INTRODCTION

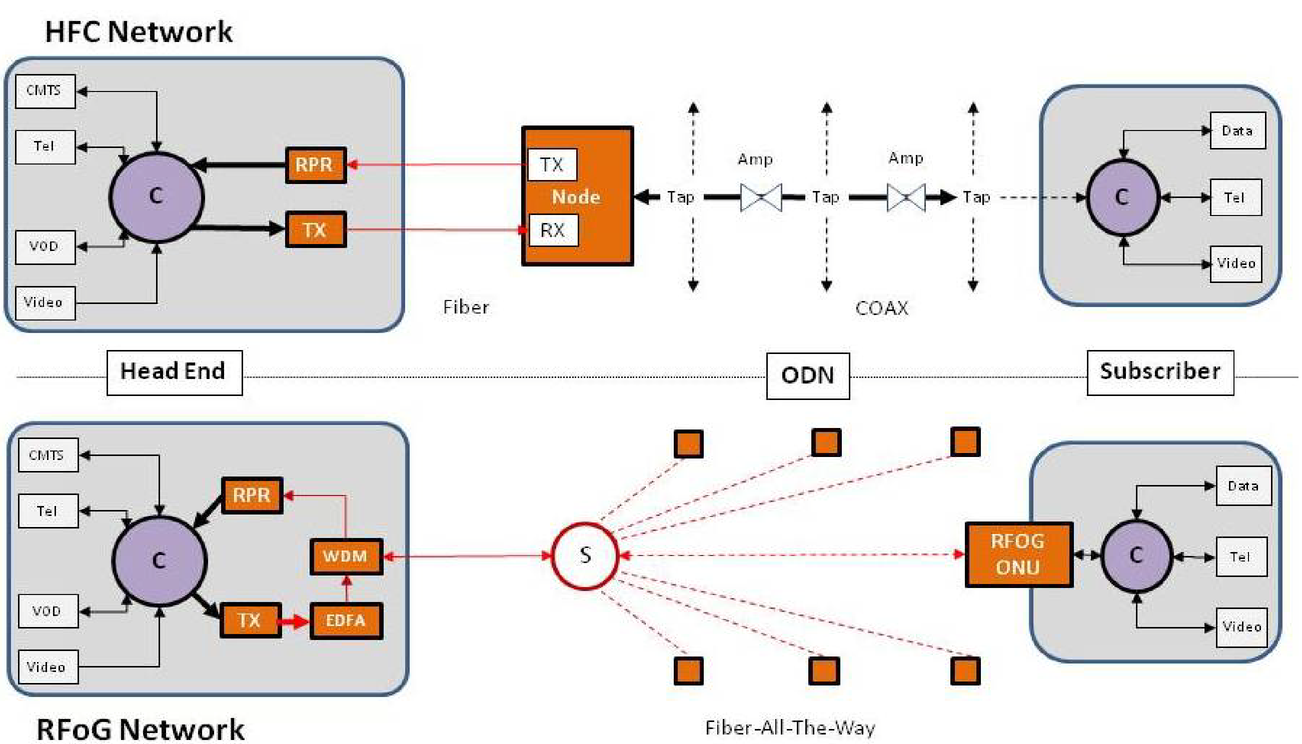
In a desire to support more subscribers with better performance and reduced cap-ex costs, many network operators are considering updating the HFC networks to a "Fiber-all-the-Way" to the home using RFoG technologies. RFoG networks are usually deployed with a maximum of 32 homes on a single ODN with the addition of amplifiers, return receivers, and WDMs in the head-end. If 64 homes were served on the same ODN, the head-end equipment costs can be reduced and the original HFC Fiber deployments can be utilized more effectively. This paper identifies some of the network planning considerations you need to be aware of when making the decision to design a 64 split RFoG network.

RFoG is a logical next step to the HFC network design.

HFC networks were introduced to allow 2-way communications on the CATV network along with better performance and lower maintenance costs while still using the original COAX trunk/tap/drop infrastructure. An HFC network design allows an MSO to deploy 2-way video and data services to their entire service area in a cost effective way without adding a multitude of head-end sites.

