Application Note

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Why do I need to inspect and/or clean the fiber in an optical BBU/RRH link?

Introduction

After ruling out traditional problems like passive intermodulation (PIM), poorly aimed antennas and/or other coaxial problems, dirty fiber connectors account for 60 to 75% of the alarms, failures, and poor throughput problems found in modern cellular systems today.

It has been several years since the initial introduction of the current BBU (Baseband Unit) and RRH (Remote Radio Head) architecture of today's wireless cellular systems. This relatively new architecture incorporates a fiber optic link between the BBU and one or more RRH units, and the data carried through this fiber optic link is typically mapped in a CPRI (Common Public Radio Interface) protocol and in some cases an OBSAI (Open Base Station Architecture Initiative) protocol may be used, however CPRI is more commonly found. Conceptually the architecture is ideal and has very few drawbacks, although in early deployments many problems were encountered with this type of architecture. In the earliest deployments of these systems, many field technicians were not familiar with the new optical interface and simply did not have the required experience to properly install, and/or troubleshoot and resolve the issues on site, which led to the brute force replacement of many early deployed RRH units. There is sufficient evidence supporting the fact that many of these replaced RRH units were determined to have no faults found after being returned to the manufacturer. So what really happened? Replacing the RRH on site seemed to resolve the issue but the manufacturer found no faults with the RRH when it was returned. It is the belief of the author that the fault generally resides within the optical link between the BBU and RRH, and not solely in the RRH itself. In this article we will take a closer look at the actual physical optical link and we will discuss the optical transceiver hardware that is most commonly used in this type of system.

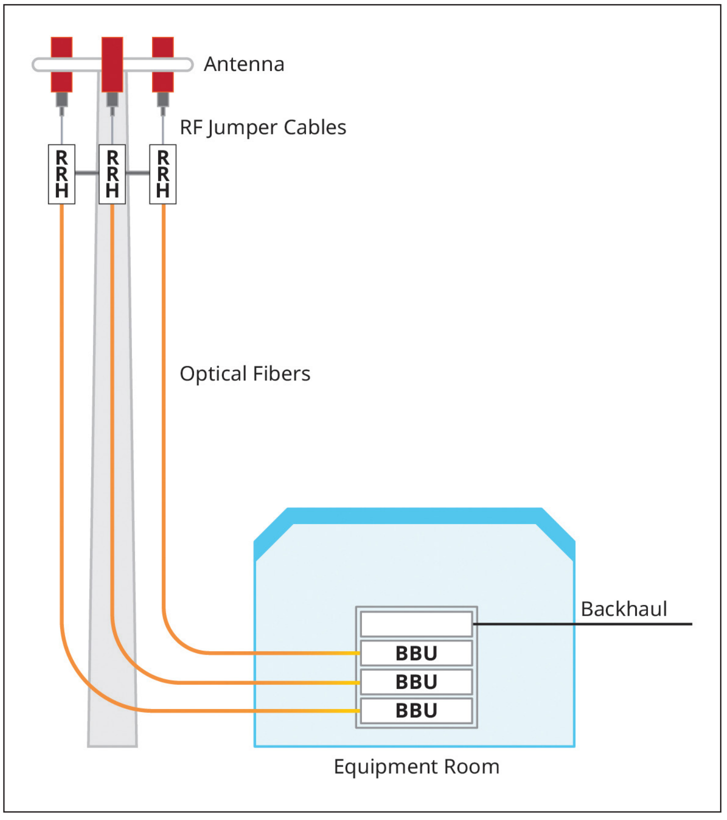

Figure 1: Example of BBU/RRH configuration with optical CPRI link

Content

Let’s start with the optical transceivers used. In the overwhelming majority of these systems, the SFP (Small Form-Factor Pluggable) and/or SFP+ (the plus refers to data rates of 5 Gb/s or higher) module is the optical transceiver of choice, mainly due to its very small size, low cost, and the abundance of pre-existing technology readily available that was originally developed for the optical wireline industry (the fiber optic core backbone). It is easy to understand why the manufacturers of this new wireless system architecture selected SFP modules as the transceiver(s) of choice.

