RF over Fiber – Taking RF signals from a few meters to kilometers with fiber optics.

By Vinny Gjokaj Ph.D – NuPhotonics

In an increasingly connected world, the demand for high-speed, high-capacity signal transmission is pushing the limits of traditional coaxial cable-based systems. Recently there has been an ever-increasing interest in RF over Fiber, a technology that merges the low-loss, high-bandwidth advantages of optical fiber with the versatility of RF communication. By transmitting RF signals over optical fiber, RFoF systems enable long-distance, interference-free signal delivery across a wide range of applications—from satellite ground stations and remote antenna deployments to 3G-5G infrastructure and defense systems. This article explores the fundamentals of RF over Fiber system design.

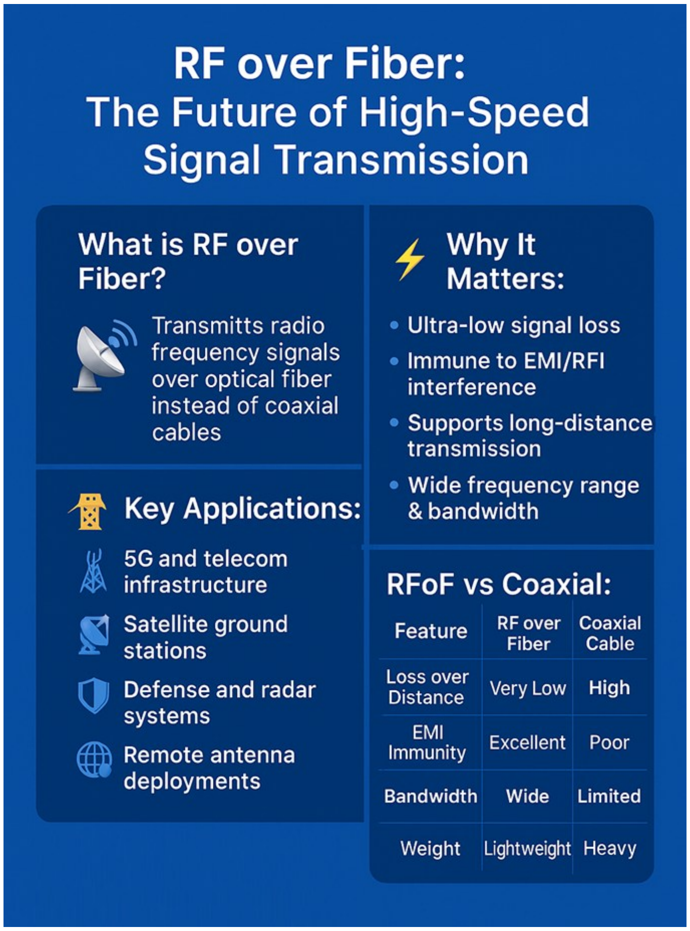

Figure 1: RFoF key features

Going the distance - signal strength

Coaxial cables offer varying performance based on cable configuration. Typical dielectric SMA cables offer about 0.25 dB/m insertion loss (2 GHz). Air filled cables to achieve slightly better performance but at a drastically higher cost. This high loss is the driving force to use RFoF for transmission distances over 50 meters. RFoF most often utilizes two wavelengths 1310nm and 1550 nm. 1310 nm loses about 0.35 dB/km of optical signal, 1550 nm loses only 0.25 dB/km. As can be seen this is drastically lower than compared to coaxial cables.

Digikey and NuPhotonics enabling ease component sourcing.

Digikey has been a global leader in enabling key components to be easily sourced. Digikey is used by hobbyists, students, professionals, and large corporations. As a leader in RF & Opto-Electronic device industry, it made sense that NuPhotonics and Digikey partner to help supply the industries with easy to use and easy to access components.

Figure 2: NuPhotonics 10G Pin Photodiode Pigtail FC/APC (DK part#: 5299-P10-TO-B-FA-ND)

There is some commercially available solutions but they often don't make financial sense and . We will go over-standard design which will enable users to develop low-cost specialized solutions with NuPhotonics parts. The products and solutions discussed here are available on Digikey for easy ordering.

