# Towards a reliable RoF infrastructure for broadband wireless access

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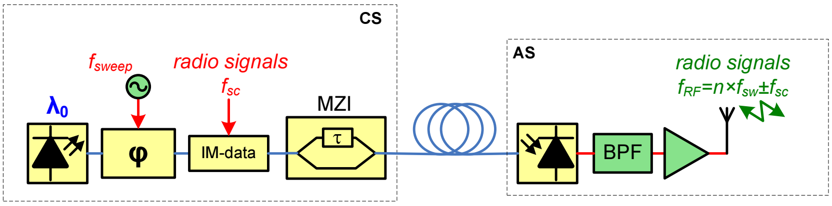
*Radio-over-Fiber (RoF) distribution antenna systems have been identified as a flexible option for the access architecture of the emerging wireless access networks, especially inside buildings, as a means of reducing infrastructure cost and antenna site complexity. Exploiting the features of the Optical Frequency Multiplication (OFM) technique, a reliable RoF physical layer can be designed, comprising bidirectional RF transmission, increased cell capacity allocation, multi-standard support, remote LO delivery and an in-band control channel for dynamic radio link adaptation and remote antenna controlling. The proposed scheme can be easily integrated in WDM-PON architectures, allowing a flexible convergence of wireless services with broadband access optical networks.*

## Introduction

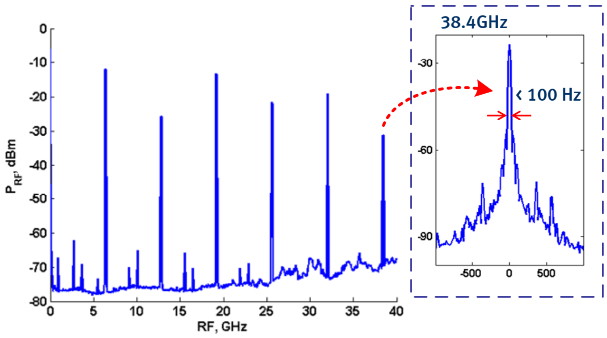
One major application of microwave photonics research is radio-over-fiber (RoF) distribution antenna systems, in which radio signals are generated at a remote central station (CS) and distributed transparently to several simplified antenna stations (AS) via optical fiber. The main goal of these RoF systems is to reduce infrastructure cost and to overcome the capacity bottleneck in wireless access networks, allowing at the same time a flexible merging with conventional optical access networks. Thus, in order to design a reliable RoF-based access infrastructure, RoF techniques must (a) be capable of generating the microwave signals and (b) allow a reliable microwave signals transmission over the optical link. The Optical Frequency Multiplication (OFM) method [1] satisfies these two main requirements by generating the microwave signals with a single laser source and low frequency electronics and presenting high tolerance to dispersion impairments in transmission over single mode [2] and multimode [3] fiber links. In this paper, we summarize a number of functionalities enabled by the OFM technique, which make possible the design of a reliable RoF-based infrastructure for broadband wireless access.

## Optical Frequency Multiplication (OFM)

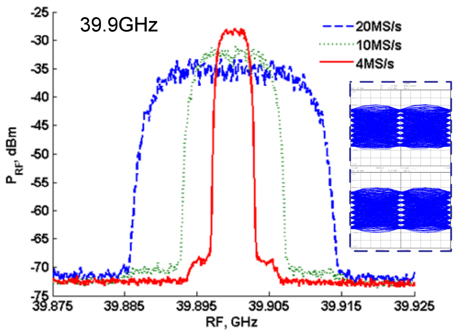
The Optical Frequency Multiplication (OFM) principle is based on harmonics generation by FM-IM conversion through a periodic band pass filter. At the CS, a continuous wave laser source $\omega_0$ is frequency modulated (FM) by a sinusoid with sweep frequency $f_{sw}$, intensity modulated by the radio signal (data) at low frequency subcarrier $f_{sc} < f_{sw}/2$, passed through a periodic band pass filter (e.g., a Mach-Zehnder interferometer (MZI)), launched into the optical fiber link and recovered at the AS by a photodetector (fig. 1(a)). At the output of the photodetector, radio frequency components at every harmonic of $f_{sw}$ are obtained ($f_{harmonic} = n \cdot f_{sw}$) (fig. 1(b), no data), with relative amplitudes depending on $f_{sw}$, the frequency modulation index and the free spectral range (FSR) of the MZI. When radio data is applied, the radio signals are obtained up-converted double-sided along with