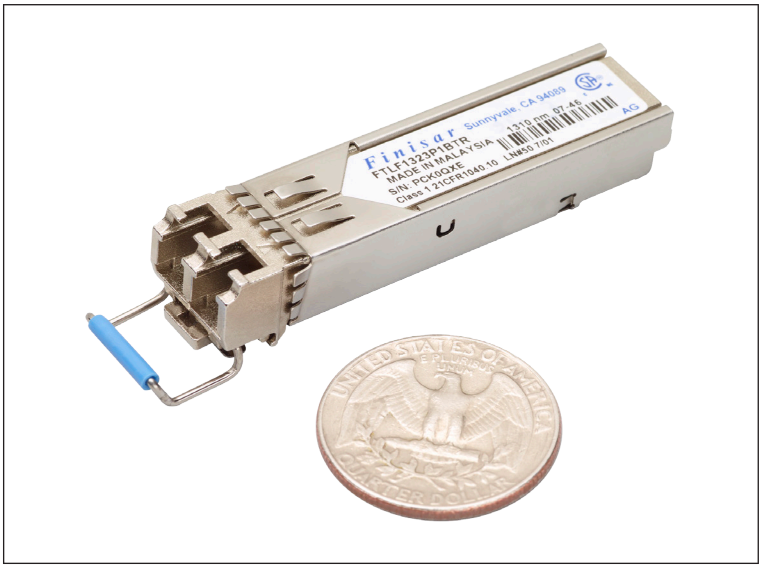

Figure 2: Typical SFP module

Let’s take a closer look at an SFP module currently available for use in the CPRI link between the BBU and RRH. We need to review some of the specifications of the SFP module(s) so that we can better understand the importance of ensuring the fibers used to connect between BBU and RRH are clean and not damaged in any way. Before we review these SFP specifications we will have to discuss the qualities of fiber optics in general and how fiber optics overall have revolutionized our communications industry.

Now let’s look at the typical fiber(s) being used. One important and attractive quality of fiber optics is their extremely low transmitted signal loss, relative to other transmission media such as coaxial. This incredibly low loss property of fiber has ultimately led to the high speed, high bandwidth connected world that we now live in. A typical Single Mode (SM) fiber loss averages between 0.22 dB/km (0.352 dB/mile) and 0.38 dB/km (0.608 dB/mile) at 1550 nm and 1310 nm respectively. There are additional losses which occur at each connector point, and in any case where the optical fiber has been damaged and repaired (fusion slice repair) there will be additional losses at those points. The typical loss for connectors is in the range of 0.2 dB to 0.5 dB. Fusion splice repairs are even lower, ranging from 0.05 dB to 0.2 dB. This incredibly low loss characteristic of fiber has enabled high speed data to be transmitted for thousands of kilometers and has forever changed the world we live in. Only fiber optics could enable this capability, and today there are thousands and thousands of kilometers of fiber connecting the entire globe. Those fibers run all the way from coast to coast in any given continent, and under the oceans those same fibers connect the continents to each other. No other communication media has ever been able to provide such a robust method of transmitting (and receiving) high speed data around the world. Traditional coaxial based communication systems simply cannot span across the oceans, and are very inefficient in comparison to fiber. Then there are satellite communication systems, these can overcome ocean spans but they are extremely expensive, both for transmitters and receivers, are difficult to deploy and maintain, and are sensitive to weather conditions which can wreak havoc on throughput, and compared to fiber, satellite systems have limited data capacity and much larger delays (latency) even under ideal conditions. The winner is clearly fiber and it is not surprising that fiber has made its way into the current wireless cellular architecture.

So, if fiber is so great, and has such low loss then why do we care if it's clean? Why do we need to have special fiber inspection scopes and special fiber cleaning kits? Why should we care? The answer mainly lies in the optical receiver technology, and the inherent lack of great sensitivity in optical receivers (which reduces even further as data rates increase) in general, but to further compound that issue is the fact that the SFP is the transceiver of choice in these systems for reasons of low cost, easy deployment, and their availability, and of course their small size. If we take a moment to review a typical RF based receiver, we quickly see that RF receivers can have (and do have) extremely good sensitivity, for example a cell phone has no problem receiving signal strength levels at –100 dBm or lower. The cell phone being used by the author is receiving an LTE signal with a displayed signal strength value of –112 dBm (as reported by the phone itself) and this low level signal received translates itself as 3 out of 5 bars showing on the phone's signal strength indicator at the top of screen.

