAL LEVEL @ House	**-3.25 dBm**

Loss for the return signal	19.25 dB
Return Transmit level	1 dBm
Return Signal Level @ receiver	**-18.25 dBm**

Again we have seen a number of RFoG NIU units that only produce a return transmit level of -2 dBm so the actual receive level may be as low as -20.25 dBm.

You need to remember, when engineering this type of system, that you do not have to build your plant so that you have 1-150 foot maximum drops. A drop of 1000 feet is OK, the loss at 1550 is less than .1 dB. Another consideration is pole attachments. I am told that, today, any time you attach strand and cable to a pole large engineering fees and lengthy engineering time usually is incurred. However I am also told that drop attachments are usually as simple as turning in the attachment form and paying the pole attachment fee.

Return Wavelength and Diode Types

Chapter 4

The majority of the installed RFoG installations use a 1310 nm FP (Fabry Perot) burst laser transmitter for the return signal. FP laser diodes have less spectral purity than DFB diodes and have a higher noise floor. Earlier FP diodes exhibited much worse distortion characteristics than DFB diodes but the newest versions of FP diodes are have almost as good of distortions numbers as DFB diodes.

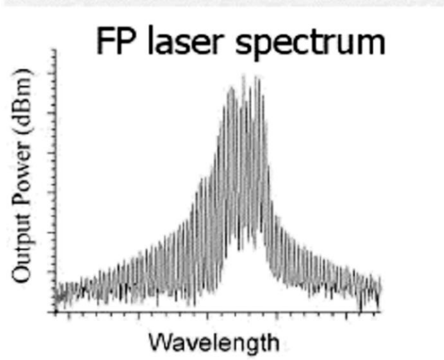


Figure 4

In the simplest form of laser diode, an optical waveguide is made on that crystal surface, such that the light is confined to a relatively narrow line. The two ends of the crystal are cleaved to form perfectly smooth, parallel edges, forming a Fabryï Pérot resonator. Photons emitted into a mode of the waveguide will travel along the waveguide and be reflected several times from each end face before they are emitted. As a light wave passes through the cavity, it is amplified by stimulated emission, but light is also lost due to absorption and by incomplete reflection from the end facets. Finally, if there is more amplification than loss, the diode begins to "lase".[1]

[1] (From Wikipedia, the free encyclopedia "Laser Diode")

In Figure 4 we can see the laser spectrum of a FP diode. Notice how the side modes are very high and almost if not equal to the primary output. It is partially because of these side modes that the noise performance of FP diode transmitters is lowered. The frequency accuracy of FP diodes is much less than DFB diodes due to inconsistencies in the resonator section of the diode.

RFoG return transmitters operate in the burst mode, which means that if no signal is present from the Cable Modem then the optical power of the return transmitter is reduced to a low level. FP transmitters are not turned all the way off, because due to the way FP diodes operate a delay would be incurred before the diode began lasing when power is restored, but is reduced in power to a level of around -18 to -20 dBm. In Figure 5 we see a graphic display of what is happening in a burst transmitter. We see that the laser output is at the -18 dBm level until the input signal from the Modem is present. As soon as signal is above a threshold level, from 15 to 30 dBmv, dependant on the manufacturer, the laser optical output goes to full output of about 0 dBm. The actual output varies by manufacturer but is usually between 0 to + 2 dBm. Some equipment ramps up dependant on the RF level and does not reach full optical output until the RF is in the 50 dBmv area. As soon as the RF or data from the modem stops the optical level falls back to the original resting state.

