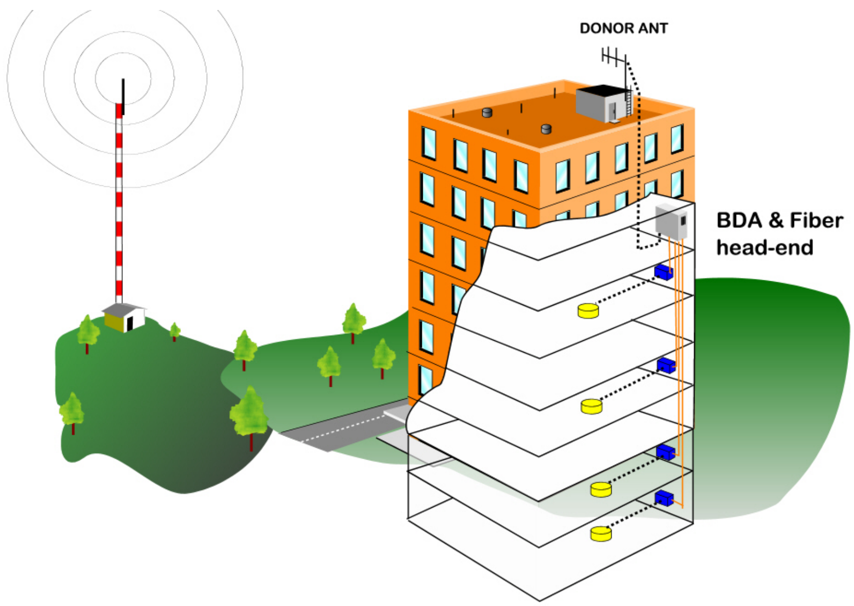
Introduction to Public Safety RF Signal Distribution using Fiber Optics



By Jack Daniel
The Jack Daniel Company
1-800-NON-TOLL
www.RFSolutions.com

Introduction

Over the last 10 years, the use of fiber optic (FO) cable in place of more conventional coaxial cables has become viable in many applications due to advances in analog fiber optic technology. This discussion is intended to inform an experienced in-building (DAS) wireless system designer familiar with fiber optic terms, specifications and devices as they would apply in a radio frequency (RF) system design.

For the purposes of introduction to FO technology some generalizations are used. When specific specifications are used, they are based on manufacturers published specifications available at the time this text was written, such as the attached FibeRFill specification sheets.

Please note that this presentation does not cover digital data or LAN type products or applications using digital fiber equipment instead of analog which is not compatible with RF-over-Fiber.

Why use Fiber Optic system for RF applications:

RF system designers are familiar with the two major limiting characteristics of coaxial cables: the RF loss increases with frequency and length. Coaxial cables are limited in the length that they may be used without additional amplification. Long lengths of coaxial cables, such as might be required in tunnels or building-to-building, rapidly become cost prohibitive, especially if in-line RF amplifiers are also required.

Fiber optic (FO) cables have very low losses compared to coaxial cables. With RF over fiber distances of many miles being practical, the system designer has a new tool to help solve difficult RF distribution challenges that would normally be impractical using coaxial cables.

The fact that FO cables do not 'leak' or couple RF signals makes them ideal when routing through noisy RF environments or running long lengths parallel to other FO or RF cables. This same feature makes FO cables ideal when used in an application that cannot tolerate EME emissions, such as TEMPEST sites, etc.

The lack of electrical conductivity may also be attractive in some applications, such as electric utilities.

Fiber optic cables can be much smaller and lighter weight than corresponding RF cables and are usually non-metallic, making installation and routing much simpler.

Fiber Optic System Conventions and Components:

The basic components of a RF - FO system consists of (1) fiber cable (including associated connectors), (2) FO Transmitters and (2) FO Receivers. The transmitter and receiver components may be single small stand-alone 'transceivers' or rack mounted units containing several fiber transceivers. Additional FO devices, such as patch panels and WDM (optical duplexers) that expand the system design options will be discussed later.

The RF to Fiber equipment locates at the base station or signal booster end is referred to as the "head-ed" of the system. The RF to Fiber equipment located at the far end of the fiber optic cable is called the "remote-end" or simple a "remote".