RFoG technology continues this evolution by allowing the optical portion of the HFC network to be extended directly to the customer premise, eliminating the trunk/tap/drop network components but retaining compatibility with existing customer owned devices. The RF signal to a customer is very high quality and the customer's in home infrastructure and equipment are not impacted. A "fiber all the way" network establishes a future-proof infrastructure that can serve an MSO for decades without physical plant upgrades, allowing an MSO to improve the quality of today's services, as well as to deploy advanced service offerings without network upgrades).

To convert an existing HFC network to an RFoG design, the HFC nodes and associated amplifiers, and powering systems are replaced with passive optical splitters. The fiber optic cables from the HFC design are often re-used for the RFoG network, and the drop/tap distribution COAX components are replaced with optical cables. (Some MSOs home-run one or two fibers for each customer back to a single splitter location, while others prefer to cascade splitters, to approximate a trunk-tap design). An RFoG ONU is placed on each customer's home to convert the optical signal back to the traditional RF feed. **To make a HFC-to-RFoG conversion practical, the optical ODN needs to be designed to support as many customers as the node it replaces without requiring additional long distance fiber.**



RFoG and HFC Physical network compatibility

A fully split HFC node, generally supports 128 subscriber homes on one return path fiber. Splitting the node again to 64 subscribers per segment is a major project since the feeder network and the fiber trunks must be redesigned. Converting to RFoG allows you to increase the total capacity of the node without changing the fiber optics trunks, since each fiber link supports both way traffic. If the RFoG network supports 64 splits, it reduces the head-end cost per subscriber by more than15%. It also becomes an effective alternative to the pure HFC upgrade since the original fiber facilities can still be used, no active electronics are needed in the node location, and the same head-end capacities are supported**. For these reasons Titan Photonics has designed and built RFoG ONUs, Return Path Receivers and EDFAs that are optimized to support 64 split optical networks**.

TECHNICALITIES AND IMPLEMENTATION.

Noise degrades the content
If an RF signal is too noisy, a customer gets a bad picture on the television and causes bit errors on data transmissions. Noise is caused when an analog signal is distorted by external sources, bad connections, EMI radiation, or network electronics themselves. Noise from all sources builds up on the network until it can cause a receiver to mistake it for a portion of the content being transmitted, corrupting that information. Once the content signal is corrupted, even a perfect network cannot make it better. Amplifiers increase incoming noise along with the signal they receive. They even generate some noise themselves. A noisy signal entering a network ALWAYS comes out noisier at the destination! **To design a high quality network, you must eliminate as much noise as possible from all sources, and eliminate as many amplifiers/electronics in the content path as possible**.

Signal to Noise ratio
HFC and RFoG use analog network technology to carry content. An RF carrier is modulated by the content (video or data), and is transmitted through the network. Laser light is modulated by the RF signal to carry the content through the optical portion of the network. Noise and static are always being generated which distorts the signal, making it difficult to get good accurate content through to the end devices. The ratio between noise and the content signal is described as the Signal-to-Noise Ratio, (SNR) measured in dB. The minimum standard noise level at a residential home is 42dB, but most MSOs strive for at least 48dB to insure that high speed data and high definition TV services will operate flawlessly for their consumers.

Reducing RF ingress noise on RFoG networks
The forward path in an RFoG network follows a point-multipoint design where one source laser feeds all RFoG ONUs on the ODN. Since there are NO amplifiers or regenerators in the outside plant, care must be taken when choosing the Transmitters and EDFAs for the application. RF ingress noise at the head-end, is a well known and understood plight in HFC systems and RFoG network designs follow nearly identical design practices. The same cannot be said for the RFoG return path, however.

The return path on an RFoG network is a multipoint to point design. The RFoG ONU uses high powered RF Transmitters to overcome the splitter losses and sensitive receivers to reduce the noise generated by the network equipment providing the optical network. Ingress noise on the return path is controlled by the RFoG ONU itself by the nature of its unique "burst mode" optical transmitter. In burst mode, the optical transmitter is not activated until a signal source inside the home transmits. Performance of the burst mode controllers in the RFoG ONU is a critical factor when choosing an RFoG ONU for use in a 64 split RFoG network. Here are some things to watch out for.