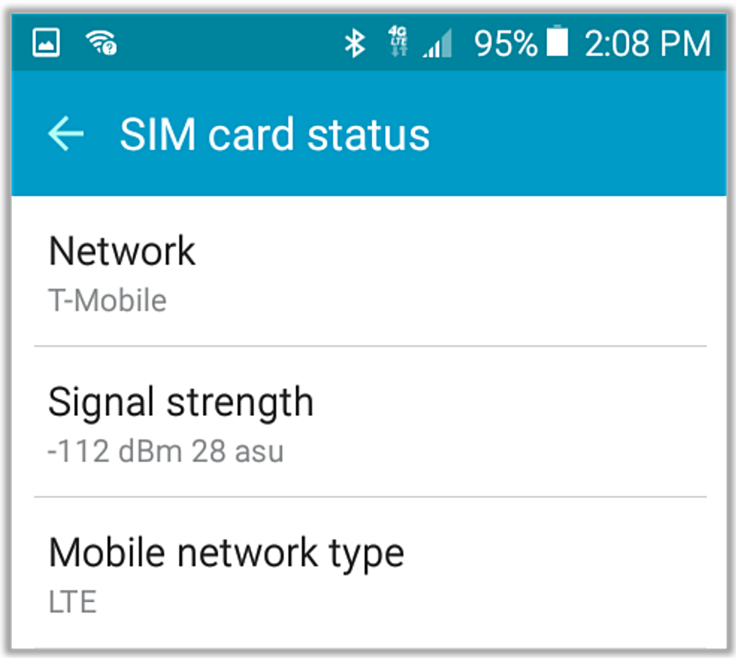

Figure 3: Actual signal strength level as indicated on LTE cell phone. Notice 3 bars out of 5, and -112 dBm

Let's compare that with a SFP+ module specifically designed for CPRI links between the BBU and RRH equipment. We will use Finisar's FTLX1370W3BTL as the optical transceiver for this comparison. This SFP+ module is compatible with 5 CPRI line rates, from 2.457 Gb/s going up to 9.8304 Gb/s. An SFP+ transceiver module is comprised of an optical transmitter and an optical receiver in a very compact package. In the last paragraph we looked at a simple RF receiver's sensitivity and saw that it easily manages to receive LTE signals at –112 dBm (signal strength). Now look at the optical receiver sensitivity on this SFP+ module. It's not –112 dBm, and not –100 dBm, it's not even –50 dBm! The sensitivity is only –12.6 dBm max! Imagine what would happen in the RF world if the typical RF receiver had such poor sensitivity? We'd probably still be using smoke signals to communicate! Could –12.6 dBm be a typo on the datasheet? No, it is correct. So what this really means is that because of the optical receiver's characteristically poor sensitivity, every measure must be taken to ensure that every possible dB of optical signal transmitted actually reaches the receiver. The transmitter optical power specification for this SFP+ module is –5.2 dBm minimum. While it is possible that the actual transmitted power may be higher, –5.2 dBm is the only guaranteed specification therefore the link budget between Tx and Rx (not counting fiber loss) could be as low as 7.4 dB (–5.2 dBm minus –12.6 dBm). RF link budgets are easily 100 dB or more. This is of course a worst case scenario. It is also useful to know that as data rates increase, receiver sensitivity decreases, and the specifications used in this example are applicable to the highest data rate supported by this SFP+ module. Even at lower rates, the link budget for most SFP or SFP+ type modules may typically average about 20 – 25 dB, which is still many orders of magnitude less than what a typical RF link budget of over 100 dB is.

There are other SFP+ specifications such as optical wavelength, extinction ratio, jitter, receiver reflectance, etc which also impact the systems overall actual performance and therefore must also be considered, however the topic of this article is purely focused on the most obvious specification which is receiver sensitivity and available transmitter power.

Another area in wireless communication networks where fiber is being used routinely today is in the microwave and millimeter wave backhaul. These radio systems are also now completely integrated units which are fed data through a fiber optic interface similar to what is currently used for the cellular industry. The same general principles and information in this article are fully applicable to the wireless backhaul segments of the networks as well.