The Fiber Optic Cable:

Fiber optic cable comes in many different types, configurations and specifications. Rather than go into great detail of the many variations, we will concentrate on the most important basics relative to RF applications.

There are two primary 'modes' of fiber optic cable operation: 'Multimode' and 'Single mode'.

In general, multimode has been in use longer than single mode and meets the needs for shorter data communications applications where the data rate is comparatively low (i.e. <100 Mbps) when compared to RF signals (2 to 4000 MHz).

While multimode cable can be used for very short cable runs (less than 2000 ft, typically), the distance restriction can limit the usefulness and future expansion of a system.

Single mode is the preferred type of cable for RF applications, especially for longer cable runs where higher output laser type transmitters can be used and where very wide bandwidth and high RF frequencies are required. Single mode losses are less than multimode. It is practical to design a single mode fiber system that has very wide bandwidth with zero net loss, end to end, using basic equipment, up to 10 pr more miles without any in-line amplification.

The physical installation considerations for FO cable is usually simpler than installing 1/2" corrugated coaxial cable, with comparable bending radius requirements. However, FO cable has least loss with minimum bends and turns of the cable, so installation in conduit (metallic or plastic) or raceways is preferred to give the optimum support and maximum practical bending radius. The bending radius is determined by the number of fibers in the same cable sheath and the mechanical construction of the cable.

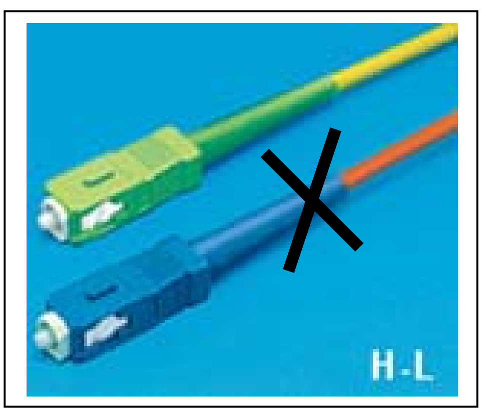
Fire resistant and Plenum rated cables are common. The costs of FO cable are dependent upon the number of fibers and the mechanical construction of the cable. It is common practice to include several spare fibers (called "dark fibers") for growth due to the small incremental cost increase.

Connectors for high performance single mode cables are unique and are generally less expensive than coaxial cable connectors. Most fiber connectors require special equipment to install the connectors or splices for minimum optical loss.

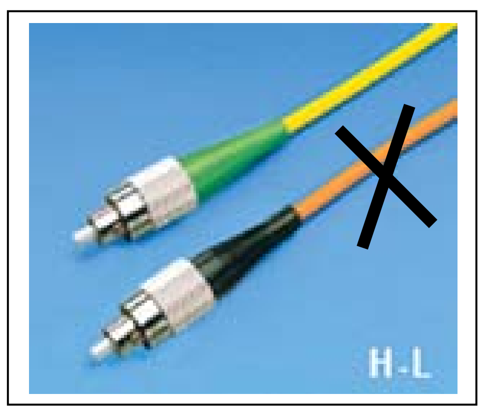
APC (Angle Polished Connectors) are used on single mode fiber to reduce the reflections back to the laser transmitter which could reduce efficiency or cause damage in extreme cases. In APC connectors the fiber end is slightly angled (8 degrees) so that any reflected light is highly attenuated instead of propagating freely within the fiber. The effect is similar to an RF isolator. Training and special tools are required to properly attach and test APC connectors. Common practice is to splice read-made connectorized pigtails to the main fibers using fusion splicing.

The most common RF over Fiber connectors are FC-APC and SC-APC type connectors.

Unlike coax connectors, popular versions, such as FC/APC types, are all the same gender and use a "sleeve" (the equivalent of a coax 'splice' or dual female connector) to complete each connection. Sleeves are purely mechanical with the optical coupling occurring directly between the butted ends of the two connectors.



Top: "SC-APC" = Use if specified
Bottom: "SC" = DO NOT USE



Top: "FC-APC" = Use if specified
Bottom: "FC" = DO NOT USE

Fiber cable RF Specifications:

For fiber loss approximations, use 0.25/1000' @ 1330 nm or 0.1 dB/1000' @ 1550 nm plus 0.25 dB loss per FC/APC connector. Note: A splice or in-line connection would use two connectors and one sleeve for a total loss of approximately 0.5 dB per splice.