1. The RFOG ONU Burst transmitter should not trigger on impulse noise Since a cable modem generally transmits >+40dB, RFoG ONUs have a high threshold for activating the laser. This value is generally around +5 dBmV to +10dBmV. Since this is such a common source of network noise, the SCTE plans to specify an even higher level in the future RFoG standard. **Titan designed the NanoNode RFoG ONU's input threshold to be > 15dBmV to accommodate the upcoming improvement in the standards**

2. The RFoG ONU should minimize optical output when it is not transmitting information. Generally RFoG ONUs do not completely shut down the optical transmitter when in the “off” state to allow them to react quickly to a legitimate RF signal. Unfortunately this “partial off” solution allows low levels of noise from a home to be transmitted to the optical network even when no information is being transmitted. This noise adds up in the ODN and raises the noise floor at the Head end. This is an issue especially when the network has 64 ONUs. **The Titan NanoNode RFoG ONU’s return path transmitter is completely deactivated while it is not transmitting, eliminating this noise ingress source.**

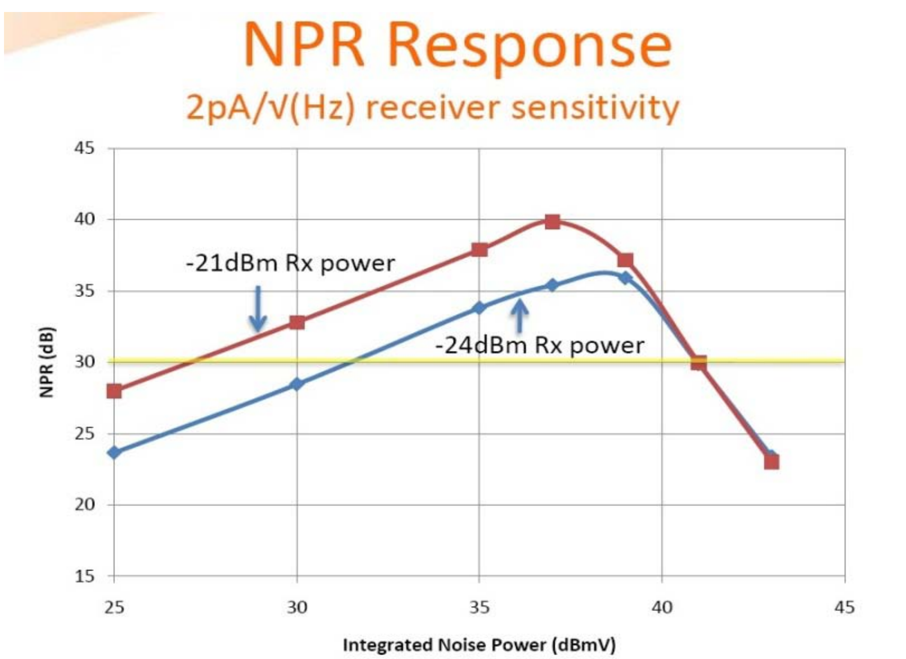
Reducing Network-induced Noise

All electronics generate noise. The amount of noise generated by a device on the network is known as the noise figure of the device. The lower the noise figure, the less noise it contributes to the network.

Lowering the noise floor

The noise floor is an accumulation of noise from all sources on the network measured at the final output stage of the system. In an RFoG network, the large loss in the optical splitters reduces the signal level of the return path mandating a high gain return path receiver. Each ONU adds a small amount to the noise floor on the network. With 64 splits, the accumulated noise can be a factor in network designs. To reduce this noise source, choose an RFoG ONU with a high On/Off ratio for the optical transmitter. This will result in a better SNR at the input to the return path receiver in the head-end.