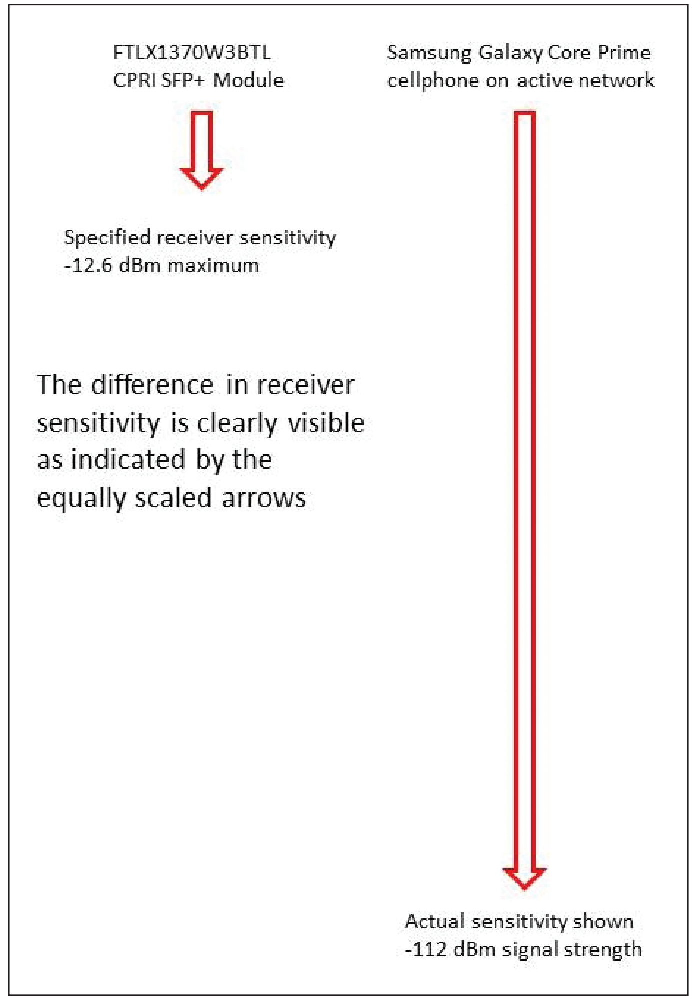

Figure 4: Comparison of typical RF receiver sensitivity vs the SFP+ optical receiver sensitivity

By now it should be obvious that there is very little margin for error in regards to signal loss from the transmitter to the receiver in the SFP+ module discussed in this article. So now that we understand the need to ensure clean and damage free fiber ends, it is good to know that there are already industry accepted pass/fail test profiles defined for this purpose such as the IEC 61300-3-35 introduced by the International Electrotechnical Commission (IEC). Instruments supporting this standard can be used to inspect fiber connector ends, and perform pass or fail judgements on the fiber connector ends as per the standard. The results can be archived and included in the reports submitted in the closeout package. On page 5 are some examples of a dirty fiber connector end and the same fiber connector end after proper cleaning. One look at the dirty fiber connector end should make you wonder just how much signal may have been lost in that optical link if the fiber had not been properly cleaned. Although it is not possible to accurately predict the amount of loss a dirty connector will have since each case will be unique, it is common to see signal losses caused by a dirty connector often greater than 1 dB, and it is highly dependent on where that dirt is actually located. Going back to the 7.4 dB signal link budget calculated earlier, if we had a 1 dB loss at each end caused by dirty connectors, that is over 25% of the link budget, and surely would cause throughput problems, alarms, or even a non operational condition. If it is anywhere in the region of the 9 μm (SM fiber) or 50/62.5 μm (MM fiber) core of the fiber itself (which is about the diameter of a human hair), then surely the losses will be significant enough to cause either a serious degradation in performance or perhaps a complete loss of operation. If there are dirt particles present on the fiber end, just the simple exercise of disconnecting and reconnecting a fiber could change the status of an operational BBU to RRH link to a non-operational status. If this type of phenomenon is occurring, it’s usually a pretty good indicator of dirty fiber(s) and it is best practice to use a proper fiber visual inspection probe (VIP) and perform the IEC 61300-3-35 standard based pass/fail tests after cleaning the suspect fiber(s).