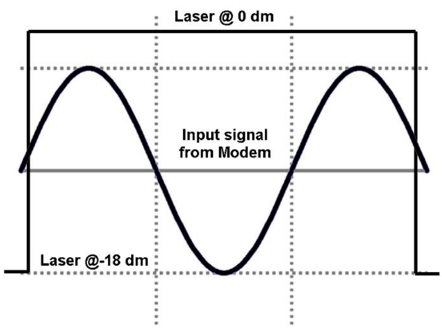


Figure 5

The bursting of the return transmitters is done to prevent extraneous signals from being transmitted back to the return receivers. Some people have asked me if the optical power is only reduced 20 dB won't there still be noise and extraneous signals transmitted beck to the Head End. I always remind them that laser receivers are square law devices and that a reduction of 20 db in optical power results in a reduction of 40 db of RF and that any extraneous signals will now be below the noise floor.

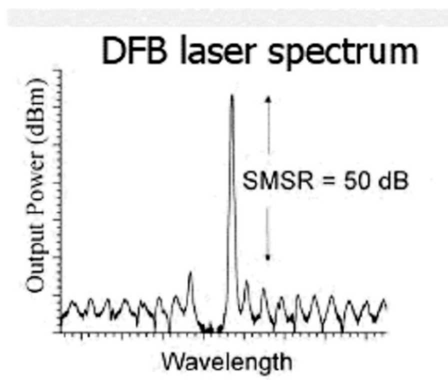


Figure 6

Distributed feedback lasers (DFB) are the other type of diode used in RFoG return Systems . To stabilize the lasing wavelength, a diffraction grating is etched close to the p-n junction of the diode. This grating acts like an optical filter, causing a single wavelength to be fed back to the gain region and lase. Since the grating provides the feedback that is required for lasing, reflection from the facets is not required. Thus, at least one facet of a DFB is anti-reflection coated. The DFB laser has a stable wavelength that is set during manufacturing by the pitch of the grating, and can only be tuned slightly with temperature. DFB lasers are widely used in optical communication applications where a precise and stable wavelength is critical.[2]

As we see in Figure 6 the Side Modes are reduced significantly from a FP laser diode which improves the noise performance.

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[2] (From Wikipedia, the free encyclopedia "Laser Diode")

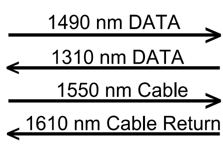
1310 nm or 1610 nm Return

Most of the presently installed RFoG installations use a 1310 nm return wavelength both FP and DFB diodes. The 1310 FP diodes are less expensive and work well for todayôs needs however the price differential between a 1310 FP and a 1310 DFB is only about $30 more and you are ready for Docsis 3.0 channel bonding. I have done some multichannel testing on FP diode transmitters and the tests lead me to believe that the FPôs will work, however the prevailing thoughts in the engineering community is that you need a DFB diode and $30.00 is a small price to pay for sleeping good at night!

Do I use a 1310 return or a 1610 return?

The answer to this questions has a couple of what ifôs. If you ever plan to add a PON system to your mix you need to go with a 1610 return. The reason is because a PON systems uses 1490 nm for forward data and 1310 nm for return data.

Before you say there is no way I will every deploy a PON system, keep in mind that it is possible to run both at the same time and a PON gives you more flexibility to provision commercial customers. A 1610 nm DFB return adds about an additional $20.00 to the price of the NIU.



If you are in a rural environment, 1310 is probably what you need, if you are in an urban area, or an area that has or is expected to grow then you need to think about a 1610 nm return.

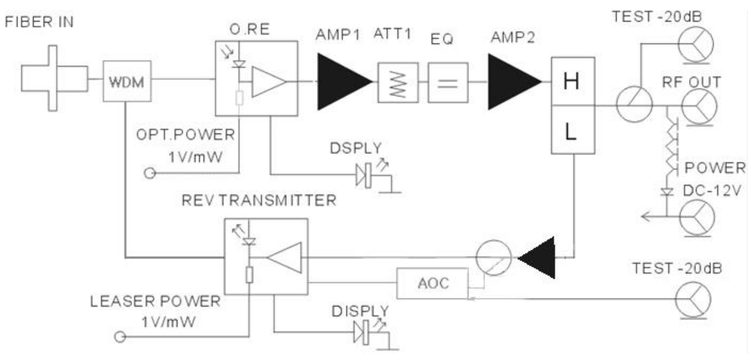
Now you may decide to deploy both and other that increasing the responsibility on you technicians when and if the change out a NIU, to make sure they get the correct replacement you can make that work also.