For propagation delay, use 1.53 uS /1000 feet = 8.05 uS/Mile, plus FO equipment delay. Typical FO equipment delay is less than 5 uS, end to end.

FO Transmitters:

Most FO transmitters that are designed for **data** transmission are modulated in a 'digital' (off-on) two state manner. RF FO 'analog' transmitters however are'linear' in operation, the light source being amplitude modulated at the RF frequency. Analog FO transmitters suitable for wireless RF applications are less common and more expensive than simple digital FO transmitters, mostly due to the additional circuits needed maintain high linearity and stability over temperature, etc.

Analog FO transmitters may use LED emitters for moderate level output (shorter range/low fiber loss) applications and solid state laser emitters (DFB type) for high power output (longer distance/higher fiber loss) applications.

In some older transceiver designs, the RF input frequency may be down converted to a lower "IF" frequency because the linear bandwidth did not extend to the input frequency range. This approach inherently increased the probability of intermodulation, RF distortion and, in some cases, unacceptable RF envelope delays. Fortunately there is no longer a need to convert frequencies below 4000 MHz as improved modulators and emitters have become available.

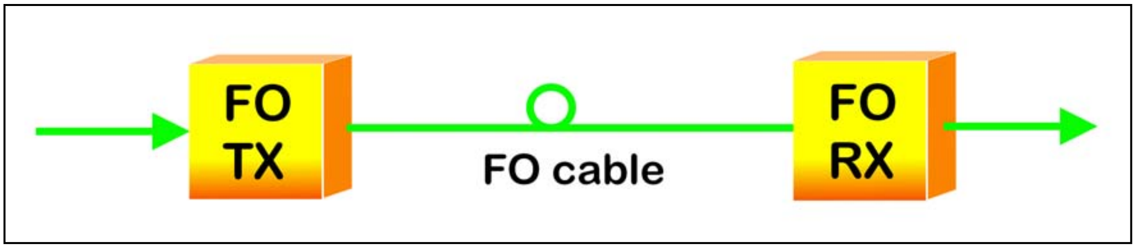
Modern linear transmitters modulate the optical emitter at the RF frequency *directly*. There are no RF conversions of any kind prior,or after, the optical components. RF system frequency bandwidths of 100 to 2200 MHz, or more, using one transmitter and one receiver over one fiber are commonly available at moderate cost.

FO Receivers:

Analog FO receivers are required to convert the FO signals back to RF frequencies. In some equipment, the gain of the receiver may be adjustable to prevent overdrive. Overdrive can distort the recovered RF signals. Receivers also include linear compensation circuits and are commonly available.

A basic RF over Fiber - RF System:

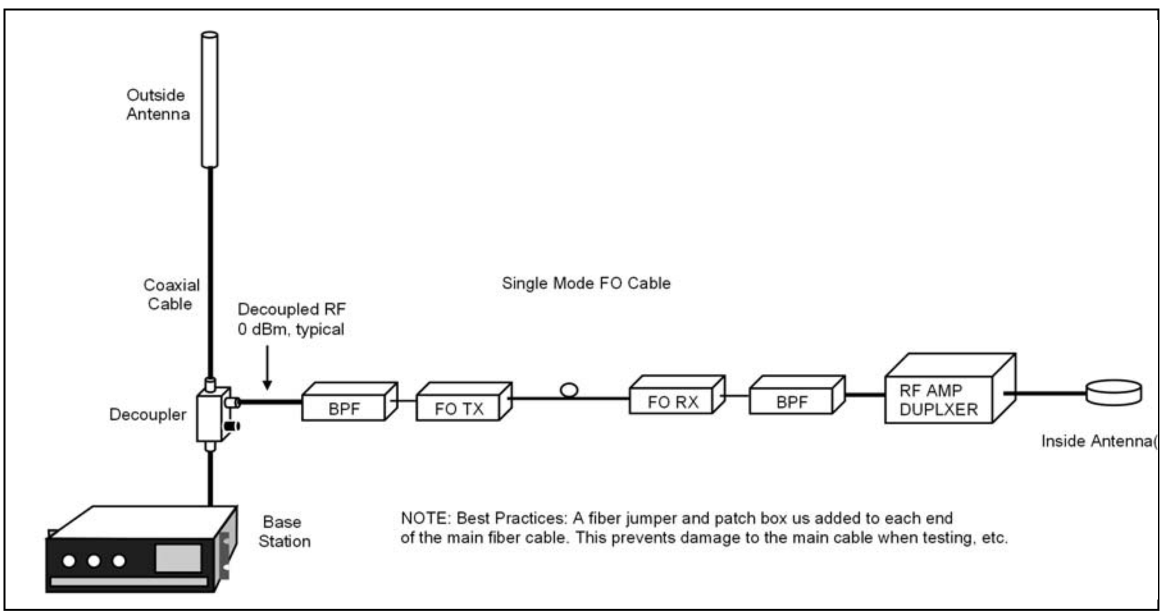
In figure 1, the most basic one way system is shown.