RFoF Transmitter Design – 10G DFB Laser

The first part of designing an RFoF system is developing the transmitter. For RFoF architecture, a data-carrying RF signal is imposed on a Lightwave signal before being transported over the topical link. A distributed feedback laser (DFB) Laser can be directly modulated by the RF signal which makes it an ideal component to transform the electrical RF signal into an optical signal. A basic diagram can be seen in Fig. 3. Since the laser is biased on the anode side, this is also the input for RF frequency. For system safety will incorporate a DC blocking capacitor **C2**. The value **C2** will be fined tuned by the desired lower frequency cut off point. Resistor **R1** in the circuit is used for impedance matching the 10Ω DFB laser to a 50Ω system. The higher the value of **R1** the better the S_{11} matching of the link with the adverse effect of increasing the optical link insertion loss. This enables precise level control for desired impedance matching and insertion loss. Resistor **R2** in the circuit is the current limiting resistance user to limit the current to the laser. Inductor **L** is a high impedance path for the RF signal while acting as a minimal resistance current path for the DC bias of the laser. Capacitor **C1** is an optional filtering capacitance, it is used to filter out power supply noise on the bias T.

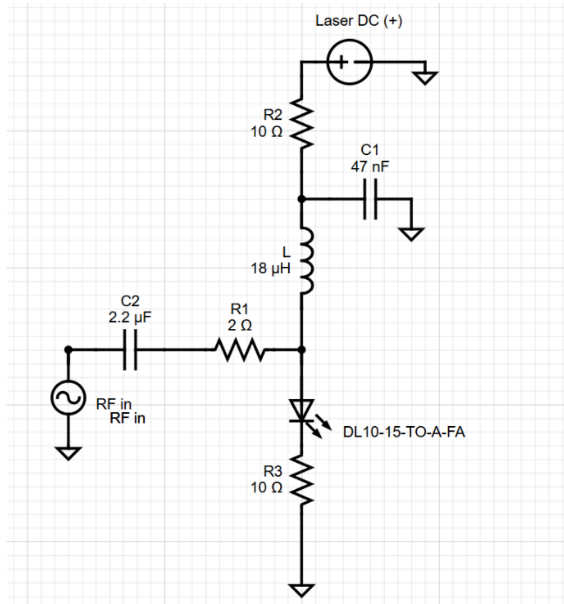

Figure 3: 10G DFB Laser with Bias-T and impedance matching

RFoF Receiver Design – 10G Pin Photodiode

With the optical light in the fiber, we now will need to convert it into an electrical signal that is more usable for us. A photodiode is just a diode that is sensitive to light. When photons of sufficient energy strikes the diode, it creates an electron-hole pair. This mechanism is also known as the inner photoelectric effect. These holes move toward the anode (+) and electrons toward the cathode (-), this effect produces photocurrent. As we are interested in broadband operation we will operate the photodiode in reverse bias. When reverse biased, current will only flow through the photodiode with incident light creating photocurrent. This also has the added benefit of increasing the linearity of the photodiode. The response time is reduced by the reverse bias by increasing the size of the depletion layer. This increased width reduces the junction capacity and increases the drift velocity of the carriers in the photodiode. The transit time of the carriers is reduced, improving the response time. Fig. 4 represents the basic circuit to operate the photodiode. Similarities can be seen between the photodiode circuit and the laser circuit. Capacitor **C** is the DC blocking capacitor to protect the RF port. Inductor **L** is a low impedance DC path to ground. Inductor **L** allows the current to flow from the DC Bias pin to ground since the DC blocking capacitor **C** will not allow a direct path to ground. Components **R1**and **C1** are selected to help improve the high frequency impedance matching.