There is a method to use a Solar Powered EDFA (see chapter xxx) to extend fiber lines a little farther to serve a few more houses and this device can amplify in both directions provided that the return is 1610 nm.

You can add 1610 returns at any time in the future, however you will have to change the WDM in the head end from a 1310/1550 to a 1310/1550/1610. If you think you may add 1610 in the future you can start out with the 1310/1550/1610 unit in the beginning. The triple wavelength unit is about $100.00 more expensive

Basic Receiving Equipment
Chapter 5

The heart of an RFoG system is the home receiver. Sometimes called a NIU (Network Interface Unit), NID (Network Interface Device), a FID (Fiber Interface Device) Micro-Node, or a R-ONU. (RF Optical Network Unit). In this book we will refer to them as NIUâs.



All of the units that are presently available have the same basic function, however there are some differences. The things you need to know and the reasons that this information becomes important are as follows:

1. **AGC**:
   Does the unit have AGC and if it does what type is it, there are 2 different ways to AGC a unit;
   a. **RF keyed AGC**. This type of AGC keys off from a channel or a group of channels. This works fine until you change from an analog line up to a digital line up and your levels change by 3-6 dB. This is something that you need to be aware off and prepare in advance for. For instance one very common unit AGCâs off from the composite of the high band TV channels (channel 7-13) and the level is factory set for Analog channels.

If your high band changes to digital then the output will change by approximately xxx dBmv.

b. **Optical AGC** This is in my mind the best as it will remain constant no matter what your line up;

c. **No AGC** This type of level control is OK, however if the unit is designed to have a 17 dBmv output with a -6 dBm light input, when you get it into a situation where you have a 0 dBm light input your RF output will now be 29 dBmv and may cause problems in the house.

2. **Tilt:**
Does the unit have some built in tilt, most units do but I have seen some that are flat and this could cause problems with excess signal in the low band channels.

3. **Future Bandwidth Needs:**
Almost of the NIU◌s I am aware have fixed diplexer filters built into the unit. If in the future you need to reallocate your frequency between forward and return you will have to replace all of the installed NIU;s in your system. There is a new NIU that has patent pending circuitry called DSR (Dynamically Scalable Return) which up to 200 MHz of dynamically scalable return bandwidth. This new development will remove any group delay problems from T-12 and make T-13 immediately available. If channel 2 is removed from the forward lineup then T-14 will be immediately available for return, etc. DOCSIS 3.0 allows returns up to 85 MHz and so if this NIU is deployed your future bandwidth needs are provided for in advance

4. **Managed NIU's:**
There are some new NIU◌s on the market which allow the Forward RF and the reverse transmit to be disabled. They also allow the operator to remotely monitor the input light level, the output RF level the temperature and possible other metrics. This option, of course raises the price approximately $100.00 per unit. On first glance it seems like a desirable option with the ability to reduce truck rolls and simplify collections but as you look at it in more depth it becomes, with a few exceptions , just an expensive toy.

a. From my own experience and from talking to many cable operators, turning off the television portion of the service, as a collection tool will result in at least 20% of these customers not having the service turned back on. On the other hand if the Internet is disrupted, the problem is almost immediately resolved, usually within hours and all of this can be done at the office with a few strokes of the computer keyboard, all with existing equipment. Donõt turn off the telephone service if you have a choice. If telephone service is disrupted over a billing problem a very high percentage will choose to cut the cord and go to cellular.

b. As far of monitoring the service levels etc., we already have that ability within the DOCUSIS platform and again any function at the NIU would be redundant.

c. In the case of move outs then dependant on the circumstances a truck roll, to reclaim the NIU will probably be needed anyway.

