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# 12 Gb/s Multiband Fiber-Wireless link using Coherent IFoF and V-band mmWave Radio

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**Abstract.** We experimentally demonstrate two Analog Mobile Fronthaul concepts exploiting coherent optical systems technology. Single Sideband generation and coherent detection of a 12 Gb/s signal with 6 subcarriers using an IQ modulator is presented along with an extended reach Fiber-Wireless transmission concept using IQM-DD system and V-band radio.

**Keywords:** Coherent communications, Radio frequency photonics, Fiber optics communications.

## 1 Introduction

The 5G hype continues to grow; Targeting the use case of Gigabit connectivity to the user, early deployments focus on the Fixed Wireless Access (FWA) scenarios, while their first commercialization stages continue to gain momentum as a potential investment [1]. In order to meet the high traffic densities, peak data rates and low-latency requirements of 5G mobile connections, the fiber-based Mobile Fronthaul (MFH) needs to be revisited through cost-efficient optical transport solutions [2]. To this end, analog Intermediate Frequency and Analog Radio-over-Fiber (IFoF/A-RoF) solutions have been intensively promoted from the research community as a path to overcome the low bandwidth efficiency of the Common Public Radio Interface (CPRI), which lacks scalability in high-capacity interconnections between the Baseband Unit (BBU) and a high number of mmWave Remote Radio Heads (RRHs). The Digital Signal Processing (DSP)-assisted IFoF has been investigated as an option for spectrally efficient FH architectures, employing Intensity Modulation / Direct Detection (IM/DD) schemes over linear low-bandwidth optoelectronics [3]. Moreover, as network operators are focusing on a more demand-driven network planning through centralized architectures and network densification [4], has led to research activities towards unlocking the bandwidth of mmWave bands for Gigabit capacity fiber/wireless fronthaul links to multiple pico/femto cells [5].

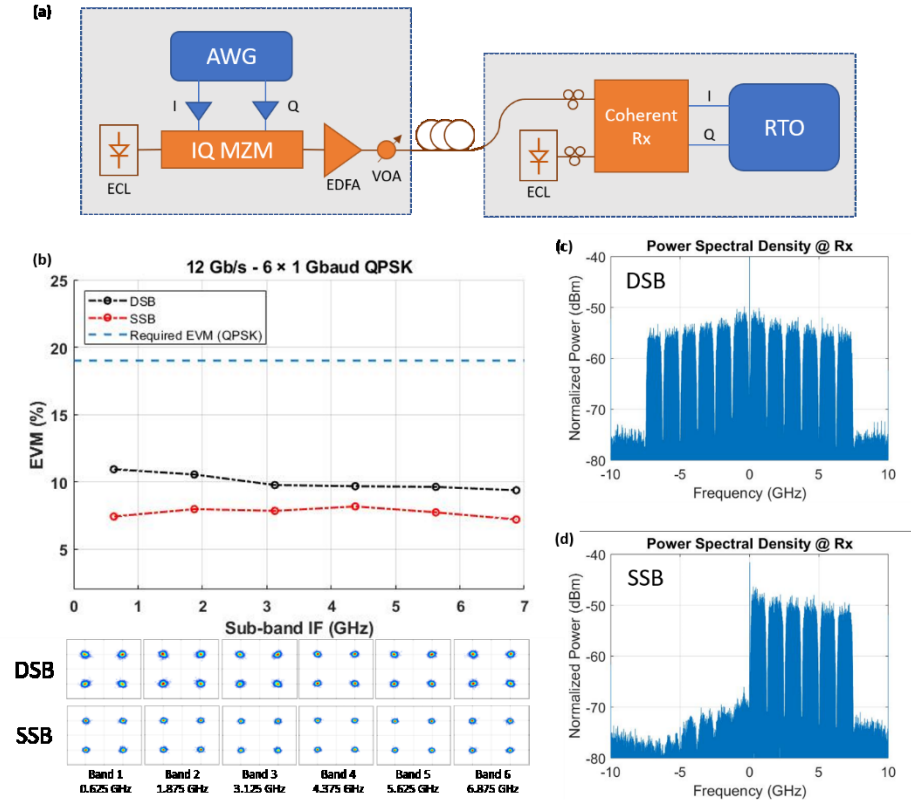
Entering the beyond-CPRI era, optical IQ Modulation (IQM) carrying native radio waveforms could also be considered as an approach to further support the above-mentioned capacity increase. By introducing a second dimension on the modulation space,