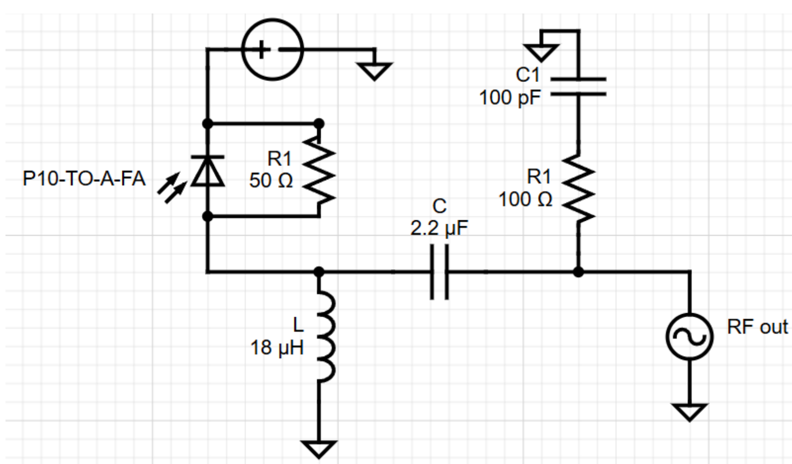

Figure 4: 10G Pin Photodiode with Bias-T and impedance matching

PCB Layout – RF design considerations

Designing PCBs for RF applications involves far more than routing signals and placing components, it's a discipline where electromagnetic behavior dominates and small layout choices can make or break performance. To achieve desired performance, we will need to pay careful attention to impedance control and ground return paths to ensure resonances are not present. The first step will be to select a PCB material. We are interested in a dielectric material that was $\varepsilon_r \sim 3$ and we are interested in a tan-$\delta < 0.01$ to ensure that we are not losing the RF signal to PCB dielectric losses. Once a material is selected, we need to design our traces. For RF trace design there are a few approaches we can take, it is preferable to utilize coplanar waveguide (CPW) as it will offer better isolation, better confining of the electromagnetic field, as well as smaller ground return paths to help ensure we minimize resonances. In Fig. 5A and 5B we can see a basic circuit layout for the circuits laid out in Fig. 3 and Fig. 4. CPW were utilized with plenty of ground VIAs to ensure minimal return paths for the RF signal. Digikey Red will be a great option for quick turn PCBs to begin testing our circuit.

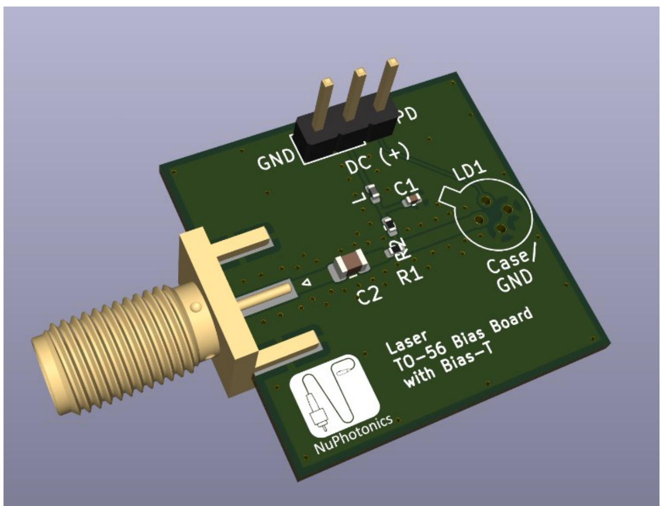

Figure 5A: 10G DFB Laser Board

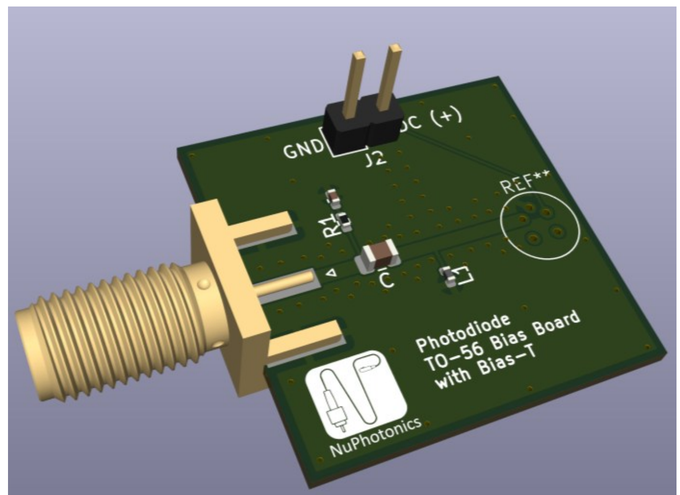

Figure 5B: 10G PIN Photodiode Board

PCB Assembly

The TO-56 laser and photodiode are easily soldered directly to the PCB as any through hole device would. This makes NuPhotonics devices easily to incorporate into standard PCBS and makes them a desirable choice for both hobbyist to industry professionals. Fig. 6 shows the assembled PCBs from Fig 5A & 5B.