In an RFoG network the location and topology determines the optical power received at the RPR from each ONU. When the signal at the return signal is very low, the noise generated by the RPR itself becomes a big factor in the overall network because the receiver noise and the signal are both amplified before being output to the head-end COAX network. When the incoming signal is too great, the receiver will distort the signal and information is again lost. For these reasons, the optical power levels on the RFoG network must be planned to insure that the received signal power is well within the receiver’s dynamic range. A low noise RPR with a wide dynamic range (such as the Titan RFoG RPR), should be utilized when designing a 64 split RFoG network to minimize its impact to the network noise floor.



- **More optical power into the RPR → wider dynamic range**

Designing the RFoG network loss plan

Planning a high performance, low noise RFoG optical network requires that a designer to insure that the network losses are calculated for both the forward and the return path. The optical loss budget is defined by the RFoG active equipment that is located in the head-end and the customer's premises. The optical loss plan is calculated from the passive optical devices and cables being used. A successful network design insures that the network loss plan does not exceed the loss budget at any RFoG ONU on the network.

Key loss contributors on the RFoG network topology (in order of significance)

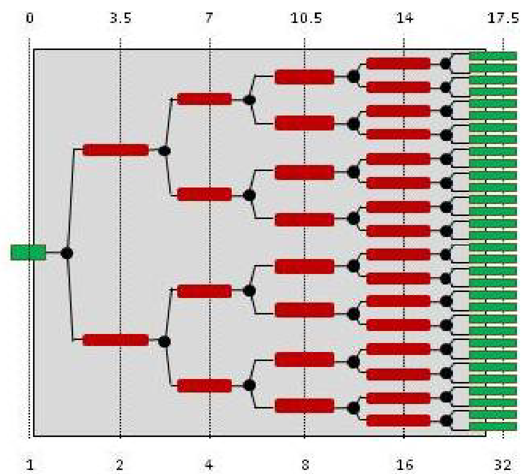
1. Splitter/combiner

An optical splitter is a type of splice where the light is divided and output on multiple fibers. The splitter is the dominant loss factor in a RFoG network. A splitter is made up of a multitude of 1x2 way splitters all attached in series Every split reduces the optical power in half, (3 dB) so the total number of splits in series impacts the loss on the network. The loss is symmetrical, so a forward path through a splitter is reduced by the same amount as the return path.

Splits	Loss (dB)
1x2	3.5
1x4	7.0
1x8	10.5
1x16	14.0
1x32	17.5
1x64	21.0
1x128	24.5

Average losses in a splitter

Loss in dB



Splits

2. Fiber optics loss

The second largest contributor to the network loss is the fiber optics itself. Fiber cable varies, but as a rule of thumb, you can figure on 0.20 to 0.22dB/Km of fiber at 1490 to 1610nm, but the loss is greater at 1310 nm (generally around 0.3dB/Km of fiber)

3. WDM loss

The RFoG WDM separates the forward and return path wavelengths for connections to the equipment in the head-end. Different WDM configurations are used depending on the return path wavelengths and if the network is to be shared with a baseband PON network. There is usually a single WDM device in the head-end for each RFoG fiber ODN. The typical loss through one of these devices is 1.5dB

4. Splice loss

Each splice in a fiber network results in a optical loss. Splicing techniques have been continually improving in the past 10 years, but a conservative rule of thumb is that each splice contributes 0.3dB loss per mechanical splice and 0.05dB per fusion splice. Fusion splicing should be used wherever possible to insure the highest reliability/lowest loss network design.

Choosing the right equipment

To know what type of optical equipment you need, first calculate the network losses you expect on your network. Since the optical network design does not contain any amplifiers, you need to provide select an EDFA with enough output power to overcome all losses in the network. Most RFoG ONUs operate with very little noise using a receive signal in the range from +1dBm to -6dBm range. Optical AGC, like that used on the Titan NanoNode, helps maintain constant RF output levels across an extended dynamic range without affecting the SNR. If the RFoG ONU does not support optical AGC, you should design the network for an optical signal level of -2dBm or -3dBm at the RFoG ONU to allow for degradation over the life of the network. If the ONU has optical AGC, designing to the -6dBm is acceptable.