In this example, RF from a RF transmitter is injected into the FO TX (Fiber Optic Transmitter) at one end of the fiber optic cable. At the other end of the cable, the Fiber Optic Receiver (FO RX) converts the signal back to RF. The input level is O dBm typically and the output level is equal to the input level. Note there is a net zero loss of RF signal end-to-end.

The FO TX is the 'head-end' and the FO RX is the 'remote end' of the system.

In Figure 2, we have refined the system shown in figure 1 into a Downlink Only, one way system, coupled directly to a base station.



The RF source is a decoupled signal from a RF transmitter (Base Station or signal booster). The full output power of the RF transmitter would damage the FO TX. Assuming the RF transmitter is also connected to an outside antenna, the decoupler used is a directional type to further reduce any unwanted signals that may be coupled via the antenna to the FO TX. The typical decoupler adds approximately 0.1 dB loss to the power going to the outside antenna.

NOTE ON WIDEBAND CIRCUIT POWER: The use of bandpass filters improves the output power per carrier by reducing unwanted energy within the very wide passband of the fiber optic system. Like all broadband systems, the maximum power allowable is based on the 'composite', or total, power of ALL the signals passing through the system. Any undesired energy that is removed by filters increases the power available to desired channels. Therefore, bandpass filters that closely match the desired passband bandwidth(s) are highly recommended.

Most FO transmitters (FO TX) are designed for a maximum RF input level of 0 dBm, which is easy to obtain from most base or repeater stations.

Over the air inputs to the FO TX usually require signal boosters (BDAs)adapted to fiber optic interfaces.

It is important to know the connector losses of the FO cable system because connectors and splices can account for the majority of optic loss in 'real' installations. In the example, an estimate of 0.5 dB was used for each paired connection (actually 0.25 dB per connector times two connectors per connection).

The FO receiver (FO RX) in the example is designed for a 'zero net loss' system design with up to 9 dB cable loss. This method of stating the system performance is typical of fiber optic system specifications, which use a 'zero loss' basis to determine the optical loss budget in a system. In other words, they design towards a 'zero loss' fiber optic link overall. Naturally, the system may still operate adequately with less or more loss, dependent upon the dynamic range of the system. Refer to manufacturers specification for exact gains.

The maximum FO receiver optical input level (i.e. that which generates 0 dBm RF output) is usually the highest level where linear prformance is assured. If that level is exceeded, RF performance may deteriorate and could even damage the receiver if exceeded greatly.

The FO RX output level may be near 0 dBm. That may be too much signal if it is fed directly to a RF amplifier or signal booster. The gain of the amplifier/signal booster should be reduced to match the FO RX level or a RF pad added in-line.

TWO-WAY RF/FO System:
A two-way system (figure 3) is basically combining the transmit path (downlink) with a receive (uplink) path as one system.