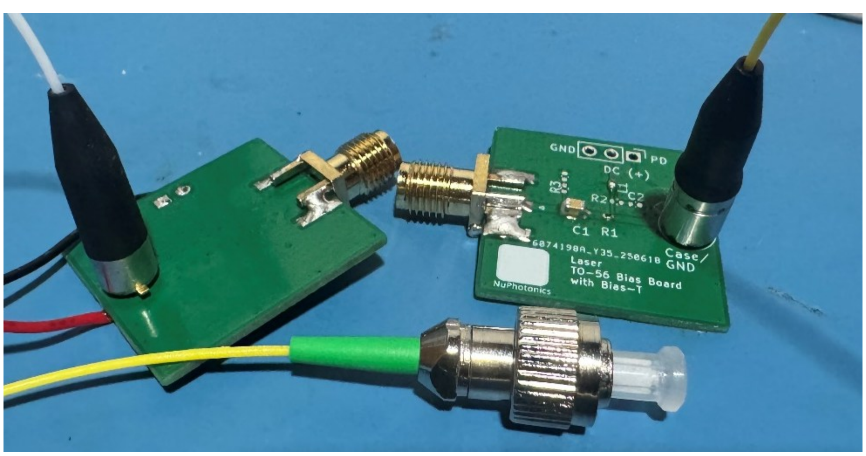

Figure 6. Assembled Photodiode & Laser PCB

RF Results – RFoF Link

With the devices mounted on PCBs that allow easy connection with SMA connectors, the devices can easily be measured. RF tests will be performed on a Vector Network Analyzer. We will be performing S-parameter tests. Specifically looking at S_{11} and S_{21}. We are interested in S_{11} as we want to see how well matched the DFB laser is. The 1550 nm is a 10-ohm series device so broadband matching the device is a challenge. S_{21} is the amount of loss or attenuation we will see in the link. Below 0 dB S_{21} means the link is losing some signal and above 0 dB the link is adding gain to the input RF signal. Fig. 78 shows the S_{21} of the link. We can see the overall system has a flat response up to 3 GHz and a 3dB bandwidth of 6+ GHz. Fig 7B. and 7C shows the S11 matching of the photodiode and laser respectively. The overall link gain is -2 dB over the entire 6 GHz frequency band. The results below show this method is an easy approach to transmitting electrical signals over long distances with fiber optic cables. NuPhotonics products provide an easy PCB mountable solution hobbyist to industry professionals can incorporate into their systems.

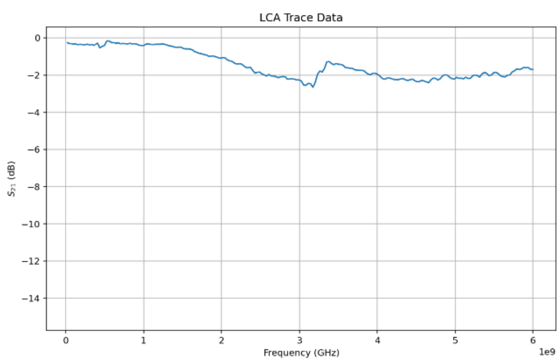

Figure 7A. Link S_{21} (dB)