The maximum output power of an EDFA is generally restricted to +21dBm at the output connector. **Adding the EDFA output and the RFoG ONU input sensitivity gives you a maximum total network budget of 27dB assuming optical AGC in the RFoG ONU.**

Calculate the network loss by adding up all of the known loss factors described above *(assuming insignificant fusion splice loss)

For 32 splits (splitter = 17.5dB) + (20Km fiber = 4dB) + (WDM = 1.5dB) 23.5dB total

For 64 splits (splitter = 21dB) + (20Km fiber = 4dB) + (WDM = 1.5dB) 26.5dB total.

As you can see the network budget for the common RFoG node is very well suited for a 32 split network, but the 64 split configuration has almost no margin for network degradation!

64 splits and high performance?

The added loss of the 64 way splitter can be compensated for, and a reliable high quality network, with superior SNR can be deployed if you keep in mind the following tips:

1. Use an EDFA with integrated WDM. The Titan HP-EDFA uses an internally spliced WDM and the output is compensated to provide a maximum output of 21dBm AFTER the WDM. Besides reducing the number of discrete components needed in the head-end, it eliminates 1.5dB WDM from the network loss plan.

2. Use an RFoG ONU with optical AGC The Titan NanoNode supports -48dB SNR with optical input as low as -6dB, allowing the receive level to be designed to -6dBm without sacrificing margin. This improves the loss budget by 3dB by allowing the network to be designed to a lower power level at the ONU.

3. Use a Premium quality Transmitter with at least 21dB SBS While not directly impacting the network loss calculations, the high quality transmitter compensates for SBS distortions caused by the high launch power needed on the 64split network that would negatively impact the SNR at the RFoG ONU location.

4. Minimize the number of mechanical spices in the network. Each can contribute 0.3 to 0.5dB to the total network loss. (Note that connector loss for the WDMs and RFoG equipment are already accounted for in the above calculations).

Return path considerations

As mentioned above the loss on the network is symmetrical and a 64 split network will result in a 26.5dB loss, assuming a 1610nm RFoG return path. The return path equipment (the ONU and the return path receiver) control the optical budget. Noise will distort the return path content the same as with the forward path but in this direction, you have little control over the optical transmitter power at the ONU, and the return path receiver must be much more sensitive.

An RFOG ONU typically has a laser transmitter power from +1 to +3dBm. Some high-power ONUs, such as the Titan NanoNode ONU, support optical launch power of +5 to +7dBm. **When planning a 64 split application, it is best to use the highest power RFoG ONUs that you can find.**

RFoG Return Path Receivers are more sensitive than traditional HFC receivers, because they need to deal with the high losses encountered on an RFoG network. It is imperative that the receiver has a low noise figure, and a wide dynamic range to accommodate a variety of network topologies. Standard HFC receivers will work for some RFoG applications, but are not best suited for 64split networks.

How can you get the return path to perform well at 64 splits?

1. Select an RFoG ONU with a more powerful transmitter. Higher optical power improves the SNR by reducing the gain necessary in the head-end return path receiver and by reducing the noise accumulation effects. The Titan RFoG ONU supports a high power optical transmitter with a launch level of +6dBm. This optical power along with the very high on/off ratio of >50dB insuring a clean robust signal into the return path receiver.

2. Select a premium RFoG Return Path Receiver. To support 64 splits, a sensitive, very low noise RPR with a wide dynamic range is necessary. The Titan RFoG RPR supports a sensitivity of 2pA/sqrt(Hz) and includes optical AGC allowing the network to be designed to -24dBm and still maintain an NPR>30dB and a dynamic range >9dB

3. Do Not use 1310nm return RFoG ONUs. Even though the 1310nm ONUs are priced lower than the 1610nm equivalent, the optical loss on the fiber is 0.1db/km greater. This can result in another 2dB loss over 20KM

CONCLUSION

As this paper has shown, controlling Noise on the RFoG network, and selecting the appropriate network components allows the RFoG network designer to deploy a high performance RFoG network and still support >20Km reaches without field electronics or special fiber optics components. Titan Photonics provides RFoG equipment specifically designed to accommodate the higher split ratios on the network making these deployments simple and affordable.