(a) OFM implementation schematic

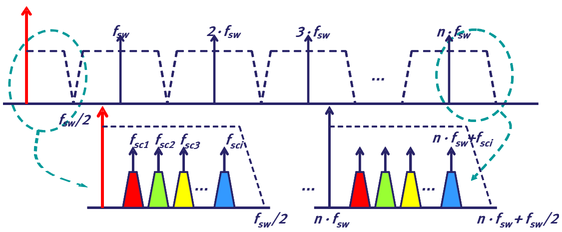



(b) harmonics generation with $f_{sw}$=6.4GHz [2]

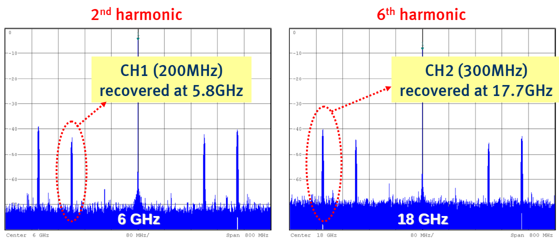



(c) QAM signals at $f_{RF}$=39.9GHz ($6^{th}$ harmonic of $f_{sw}$=6.4GHz, $f_{sc}$=1.5GHz) [2]

Figure 1: Optical Frequency Multiplication technique



(a) RF bandwidth capacity




(b) simultaneous transmission/upconversion of QAM signals to 5.8GHz and 17.7GHz ($f_{sw}$=3GHz, $f_{sc_1}$=200MHz, $f_{sc_2}$=300MHz)

Figure 2: RF bandwidth capacity and multistandard support

the generated harmonics at $f_{RF} = n \cdot f_{sw} \pm f_{sc}$ ($n$ indicates the $n^{th}$ harmonic), at the AS (fig. 1(c)).

## Increased cell capacity allocation and multi-standard support

As explained before, in a RoF link employing OFM, any radio signal at low frequency subcarrier $f_{sc} < f_{sw}/2$ can be introduced by intensity modulation at the CS, transparently transmitted to the AS, and recovered up-converted along with the desired harmonic. On the condition that the maximum RF bandwidth ($f_{sw}/2$) is not exceeded, different wireless signals can be transmitted simultaneously in a subcarrier multiplexing (SCM) scheme [4] (fig. 2(a)). Hence, at the AS, the obtained up-converted signals can be selected at the same or at different harmonics bands. This opens the possibility of *increasing the cell capacity* of a wireless system at the AS, when the signals are selected in the same harmonic band. Also, a proper election of the $f_{sw}$ and $f_{sc}$'s at the CS enables the simultaneous recovery of

