Applications Of Analog Fiber Optic Links In Wireless Networks

Introduction

While the world is increasingly moving towards digital technologies, analog transmission continues to play a crucial role in various applications due to its unique advantages and compatibility with certain types of signals and systems. Analog transmission remains a valuable technology in specific contexts. The coexistence of analog and digital technologies allows for a diverse range of applications to be addressed with the most appropriate and cost-effective solutions. Analog fiber optic transmission still plays an important role in applications like CATV networks, RFOG, Satellite ground stations, public safety communications, low latency networks, and aerospace and defense, especially in scenarios where high-quality, reliable, and interference-resistant signal transmission is essential.

In these applications, analog fiber optic transmission offers advantages such as high bandwidth, low signal loss, resistance to electromagnetic interference, and the ability to transmit signals over long distances. As technology continues to advance, the use of analog fiber optic links in wireless networks will likely expand to meet the growing demand for high-performance and reliable communication solutions.

An important application of analog fiber optic link in wireless networks is Distributed Antenna Systems (DAS)**.** DAS involves the use of a network of antennas to provide wireless coverage in large or complex environments, such as stadiums, airports, and buildings. Analog fiber optic transmission is used to transport radio frequency (RF) signals from the central base station to remote antennas distributed throughout the coverage area. This ensures consistent and high-quality wireless connectivity. This whitepaper will address some challenges in designing a fiber optic link in wireless networks as well as opportunities to improve link performance.

Noise sources in linear fiber links

In linear fiber optic links, noise sources can impact the quality of the transmitted signal. Linear fiber links are characterized using linear components, meaning that the signal is amplified or processed without significant nonlinear distortion.

Here are some common noise sources in linear fiber optic links:

Quantum noise also known as shot noise, is inherent in any optical communication system due to the discrete nature of photons. It is a fundamental limit to the precision of optical measurements and can impact the received signal quality.
Shot noise, also known as Poisson noise, is a type of noise that occurs due to the statistical nature of discrete particle arrival, such as photons in the case of light. The shot noise formula describes the statistical variation in the number of particles arriving at a detector over time. The shot noise power is proportional to the square root of the average number of particles arriving in a given time interval. The shot noise formula is given by:

$$I_{shot} = \sqrt{2qI\Delta f}$$

here:
I_{shot} is the shot noise current,
q is the charge of an electron (approximately 1.6×10−19 coulombs),
I is the average current (or the average number of particles per second, such as photons or electrons),
Δf is the bandwidth of the measurement.
It's important to note that shot noise is proportional to the square root of the current, meaning that it becomes more significant at lower average currents or when dealing with low-intensity signals. As the average current increases, shot noise becomes a smaller proportion of the total noise. The equivalent RIN from shot noise is:

- **RIN_{SN} = -155 – 10Log(I_{PD})** where I_{PD} is DC photodiode current in mA

Thermal noise Thermal noise is introduced by temperature variations in the electronic and optical components. Temperature-induced changes in the properties of the materials can lead to variations in the transmitted signal. The equivalent RIN from thermal noise is:

- **RIN_{TN} = 20Log(EIN/I_{PD})** where EIN is equivalent input noise current in pA/$Hz^{1/2}$

Relative Intensity Noise (RIN) RIN is a type of noise that can affect the performance of lasers, including those used in fiber optic communication systems. RIN is a form of amplitude noise, and it manifests as fluctuations in the optical power of the laser over time. In the context of lasers, RIN is particularly relevant in the telecom and optical communication industry.

Laser RIN is caused by various factors, including spontaneous emission within the laser gain medium, amplified spontaneous emission (ASE), and other quantum effects. These factors contribute to fluctuations in the intensity of the laser output.

RIN is typically expressed as a dimensionless quantity, often represented in decibels relative to the optical power. RIN measurement is usually performed in the frequency domain.It is measured over a certain frequency range and is denoted as RIN(f), where 'f' is the frequency. The RIN in the frequency range that covers the data signal frequencies is often of interest in optical communication systems.

RIN can impact the performance of optical communication systems by contributing to noise in the transmitted signals. In particular, RIN can affect the signal-to-noise ratio (SNR) and the bit error rate (BER) of the communication link.