5. **Test Points:**
   About 50% of the NIUõs I have looked at have test points on the forward and reverse sides. These are very handy when setting the system up and when trouble shooting. They are not essential but nice to have.
6. **Function Lights:**
   These lights, which give a visual indication of the presence of incoming light and the presence of return signals are helpful at the time of installation and can make the installation go faster. Most units have at least one light and many have both. Make sure that if the unit has a visual indicator of return signal, that it has a built in long time constant or you will not be able to see it with modem traffic. It will only indicate the presence of signal when using a signal generator to simulate return.
7. **Constant Light On:**
   On some NIUõs you have the ability to turn on the return light in a constant state for set up and trouble shooting. Although not a essential feature it is very handy.

NIU Plastic enclosures:

The NIUÕs are to be mounted in some type of an enclosure on the side of the house to protect them from the elements and to protect the fiber from damage. Many manufactures have custom enclosures, like the box for Commscope BrightPath® unit, shown to the right, that fit their NIU. While these are very handy you should give serious consideration to generic enclosures so that you can changed NIUÕs in the future. While all NIUÕs will fit in a generic enclosure, only the manufactures unit will fit in the manufactures box.


BrightPath® Enclosure & NIU

Generic w/Hitachi


Generic w/BrightPath®


Generic w/Alloptic


Generic w/4Cable TV

As you can see in the above pictures you can use a wide variety of NIUÕs in the generic enclosure but in the OEM enclosure you are limited to the manufacture specific NIU. This might seem inconsequential now but I can think of a number of scenarios where you might want to change NIU vendors. To name a few:

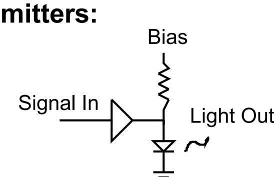
1. The vendor goes out of business or declares the product end of life and no longer supports it;
2. A NIU with improved noise performance comes on the market;
3. You find an equal product at a lower price;
4. Your present vendor is sold and the new companies customer service is horrible.
5. Etc.

1550 nm Transmitters

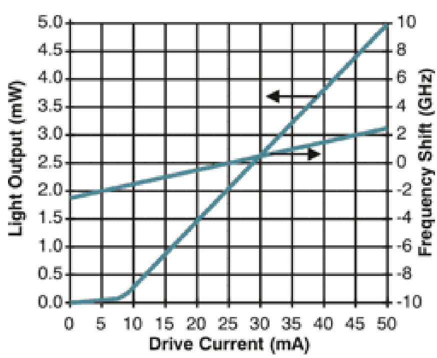
Chapter 6

Transmitters used in RFoG systems are 1550 nm transmitters. These come in two types, direct diode modulated transmitters and externally modulated transmitters. Direct diode transmitters are much less expensive but they suffer from diode ñchirpò and thus are limited in usefulness. Externally modulated lasers can be manufactured with little or no chirp and thus are better for RFog installations. Both types have their use and in this chapter we will show you the differences and how to choose the transmitter best suited for your application.

Direct Diode Transmitters:



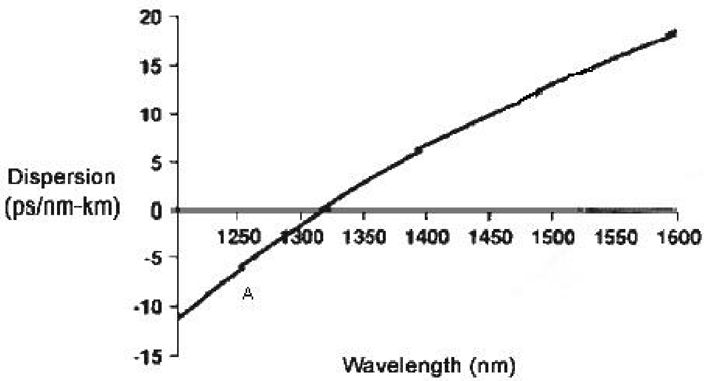
Direct diode modulation is the simplest type of modulation, the RF signals amplified and then fed to the diode. The diode is biased on and modulated light is emitted. Unfortunately in a direct diode modulated laser, not only the output power but also the laser frequency fluctuates with the modulation current. Thus the diode is both amplitude modulated and frequency modulated. This frequency modulation is called óchirpò or diode chirp.