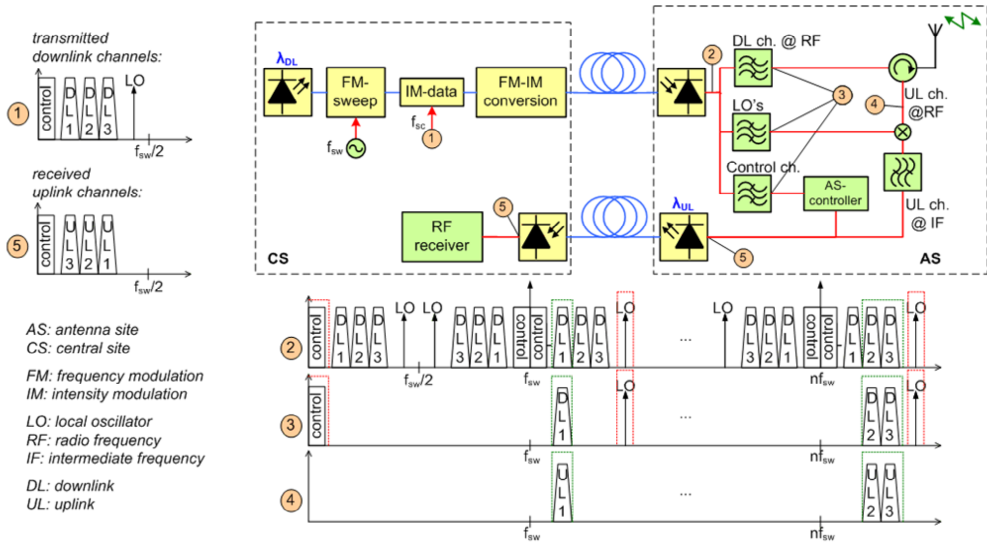



Figure 3: Bidirectional RoF link employing OFM [5]

the wireless signals at different harmonic bands (fig. 2(b)). In this way, *multiple wireless standards* can be simultaneously and transparently transmitted to the same AS, e.g. WiFi and WiMax, in a single OFM link, employing only one laser source and and low frequency electronics at the CS.

## Dynamic radio link adaptation with OFM

Dynamic radio link adaptation to the physical medium is a key feature in wireless transmission to guarantee system performance. Thus, a RoF link has to support this adaptability without incurring in additional signal degradation along the optical path, being as independent as possible of the radio link adaptation procedures. Whereas link/MAC and baseband adaptation can be controlled from the CS, the RF adaptation may occur either at the CS or at the AS. In this last case, adaptive remote AS configuration might be necessary. Hence, a trade-off between AS-simplicity and minimum level of AS-intelligence needed arises. OFM enables a flexible mechanism for the dynamic radio link adaptation support [4]:

- *Dynamic carrier frequency allocation* can be easily performed from the CS by tuning low frequency subcarriers.
- *Transmit power* can be remotely controlled from the CS and adjusted at the AS, to alleviate optical dynamic range requirements in the RoF link; for this purpose, an *in-band control channel* has to be transmitted simultaneously with the wireless data channel from the CS to the AS.

In a more general approach, an in-band control channel in the same optical link may enable other mechanisms for remote antenna configuration and controlling during network optimization and dynamic resource allocation.

## Bidirectional RoF link employing OFM

Figure 3 shows a schematic of a bidirectional RoF link employing OFM [5]. At the CS, a pilot subcarrier $f_{sc_{pilot}}$ can be also multiplexed together with the downlink radio channels and the control channel. At the photodetector output, this subcarrier is up-converted together with the RF channels to $f_{LO} = n \cdot f_{sw} \pm f_{sc_{pilot}}$, and can be used as a local oscillator (LO) at the AS. In this way, the uplink RF channels arriving at the AS are mixed with the remotely delivered LO's and down-converted to low intermediate frequency (IF) $f_{UL} = |f_{LO} - f_{RF}|$. The resulting IF uplink signals can modulate the intensity of a low cost light source and be directly transmitted to the CS, where they can be further processed by a low frequency RF receiver.

## Flexible wireless-optical convergence

OFM has the advantage of generating microwave carriers with the use of one single laser source. When considering bidirectional transmission, two separate wavelengths ($\lambda_{DL}$ and $\lambda_{UL}$) compose the RoF link. Thus, the extension of this OFM-based RoF link towards a distribution antenna system design implies the multiplexing of wavelength pairs per AS. This scheme can be easily integrated in wavelength division multiplexing passive optical network (WDM-PON) architectures, which are nowadays very popular in fibre-to-the-home (FTTH) broadband access [5].

## Conclusions

Optical Frequency Multiplication is a flexible and cost-effective RoF technique that enables multiple functionalities required for the support of wireless access systems. Increased cell capacity allocation, multi-standard support, remote LO delivery and in-band control channel for dynamic radio link adaptation and remote antenna controlling can be provided with a single laser source and low frequency electronics at the CS. Additionally, RoF distribution antenna systems based on OFM can be smoothly merged with broadband access optical networks like WDM-PON, allowing a flexible convergence of optical fiber's high capacity and wireless access flexibility.

## References

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