RIN Reduction Techniques Various techniques are employed to reduce RIN in laser sources. At device level, optimizing laser design, and using higher-quality laser components can significantly reduce the RIN noise. Designs with external-cavity lasers (ECLs), and semiconductor optical amplifiers (SOAs) can further reduce the noise in the laser source. At the system level, implementing feedback control mechanisms, and employing advanced modulation formats that are less susceptible to RIN effects are some of the approaches in high-performance optical communication systems to mitigate the penalties from RIN.

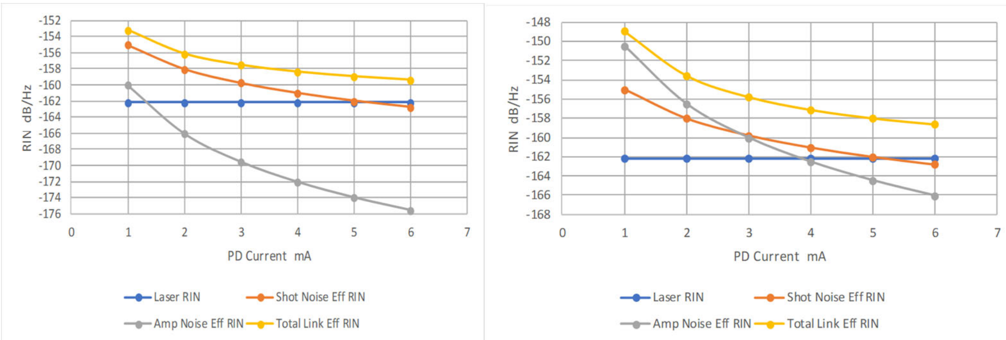
Understanding and managing RIN are crucial for the design and operation of optical communication systems, especially in applications where high precision, low noise, and optimal signal quality are paramount. Ortel researchers and engineers continually work on developing lasers with improved RIN characteristics to advance the performance of optical networks.

Low noise optical receiver for analog optical links

Designing a low-noise receiver for an analog optical link is crucial for achieving high signal fidelity and maximizing the link's performance. There are two key considerations for designing a low-noise linear receiver device:

Photodetector Selection Choose a photodetector with low noise characteristics. High-speed photodetectors with low dark current and low noise equivalent power (NEP) are preferred.

Transimpedance Amplifier (TIA) Implement a low-noise transimpedance amplifier (TIA) immediately after the photodetector to convert the photocurrent into a voltage. Design the TIA with low input-referred noise and sufficient bandwidth to capture the signal frequencies of interest. A good design can also mitigate the problem of low return loss at the output



Relative noise sources for two levels of receiver amplifier noises: (1) 10 pA/Hz$^{1/2}$ Noise level consistent with linear receiver designs with negligible distortion up to 3-5 mA DC photodiode current. (2) 30 pA/Hz$^{1/2}$ Typical noise level using ORTEL 2522 microwave PD and low noise RF amplifier. RIN assumed to be -162 dB/Hz which is typical of high-speed laser in 3-4 GHz frequency range.

There are also some strategies and features for optimizing the performance of a receiver in the context of an analog optical link:

Bandwidth optimization in both electrical and optical domains: Optimize the receiver bandwidth to match the signal bandwidth while filtering out unwanted noise. Excessive bandwidth can introduce noise without capturing additional signal information. Filtering techniques, such as low-pass or band-pass filters, can suppress out-of-band noise and interference. This is particularly important in environments with high levels of ambient light or electromagnetic interference.

Automatic Gain Control (AGC): Consider incorporating an AGC circuit to dynamically adjust the receiver gain based on the received signal strength. This can help prevent over-amplification in the presence of strong signals and reduce noise during low signal conditions.

Optical Pre-amplification: If the optical signal is weak, consider using an optical pre-amplifier to boost the signal before it reaches the photodetector. This can improve the signal-to-noise ratio at the input of the receiver.

Temperature Stabilization: Stabilize the temperature of critical components, such as the photodetector and associated electronics, to minimize temperature-induced noise.

Grounding and Shielding: Implement proper grounding and shielding techniques to minimize the impact of electromagnetic interference on the receiver.

By carefully considering these factors and incorporating low-noise components and design principles, it is possible to achieve a low-noise receiver for an analog optical link, ensuring accurate and reliable signal reception. Additionally, regular testing and optimization of the receiver performance in real-world conditions are essential for maintaining optimal link performance.