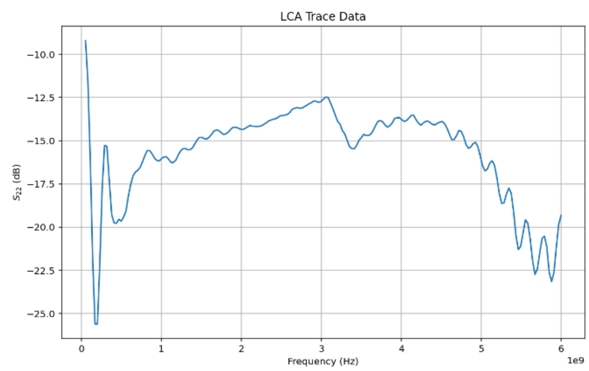

Figure 7B. Photodiode S_{11} (dB) Matching

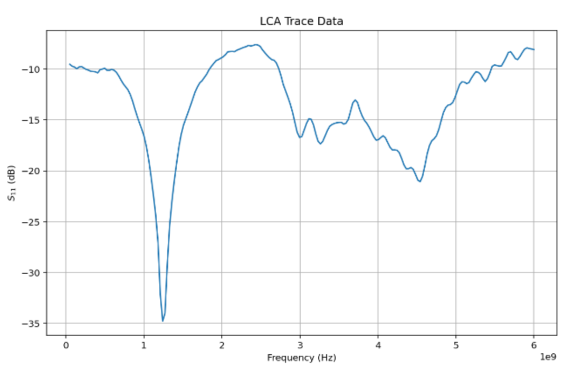

Figure 7C. Laser S_{11} (dB) Matching

Conclusion

In this article we went over circuit design for a basic RFoF link. This article highlights how easy RFoF link design can be with NuPhotonics products that are readily available on Digikey for prototyping. This article scratches the surface of RFoF link design. This area of communication is an advanced and ever-increasing area of research and development interest. RFoF enables the seamless integration of radio-frequency systems with the low-loss, high-bandwidth, and interference-resistant advantages of optical fiber. As wireless networks, satellite links, and defense applications demand higher frequencies, wider bandwidths, and longer reach, RFoF offers a scalable and future-proof solution. Ongoing research ensures improvements in linearity, noise performance, and cost-effectiveness are key factors for unlocking the full potential of 5G, 6G, advanced radar, and next-generation communication systems.

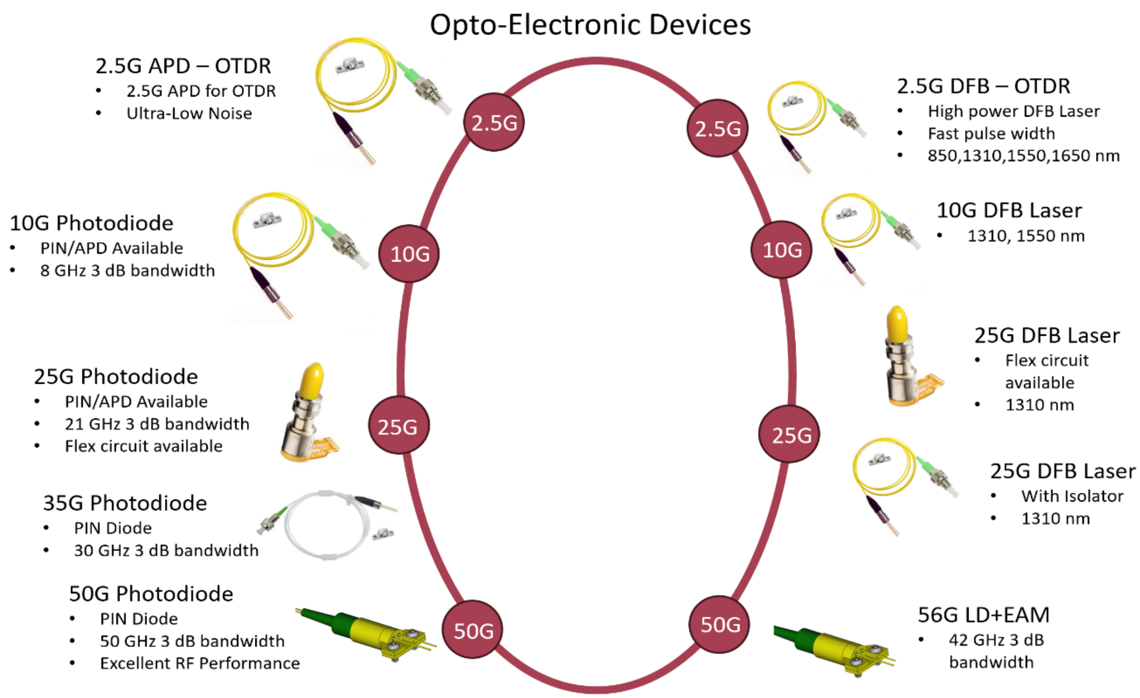

Figure 8. Available Laser and photodiodes