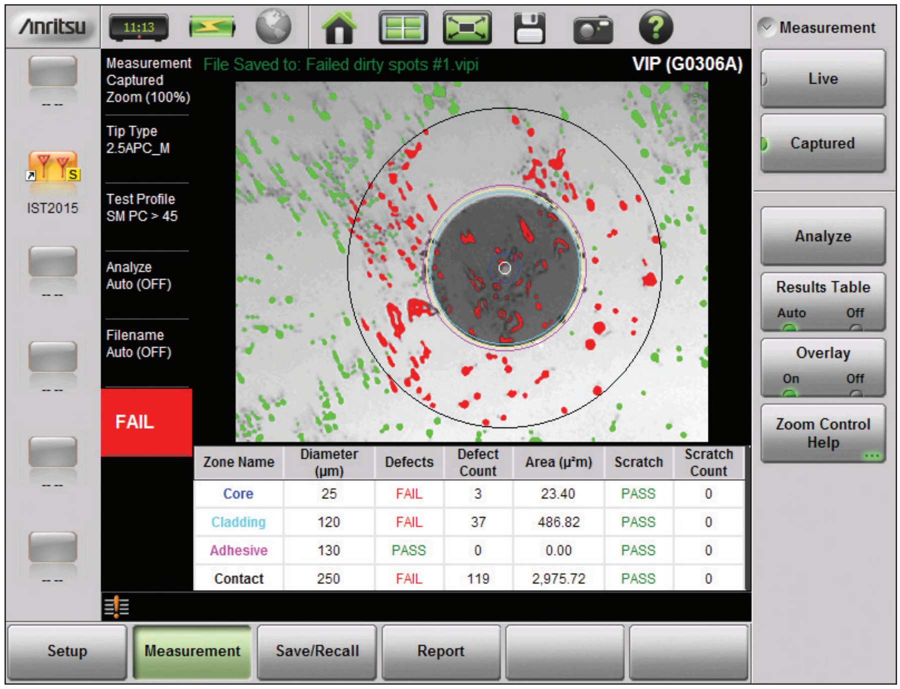

Figure 5: Dirty fiber connector end fails IEC 61300-3-35 standard based test (Oil left on connector end by only one single touch with a bare finger)

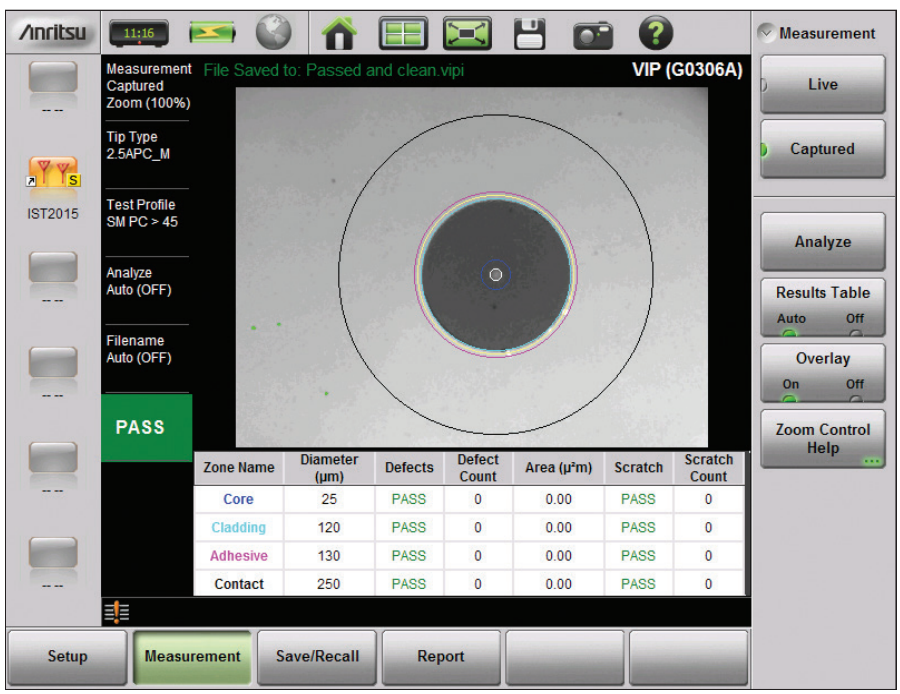

Figure 6: Same fiber connector end after proper cleaning. Now passes the IEC 61300-3-35 standard test easily