The chirp interacts with the dispersion in the fiber at 1550 nm and causes CSO distortion. The worse the chirp the faster the CSO degrades.

The CATV industry has used direct diode modulated lasers at 1310 for many years, in fact all 1310 nm CATV lasers are direct diode modulation. Yes, the diode modulators do have chirp at 1310 nm also, but and the big but, is that the fiber dispersion at 1310 nm is almost 0 while at 1550 nm it is high.

Typical Dispersion vs. Wavelength Curves



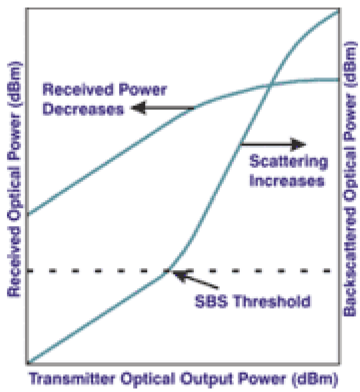
As you can see in the above chart the dispersion at 1310 is basically 0 while the dispersion at 1550 is about 15-17 ps/nm-km.

Most commercially available direct diode transmitters are limited to about 10 km maximum distance. There are some units that are rated out to 20 km but you need to be careful as then units are designed to give about a -55 dBc CSO at 20 km however if you come back and check at 10 km the CSO is below 50 dBc.

4Cable TV has a patent pending direct diode transmitter that is good to 20 km with CSO at -53dBc and it is a linear slope all the way back to the transmitter where it is 68 dBc.

Direct diode transmitters are great if you can stay within the 20 km radius and the cost savings are substantial. A externally modulated transmitter with adjustable SBS will cost from $8500 to $12,000 or more. You can get a 10 km direct diode laser for $2,200 and a 20 km unit is $3500.

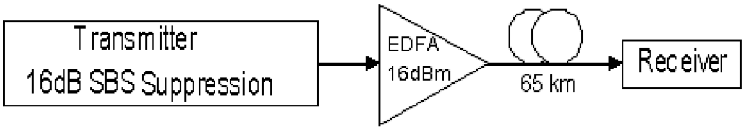
Stimulated Brillouin Scattering (SBS): Pronounced (brēywan) SBS is the easiest fiber nonlinearity to trigger. When a powerful light wave travels through a fiber it interacts with acoustical vibration modes in the glass. This causes a scattering mechanism to be formed that reflects much of the light back to the source.

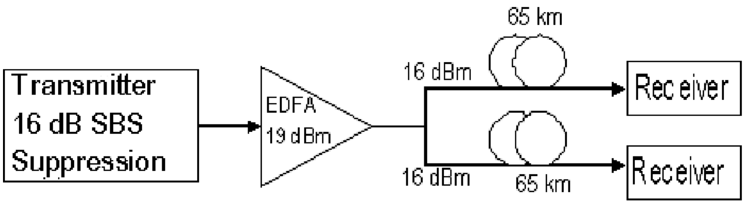


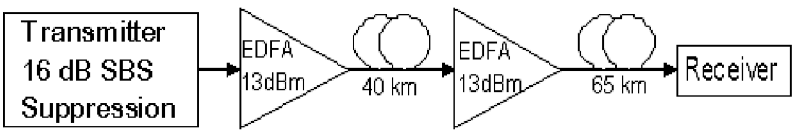
As you can see by the above graph you can reach a point where the received power decreases with an increase in launch power.

What this means when we are designing a system is that your 1550 transmitters will have a SBS spec and that number is the maximum level of light that you can inject into a fiber without triggering a SBS problem.