RF distortion and predistortion

RF distortion is another impairment in the analog optical transmission links. Dominant distortion mechanisms are laser linearity, and in the case of 1550 nm, the combination of chirp and fiber dispersion. Most fundamental laser distortion sources at higher frequencies that fall into wireless signal ranges is from basic laser physics of interactions between carriers and photons in the laser cavity. The primary metric for laser dynamic distortion is the laser relaxation oscillation resonance frequency. RF distortion has a frequency dependence of $(f/f_r)^4$, so it is critical to use lasers with high resonance frequencies (F_r). Design factors need to be taken into consideration to maximize resonance frequency. There are several other technical factors exist that can add or subtract from laser resonance distortion.

RF predistortion techniques are used in virtually all linear fiber links used in analog communication networks. Predistortion circuits produce distortion equal in amplitude and opposite in sign to that of the laser. ORTEL wideband predistortion circuits were designed using carefully selected RF diodes and passive components. The main technical challenge in designing predistortion circuits is to track the laser over a wide frequency range.

The circuits were built from high volume components and are small in size (< 1 cm^2). The design is related to, but not identical to digital predistortion designs. In CATV analog links, RF predistortion improves both 2nd and 3rd order linearity by 10-20 dB. Wireless links represent a challenge for RF predistortion due to a large frequency dependence of laser resonance distortion.

ORTEL has a long history of innovation in the areas of pre distortion and low noise receivers. ORTEL engineering has researched two proof of concept predistorted wireless transmitters.

1. 0.5-3.0+ GHz transmitter with expected improvement in both 2nd and 3rd order distortion of 10 dB and CNR over the band of approximately 5dB

2. "Programmable" 0.5-5.0+ GHz transmitter to improve 3rd order distortion by 10 dB over any 1 GHz wide frequency range. The programmable version can set frequency anywhere from 1-4.5 GHz. 10 dB 3rd order cancellation over frequency range +/- 0.5 GHz from set frequency is expected.

Proof of concept prototypes can be designed with mechanical form factors convenient for our customer's evaluation. Final product of this type could have a form factor similar to small form factor digital transceivers (XFP, etc)

ORTEL can offer this type of design services for partners interested in leveraging our experience in design, supply chain management and assembly services.

A Photonics Foundries Enterprise
2011 Chestnut Street | Alhambra, CA | 91803 | USA
www.ortel.com

Ortel Products for Wireless applications


1997 Coaxial DFB Laser Module: ORTEL's Model 1997 DFB coaxial laser offers a high-performance solution for signal distribution in L-Band, S-band, 5G and next-gen wireless/DAS applications. The 1997 is available in 1310nm and 1550nm wavelengths. There is already a history of over 100K units deployed in the field already.


1754 and 1764 1550 nm DWDM DFB Laser: ORTEL's 1754 laser module is a DWDM laser for analog wireless and DAS applications. It features a distributed-feedback (DFB) device designed specifically for RF and wireless applications. The 1764 laser has a wide temperature range for reliable performance in harsh node environments and narrow transmitter designs. It also features low adiabatic chirp to maximize signal quality in short and long lengths of fiber


1615A 1310 nm 2.7 GHz DFB Laser: ORTEL's 1615A 1310 nm DFB laser module is designed for both wireless and DAS applications. This highly-linear OC-48 pinout compatible device delivers superior distortion performance over an enhanced temperature range of -40 °C to +85 °C.


7830W 3 GHz Optical Receiver: ORTEL's 7830W 3 GHz optical receiver is a singlemode fiber pigtailed module featuring a low-noise, impedance-matched broadband photodiode and RF amplification. The device receives optical analog and/or digital signals for a range of video broadcast options, and delivers the corresponding RF electrical output.


5200 Series 3 GHz and 6.5 GHz High-Performance Fiber Optic Inter-Facility Links: ORTEL's 5200 Series, 3 and 6.5 GHz Fiber Optic Inter-Facility Links (IFLs) are a high-performance, cost-effective alternative to coaxial cable for 50 MHz to 6500 MHz communications applications. They are a compact, weatherproof fiber optic transmitter and receiver pair for applications where high-performance under demanding conditions is critical. ORTEL's fiber optic IFLs function as transparent RF fiber links. These IFLs eliminate the limitations of copper systems by enabling longer transmission distance while retaining the highest level of signal quality. In addition, ORTEL's fiber optics provide several other significant network advantages, including simplified network design, ease of installation, and immunity from EMI/RFI and lightning.