Summary

With a worst case of 7.4 dB link budget (not counting connector and/or splice losses) available in the Finisar SFP+ module example above, it should now be very clear why the need to inspect and properly clean the fiber cables used in these systems is of the utmost importance. History has already shown that dirty fiber accounts for about 60 - 75% of all failed BBU/RRH systems. Having the ability to perform standards based optical pass/fail testing on the fiber(s) used in these systems is simply a must. There are several hand held products available from Anritsu which offer VIP (Visual Inspection Probe) capability, and the most industry recognized is the Site Master S331L as well as the Microwave Site Master S820E. Another portable, hand held product providing VIP inspection capability as well as CPRI analysis is the Anritsu MT1000A although it may not be as well known to the typical installer of cellular equipment.

Figure 7: Examples of some Anritsu products supporting IEC 61300-3-35 Pass/Fail fiber inspection tests

Appendix

Other typical causes of failure (not in any particular order) in these systems include the following:

1. Mismatched SFP modules used. Meaning either mismatched line rate, mismatched optical wavelength, or mismatched fiber type (SM vs MM). The most common optical wavelengths used with single mode fiber are 1550 nm and 1310 nm, and the most common wavelengths used with multimode fiber are 850 nm and 1300 nm. As one gains more experience and knowledge, they should easily be able to recognize whether the fiber type needed is single mode or multimode simply by knowing the optical wavelength being used. Although the receiver section (Rx) for the SFP+ module in this article is rather broadband (1260 nm to 1600 nm) meaning this receiver may function with either 1550 nm or 1310 nm wavelengths. It is always best practice to use matched pairs of SFP modules between the BBU and RRH for best results.

2. Incorrect fiber type used. The SFP+ discussed in this article requires single mode (SM) fiber, terminated in duplex LC connectors. Generally the jacket color for SM fiber is yellow. The core of SM fiber is 9 μm in diameter, and the ferrule (the opaque white part you see) is 1.25 mm in diameter for an LC connector. Compare that with a multimode (MM) fiber terminated in duplex LC connectors. The ferrule of the MM fiber is also 1.25 mm, however the core is either 50 μm or 62.5 μm, and the jacket color for MM fiber is usually orange. If a MM fiber is used in a SM system, or vice-versa, there will be problems and the system will be inoperable. Therefore, it is extremely important to always use the correct fiber type which is matched to the SFP(+) type being used in that particular system. To the naked eye, you cannot see the difference between SM and MM fiber simply by looking at the LC connector and the visible 1.25 mm ferrule (typically white color for both SM and MM types of fiber).

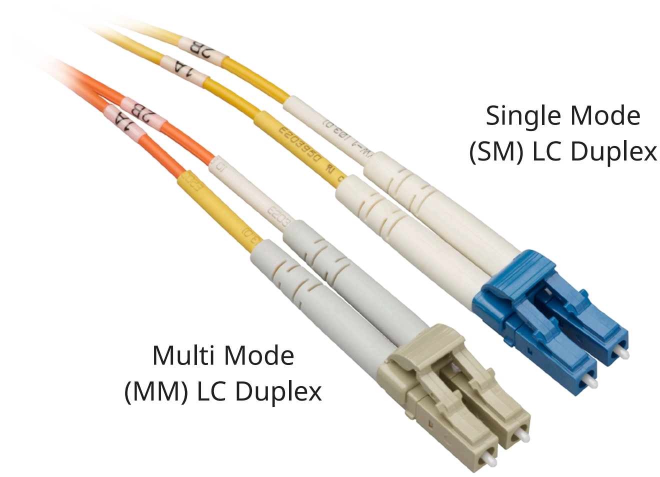

Figure 8: Photo of Single Mode (SM) and Multimode (MM) duplex LC connectors. Either one will connect to the SFP+ but the MM version (orange + grey) would be incorrect and the CPRI link between BBU and RRH would not operate