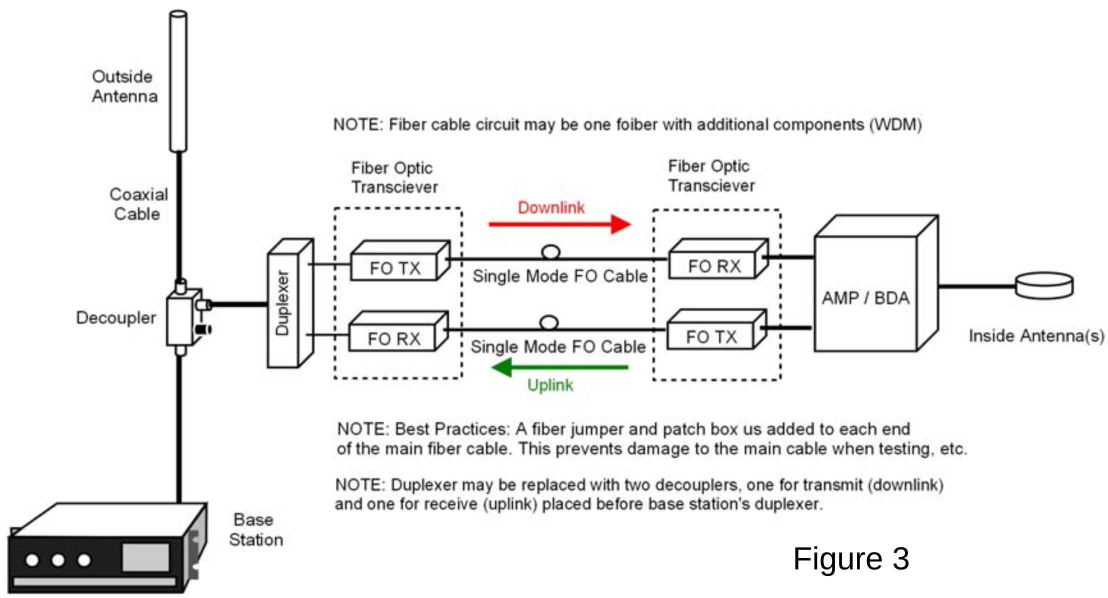


Figure 3

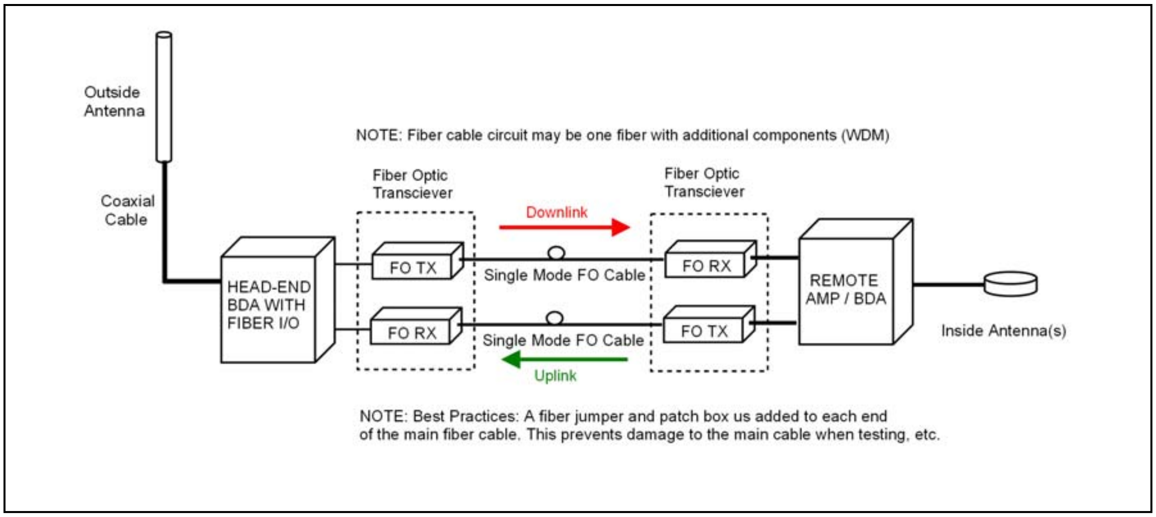
The fiber equipment located at the base station (or signal booster) is the head-end. The equipment located at the other end of the fiber cable is the remote -end.

Note the "Amp/BDA" at the remote end is a special in-line amplifier/duplexer designed to amplify the RF levels to/from the inside antenna. This is not a common Off-the-Air type signal booster or BDA.