which results in doubling the link capacity, a link featuring higher immunity to transmission impairments is also feasible. Since both magnitude and phase components of the optical field are modulated, effects such as chromatic dispersion can be pre-compensated, thus improving power and noise margins of the link [6]. Moreover, modulation of the optical carrier in both dimensions has been widely investigated as it offers extended dynamic ranges compared to schemes based solely on the modulation of optical intensity and significant gains on the driving RF signals can be obtained, compared to IM/DD schemes [7]. Leveraging the penetration of coherent systems, even for the last mile of optical access, the transmission of coherent analog RoF signals over coherent Passive Optical Network (PON) infrastructure, can be nowadays considered as a competitive MFH solution for specific 5G-related concepts [8]. Their proven coexistence with baseband optics, allows for sharing existing fiber infrastructure dedicated for coherent PON links and coherent Tx/Rx equipment allowing for generate/detect wide-band RoF waveforms [9]. Such equipment reuse enables for further cost savings lowering installation expenses of new equipment for the fronthaul deployment [10].

Within this paper we present two experimental demonstrations which introduce the Coherent IFoF transport into FWA scenarios with Gb/s capacity. First, we validate the feasibility of Single Sideband (SSB) IFoF transmission using IQM and coherent detection on a 12 Gb/s Digital Subcarrier Multiplexed (SCM) signal with 6 bands. It is shown that the performance of the SSB scheme exceeds its Double Sideband (DSB) counterpart in terms of Error Vector Magnitude (EVM). Our presented transport scheme can be also adopted in centralized radio access topologies where all the digital stages are removed from the RRHs. To this end we demonstrate a second scenario for a downlink Fiber-Wireless interconnection (Fi-Wi) in which SSB IFoF using an IQM-DD scheme is combined with V-band radio equipment for wireless indoor transmission. Raw capacity of 12 Gb/s with EVM below the 3GPP specification is achieved for 25-km and 50-km long fiber and 5-m wireless links showcasing the immunity to chromatic dispersion induced power fading.

## 2 Multi-band SSB IFoF using IQ Modulation and Coherent Detection

In the context of exploiting existing coherent optical link topology, we demonstrate transmission of an IFoF signal using IQ modulation (IQM) and coherent detection. In addition to its cost-efficient features, due to existing hardware reuse, the proposed implementation allows for mitigation of chromatic dispersion induced power fading of the IFoF signals. The IQ modulators at the coherent transmitter side can provide an optical SSB (OSSB) signal using Hilbert transformation (HT) in the driving signals on the RF domain [11]. The analytical signal (SSB equivalent) is defined as a complex signal with real and imaginary parts consisting of the signal itself and its Hilbert transform respectively. Feeding the two signals (real and imaginary part) into the In-phase and Quadrature inputs of the modulator, the resulting optical spectrum at the transmitter output consists only of its lower sideband. The experimental setup is illustrated in Fig. 1a.



**Fig. 1.** (a) Experimental setup of the SSB generation using IQ modulation and coherent detection. (b) EVM Diagram per band and respective constellations for the DSB and SSB transmission in back-to-back configuration. (c) Recovered spectra after coherent reception of DSB and (d) SSB generated multiband schemes.

As a reference signal, we are considering a SCM signal consisting of 6 bands at equidistant IF carriers, with a total bandwidth of 7.2 GHz. An Arbitrary Waveform Generator (AWG) was used to provide the data signals for both In-phase and Quadrature streams for the multiband scheme. The SCM signal and its Hilbert transform were digitally synthesized and loaded into the Generator's memory. Each subcarrier was Quadrature Phase Shift Keying (QPSK) modulated at 1 Gbd, while the subcarrier frequencies were at 0.625 GHz, 1.875 GHz, 3.125 GHz, 4.375 GHz, 5.625 GHz and 6.875 GHz. Pulse shaping using Root Raised Cosine (RRC) shaping filters with roll-off factor  $\alpha = 0.2$  and digital linear pre-distortion of the optoelectronic components' frequency response were also performed. Both RF streams were amplified by two linear drivers to achieve voltage levels of  $\sim 5$  Vpp at the RF inputs of the modulator. An External Cavity Laser (ECL) with  $\sim 100$  kHz linewidth, provided the optical carrier at 1545.45 nm to the IQ MZM while an EDFA followed by a Variable Optical Attenuator (VOA) was employed to set the launch power of the optical transmitter. A polarization diversity coherent receiver was used for intradyne detection, with input signal and