3. Distance between BBU/RRH too long for type of SFP and fiber used. An experienced installer or site technician may have gone through and verified that the SFP modules are matching and the correct fiber type for the SFP modules was used, and they may have even ensured that the fibers are clean and damage free yet the system still doesn't work. Most likely the cause would be that the system was configured using MM type SFP modules and MM fiber, but the distance between the BBU and RRH is too long for the required line rate. Multimode fiber is simply not capable of high speed data transmission (>1 Gb/s) over very long distances. Therefore whenever the distance between the BBU and RRH is long, SM type SFP modules and SM fiber should always be used. SM fiber was significantly more expensive in the past, and the line rates were lower, so MM fiber was used for the cost savings. Luckily today SM fiber and even the SM modules have come down in cost significantly, and with data rates constantly increasing, the majority of systems being deployed now use only SM equipment.

4. Dirty fiber. As seen in figure 5, this accounts for the majority of problems found in these types of systems.

5. Damaged fiber. The fiber can be easily damaged, and surface scratches and/or chips and pits can be impossible to see with the naked eye yet they can easily cause a significant loss of optical transmit power. Other types of damage to fibers include pinched fibers or fibers which have been excessively bent (often referred to as macro bends). Optical fiber will behave like an attenuator if it is excessively bent or pinched. Excessive bending can occur easily if a person is pulling fiber through a maze of tubes and must pass through some 90+ degree corners, even something as simple as over tightening a cable tie can cause sharp bends, or when someone tries to roll up the excess fiber in an attempt to clean up the installation. Pinched fibers can easily occur when clamping the assembly to a tower or other structure. A user must take care to ensure that the fiber does not get pinched by the clamps used to secure it.

6. Tx/Rx connected incorrectly. In most cases the fiber optic cables used are duplex LC type, and those plug directly into the SFP module. In most cases it is not possible to mix up the Tx and Rx fiber when using standard duplex LC connectors. However, there are a large amount of variants in use today and there is a great deal of hybrid cable assemblies. These hybrid cable assemblies often bundle power, fiber, and sometimes CAT 5e cables into one ruggedized, weatherproof cable assembly. The fiber ends may be terminated with single LC connectors (not duplex) therefore it is important to make sure that the Tx and Rx are connected to the correct and corresponding Tx and Rx ports on the SFP.

7. Another possible example of incorrectly connected Tx/Rx would be found in systems employing redundancy protection. In essence a parallel set of hardware may exist as an automatic system failure prevention backup. If the wrong Tx/Rx fibers are connected to the wrong set of hardware, naturally the main system and backup system will be inoperable.

8. Connectors not fully seated into the SFP modules. These LC connectors (duplex or simplex) are very small and rather delicate. They have a very small plastic tab (see figure 8) which is designed to lock the LC connector once it is inserted far enough into the SFP module. The technician or installer must listen carefully for a click sound which will occur as the locking tab springs upward into the designated opening for it once the connector has been inserted fully. To release the LC connector(s) from the SFP module, you simply press downwards on the locking tab and while holding the tab down, pull the connector out carefully. This is very similar to how CAT 5e or CAT 6 twisted pair cables lock and unlock from their corresponding jacks. Often the environment where the SFP based system is being deployed may be very noisy and the connector locking click sound cannot be heard. The technician or installer may think that it has been fully inserted but finds out later that it wasn't properly seated all the way and this was the cause of the problem. With such a small optical link budget, even the smallest gap between the fiber end and the receiver or transmitter will result in a huge loss of signal.

9. Wrong sectors connected. In a typical multi-sector RRH system, being fed from a single BBU, the possibility of connecting the wrong fiber Tx/Rx pair to the wrong sector RRH is a reality. Some older systems actually deployed one RRH per sector, more modern systems now deploy one RRH for all 3 sectors. This is for one basic system, as the systems become more complex, (more technologies, more carriers, more antennas, etc…) there will be many fiber pairs and if they are not all properly and clearly identified and connected to the right locations, the system will be inoperable.

10. Many RRH's have additional SFP ports to support a daisy chain or a ring type of topology. Plugging the SFP module into the wrong SFP port on the RRH will surely result in a non-operational system.

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Specifications are subject to change without notice.

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11410-00985, Rev. A Printed in United States 2016-12