If you study the three following examples you can see how to properly comply with the SBS rules and how to do it improperly







The first two examples are correct usage and the last one is incorrect. **THE SBS SHOULD BE SET TO EQUAL THE POWER LEVEL OF THE LIGHT THAT IS LAUNCHED INTO THE FIBER.**

Notice in the above examples that although the light level may be higher at the output of the EDFA, the light launched into the fiber should be at the level of the SBS setting of the transmitter.

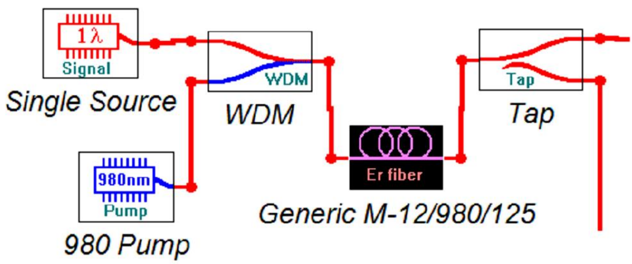
You can get transmitters with adjustable SBS up to 19 dB but that is about the maximum level that can be launched into your fiber.

If you are using, for short distances, a direct diode transmitter you usually can safely assume an SBS of 17 dB

EDFA’s

Chapter 7

If there is a heart and sole to a RFoG system it is the EDFA. EDFA stands for Erbium Doped Fiber Amplifier. It is the EDFA that allows the 1550 nm forward light to be amplified to a high enough level to enable it to be split enough times efficiently and cost effectively to serve customers.



Basic principle of EDFA (Wikipedia)

A relatively high-powered beam of light is mixed with the input signal using a wavelength selective coupler. The input signal and the excitation light must be at significantly different wavelengths. The mixed light is guided into a section of fiber with erbium ions included in the core. This high-powered light beam excites the erbium ions to their higher-energy state. When the photons belonging to the signal at a different wavelength from the pump light meet the excited erbium atoms, the erbium atoms give up some of their energy to the signal and return to their lower-energy state. A significant point is that the erbium gives up its energy in the form of additional photons which are exactly in the same phase and direction as the signal being amplified. So the signal is amplified along its direction of travel only. This is not unusual - when an atom ñlasesò it always gives up its energy in the same direction and phase as the incoming light. Thus all of the additional signal power is guided in the same fiber mode as the incoming signal. There is usually an isolator placed at the output to prevent reflections returning from the attached fiber. Such reflections disrupt amplifier operation and in the extreme case can cause the amplifier to become a laser. The erbium doped amplifier is a high gain amplifier.

The length of Erbium Doped Fiber is pumped by either a 980 nm pump or a 1480 nm pump. The 980 pump allow for lower noise figures while the 1480 pump is a little more efficient and allows for lower pump levels. You can pump the EDF (Erbium Doped Fiber) from either or both directions and with multiple pump diodes.

EDFA amplifiers operate in a saturated mode very similar to a limiter in a FM IF amplifier. Because they operate in a saturated mode when gain is measured it is normally measured with an input of -30 dBm.

EDFA's are rated by their output power, ***NOT THEIR GAIN,*** Thus a 20 dB EDFA will have an output of 20 dBm. The output will remain within about ± 1 dB with an input from -10 to +10 dBm.

The theoretical noise figure of an EDFA is 3 dB however they practically range from 3.5 to as high as 8 dependant on the gain and output power of the unit. The principal source of noise in DFAs is Amplified Spontaneous Emission (ASE). Operating the EDFA in a saturated mode reduces spontaneous emissions and keeps the noise down.

EDFA's operate in 2 bands the *Conventional* band ,C-Band from approximately 1525 nm – 1565 nm, and the *Long*, or L-band, from approximately 1570 nm to 1610 nm. The major difference in the C and L band EDFA's is the L-Band amplifiers use longer lengths of doped fiber.