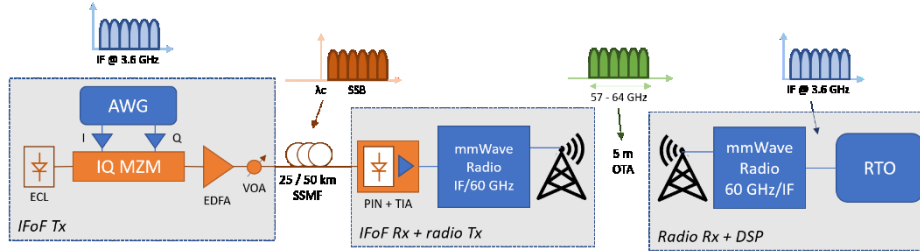
Local Oscillator (LO) power levels at 0 dBm and +10 dBm respectively. The (LO) laser source was similar to the one employed at the transmitter side. Since a single polarization signal was transmitted, only one pair of the two output IQ streams of the coherent receiver was sufficient for demodulation. The in-phase and quadrature photocurrents were fed to a 33 GHz Real Time Oscilloscope (RTO) where they sampled at 80 GSa/s and digitized for offline processing. There, a standard DSP coherent demodulation chain was employed, with downsampling, retiming, equalization and carrier frequency and phase recovery stages yielding the final estimate of the received signal.

In Fig. 1b we present the Error Vector Magnitude (EVM) plot for each subcarrier after coherent detection and DSP for both the Single (SSB) and Dual Sideband (DSB) cases. It should be noted that for the DSB generation the quadrature channel from the AWG was switched off, while the optical power at the EDFA output was tuned using a Variable Optical Attenuator (VOA) in order to keep constant the same optical power at the transmitter output as in the SSB case. It is observed that after coherent reception and DSP the SSB signal exhibits improved performance of  $\sim 2.26\%$  EVM compared to the DSB case. The recovered spectra after coherent reception for both cases are depicted in Fig. 1c and 1d for the SSB signal, as well as for its DSB counterpart, are also depicted.

It is evident that the SSB property at the RF domain before the IQ modulator at the transmitter side is also preserved after coherent detection. Such a feature could be a potential solution to interconnect IFoF/RoF links with IQ baseband Radio frontends, without any external mixing stages at the radio equipment of an RRH. On the other hand, this approach comes at the cost of using an additional laser source for the coherent receiver, which in turn poses increased processing demands for carrier recovery on a digital receiver of these radio signals.

### **3 25 km / 50 km Fiber and 5 m V-band Wireless Transmission with SSB using IQM-DD**

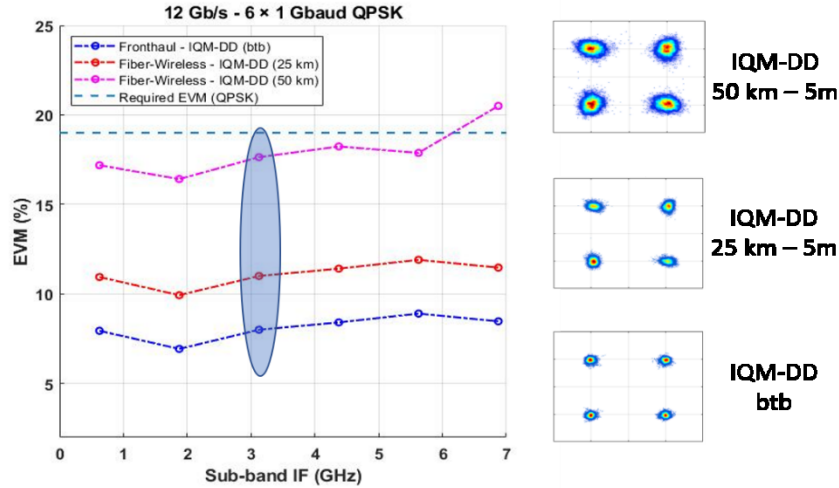
The robust performance of the SSB scheme against the optical power fading, induced by the interplay of fiber's chromatic dispersion and the chirp of analog RoF transmitters [5], is a prerequisite for transmitting IFoF and RoF signals without imposing limits on the range of the possible fiber link lengths but extending them to longer distances. As presented in [3] the performance of a DSB multi-band IFoF signal is strongly limited by the chromatic dispersion fading for a 25 km link, with the bands close to 8 GHz being the ones exhibiting severe degradation. In the previous section, we proved that an optical IQ modulator facilitated SSB generation of such multiband radio signals. By modifying the topologies presented in [3] and [12] from IM-DD to IQM-DD, as shown in the testbed of Fig. 2, we implemented an extended-reach Fi Wi link with up to 50 km fiber and 5 m wireless distances.