If the decoupler is to be placed in a duplexed antenna line, as shown above, only one directional decoupler is used and a duplexer is used in reverse to separate the downlink and uplink connection to the FO transceiver. Some manufacturers refer to this as a 'radio interface'. The duplexer's filters serve the bandpass filter functions at the head-end. Similar filters are in the dupleexr at the remote-end.

If available, two decouplers can be located at either the two head-end radio antenna ports (transmitter and receiver) or the duplexer radio ports (not antenna port) to take advantage of any additional TX - RX isolation existing in the radio system. For example, in a multichannel system, one decoupler would be placed in the transmit combiner output and the other in the receiver multicoupler input. This is common in trunked system applications.

SIGNAL BOOSTER INTERFACE:
Interfacing fiber to a signal booster is the same as connecting to a duplex base station. Since the fiber circuit is not bi-directional, the installation requires separate downlink and uplink connectors to the signal boosters. The signal booster connected to the donor (outside) antenna is commonly called the 'head-end' signal booster. The figure below illustrates the basic interface:



HOW MANY FIBERS TO USE:
The optical signals used in the fiber optic cable have similar interference considerations as RF signals inside a coaxial cable. Since the FO cable is bi-directional two signals on the same optical frequency can't be separated from one another and cause interference to each other.

In wide bandwidth analog FO applications, 1330 nm is the most common and lest expensive optical signal frequency. 1510 nm is near the minimum loss frequency of single mode fibers, making longer distances possible. When one optical frequency is used for both directions (2 fibers), it simplifies testing and minimizes spare equipment models. That means two fibers can be used in a two-way system design, one for the 'downlink' (repeater transmit frequency) and one for the 'uplink' (the portable transmit frequency).

Since most fiber optic cables contain many 'pairs' (i.e. 6, 24, 50, etc.) in anticipation of future growth, the addition of a few more fibers has minimal effect on overall cable installation costs. Unused single mode fibers (i.e. "dark fibers") may already exist in a previously installed fiber cable.

However, if the optic fiber availability is limited, there is the equivalent of duplexing two optical signals onto one fiber, using a different frequency in each direction. The second frequency is usually 1550 nm. This frequency is also near the lowest loss frequency of single mode fibers, but slightly more expensive to implement in fiber optic transmitters, another reason for favoring 1310 nm if possible.

In fiber optic systems, a 1310/1550 nm duplexer is called a "WDM" which is the abbreviation for "Wavelength-Division Multiplexer". It has three ports: (1) 1310 nm, (2) 1550 nm and (3) duplexed (FO cable) port. It is connected using standard FO connectors, discussed earlier. These are passive devices not requiring external power.

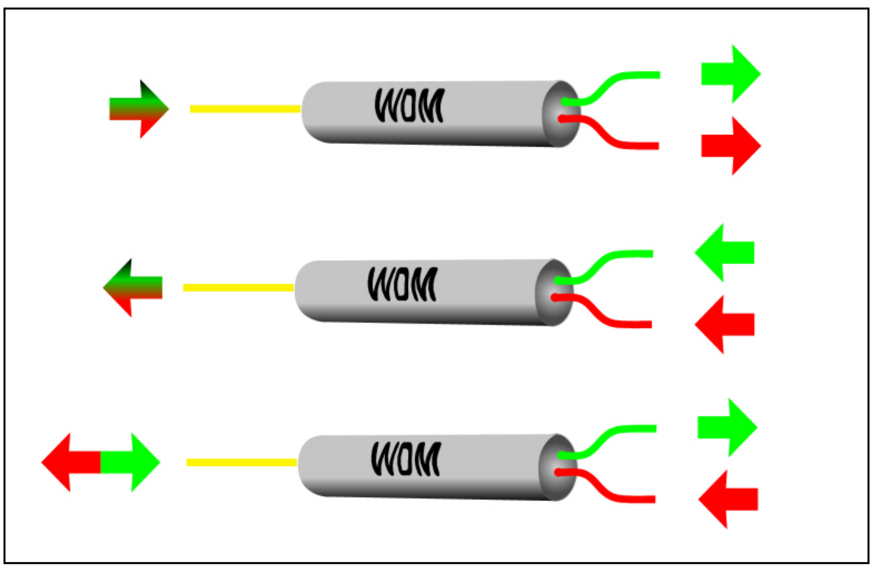
WDM devices add loss to the system and therefore reduce maximum operating cable lengths. Losses include internal coupling losses as well as connector losses. While specifications from brand to brand may vary slightly, the general specifications are:

1310 to 1550 port isolation (Directivity): >55 dB

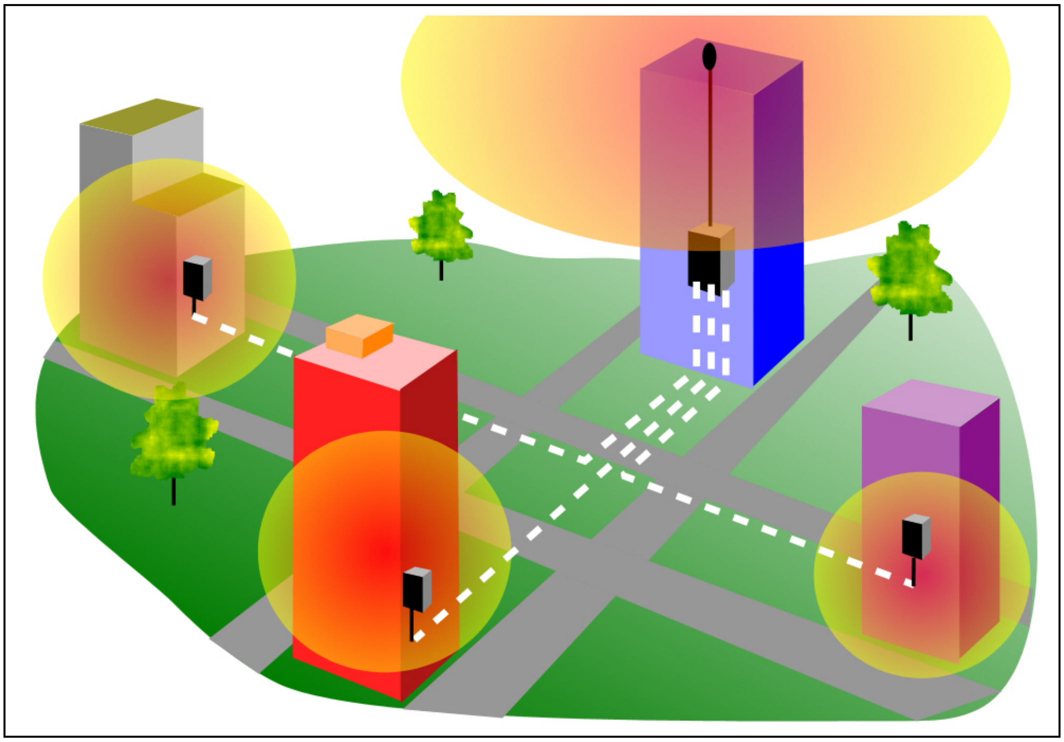
1310 or 1550 port to cable insertion loss: <1 dB

Return loss using APC connectors: <-55 dB

Unlike RF duplexers, WDM devices can have directional characteristics and come in different configurations. A "unidirectional' type has the two signals going the same direction, which is NOT normally applicable to our requirement. A "Bi-directional" type is most like a RF duplexer as seen at the bottom below:



USING FIBER TO CONNECT MULTIPLE LOCATIONS:
In some situations, the fiber optic distribution may have to connect several remote sites to one base station. A frequent application is a 'campus' like situation where the repeaters are located atop one major building and several other buildings (with RF obstructed areas, basements, etc.) are located within a few miles of the repeater building. The repeater site is the head-end.