**Fig. 2.** Experimental setup for the 50 km fiber and 5 m V-band wireless transmission using IQM-DD for OSSB generation.

Similarly to section 2, we consider the same reference signal to be a SCM scheme consisting of 6 similar bands at equidistant IF carriers to be SSB generated by the IQ Modulator. After the fiber link (25 km or 50 km SSMF) we employ Direct Detection using a 10 GHz photoreceiver composed of a PIN photodiode (0.7 A/W responsivity) and a low noise Transimpedance Amplifier (TIA of 20 dB gain). The output fed into a mmWave upconverter (Noise Figure of 8dB) connected to a V-band directional Tx antenna. The signal was received by an identical antenna (Rx), located at a 5 m horizontal distance from the Tx-antenna. Standard pyramidal gain horn V-band antennas of 23 dBi gain and  $10^\circ$  beamwidth were employed to realize the Over The Air (OTA) transmission link. After the mmWave-to-IF downconversion, we evaluated the Fiber-Wireless (Fi-Wi) link on the receiver side by performing offline DSP on the digitized data acquired by the above-mentioned real time oscilloscope. At the receiver side DSP, downsampling to 2 samples/symbol, retiming and carrier recovery and equalization stages were employed to mitigate for the transmission impairments of the combined Fi-Wi link.

The EVM performance of the proposed Fi-Wi scheme is illustrated in Fig. 3. For the 25 km fiber and 5 m wireless link, the performance of all 6 subcarriers of the multiplexed signal were well below the EVM threshold of 3GPP, achieving an average 6% EVM margin. For the FiWi transmission on the 50 km fiber and 5 m wireless link the margin is reduced to minimum values however achieving acceptable performance [13]. The above EVM performance achieved for all the different bands after the fiber/wireless transmission for both cases reveal the immunity of the analog IFoF transport against the fiber transmission impairments, compared to the results shown in [3]. It is also evident that the EVM penalty for the longer fiber transmission (50 km SSMF) is associated only with the lower received optical power which approaches the sensitivity of the photoreceiver. Therefore, it is evident that an IFoF link, using an IQM-DD scheme, achieves cancellation of the chromatic dispersion induced fading even for long fiber links, given that the power budget of the link supports transmission to such distances.



**Fig. 3.** EVM diagram per band for the FiWi transmission of the SSB signal using IQM-DD RoF transmission. Constellation diagrams are included for the 3.125 GHz IF.

## 4 Conclusion

We have demonstrated two experimental concepts where the use of coherent optical transceivers supports high capacity FWA connectivity through IFoF. SSB generation of a 12 Gb/s signal with 6 QPSK subcarriers using an IQ modulation is successfully detected using a coherent receiver, allowing for possible coexistence between Analog MFH and coherent PON infrastructure. On top of this, a Fiber-Wireless Fronthaul scenario with extended fiber reach (50 km) capabilities is showcased by an IQM-DD system where the SSB IFoF signal exhibits high tolerance against fading impairments due to fiber chromatic dispersion. Successful Fiber-Wireless transmission using V-band radio equipment is verified with EVM performance within the specifications of the 3GPP standards.

## Acknowledgement

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