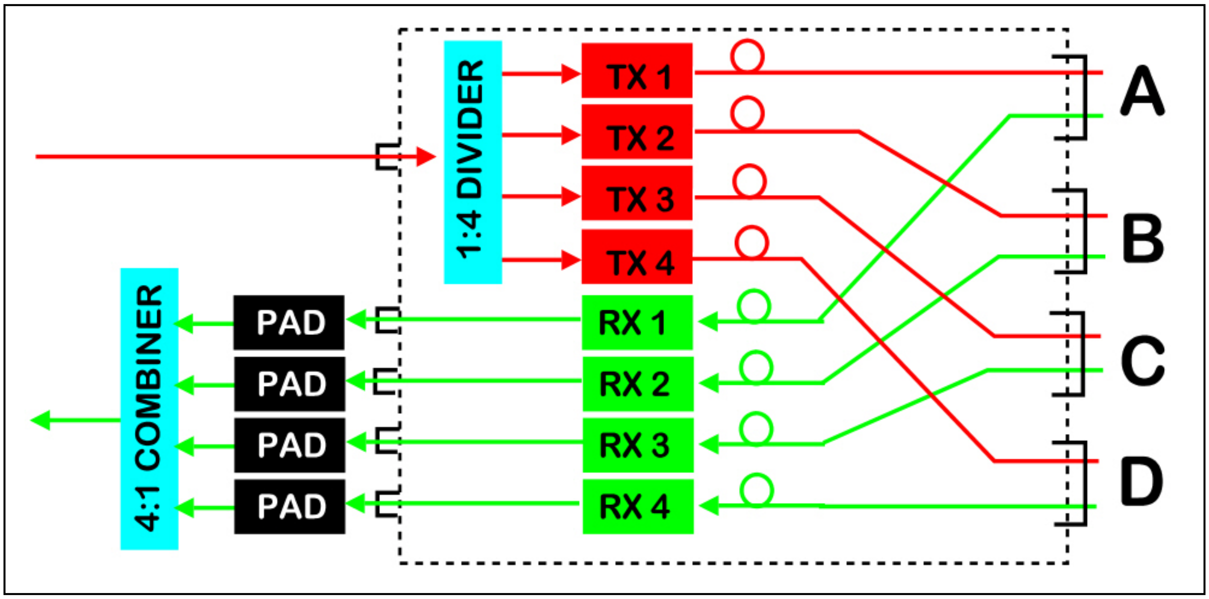


Unused single mode fiber optic cables often already connect the buildings for data communications and spare fibers can be used for the RF over fiber system to enhance radio signals in the other buildings.

A multipoint fiber optic transceiver assembly at the base station is commonly called a "head-end". The distant end of the fiber is called the "remote hub" equipment.

Multi-remote fiber head-end shelves come with transceivers to feed 1 to 5 remotes per 19 inch shelf.

A 4 remote head-end shelf diagram is shown below. the number if remotes can be increased by adding more multi-remote shelves at the head-end.



Note that each FO receiver output at the repeater site has individual pads to reduce the composite noise floor and provide FO RX to FO RX isolation and minimize receive combiner intermodulation. For example, if 40 dB pads are used, an additional 80 dB of combiner port-to-port isolation occurs.

In real applications, it is good practice to include decoupled taps as test points to read the RF levels going into the combiner for test and maintenance. Be sure to include the RF combiner losses in signal level calculations and pad estimates.

A similar system design is possible when WDM's are used. If WDMs are used, the number of fibers is reduced by 50% but a WDM must be added at each remote site and another WDM for each fiber added at the repeater site. In the 4 remote site example, it would take 8 WDM's to operate all the fibers full duplex and 4 FO transmitters would have to be 1550 nm models.

Note: FO receivers are not frequency selective and the same unit can receive 1330 or 1510 nm optical signals equally well.

MORE COMPLEX SYSTEMS: Neutral hosts

With the building blocks described here, much more complex systems can be developed. Many other devices are available to amplify, multiplex and split optical signals, however many are not suitable for linear operation.

High rise building owners may find it profitable to install a rf distribution system shared by multiple cellular and PCS service providers. These are called 'neutral host systems'. Due to the bandwidth, these systems commonly use fiber optic distribution.

Including public safety channels in a neural host system can be problematical. In addition to technical incompatibilities, issues of 24/7 access, serviceability and system modifications may be difficult to resolve.

Additional information on neutral host type systems are available from manufacturers such as MobileAccess, fibeRFill, etc.

In-Building design software.
In-Building system design software has become very sophisticated and expensive. However, for complex systems and complex structures it is almost a necessity and will save time and provide a professional presentation. A popular example is iBwave software.

This software can be used for both fiber and non-fiber system designs.

For more information see the following brochures or Visit www.RFSolutions.com

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Email: jackdaniel@RFWise.com