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# Radio over Fiber tunnel for 60 GHz wireless Home Network

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**Abstract:** 60GHz radio coverage is extended by using RoF at intermediate frequency with two hops in the air. MMF and low-cost photonics are used. Real-time transmission between two commercial Wireless-HD devices at 3Gbit/s is achieved.

## 1. Introduction

The number of connected devices increases inside the Home Area Network (HAN), the instantaneous capacity will have to reach the Gbit/s due to a variety of services coming from in-house exchanges and from the access network. Inside the home, users are accustomed to wireless connectivity as it is a convenient and flexible technology. Wi-Fi IEEE 802.11n achieves data rates higher than 100Mbit/s, but new radio standards as IEEE 802.15.3c [1], IEEE 802.11ad [2] or Wireless-HD [3] move towards multigigabit/s data rates thanks to the use of the 57-66 GHz unlicensed frequency band. However, the drawback of such mm-wave signals is their short range limited to a single room, due to the strong absorption of atmospheric Oxygen. A promising solution to extend their coverage and interconnect the home devices whatever their location consists in using Radio over Fiber (RoF) technology to distribute the radio signal to several Access Points (AP) spread around the home/building. The RoF systems can be transparent for the wireless standard because the radio signal is transmitted in its native format after transposition onto an optical carrier. Moreover, the introduction of optical fibers as infrastructure in the HAN is future proof in terms of data rates increase, capacity of delivering a multiplicity of parallel services [4] with high quality of service and minimization of the electromagnetic fields exposure.

As we have already demonstrated in a previous paper [5], the direct optical distribution of 60 GHz radio signals or Intermediate Frequency (IF) transposed radio signals over fiber leads to the same quality of transmission whereas the cost of the system is drastically reduced in the second case. In this paper, we present, for the first time to our knowledge, experimental results on 60 GHz RoF transmission at IF with two hops in the air.

## 2. Proposed solution to extend the coverage of mm-wave radio signals

We implement a point-to-point RoF link with two hops in the air that we call "RoF tunnel" as shown in Figure 1. The advantage of this scheme is that it allows two wireless devices located in two rooms far away from each other to communicate as if they were visible to one another, however, it is at the same time quite demanding as the RoF system must tolerate the losses and the distortions introduced by the two air links.

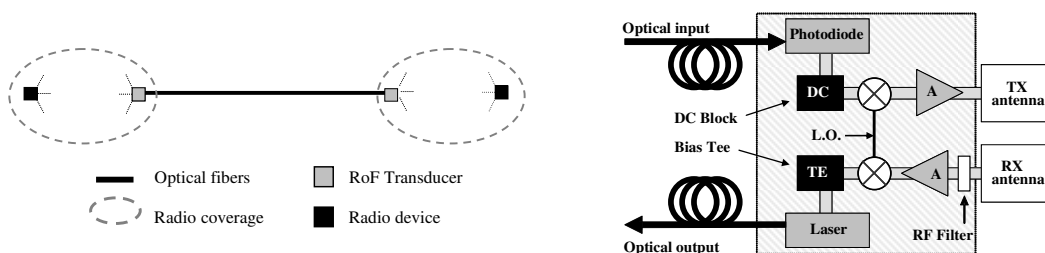


Figure 1 : RoF tunnel at the left (point-to-point link) and RoF transducers at the right.

A RoF system may be of interest for the context of HAN only if it is low cost. For this reason we chose to realize electro-optic (E/O) and optic-electric (O/E) conversions by means of VCSELs (Vertical-Cavity Surface-Emitting Laser) and PIN with transimpedance amplifier typically used for 10Gbit/s digital communications over multimode fiber (MMF). Consequently, in each transmission direction, the mm-wave radio signals are first down-converted by a local oscillator (LO) to a lower frequency (IF) before directly modulating the laser, then they are up-converted after the optical reception. Additionally, the RF power is optimized, firstly at the E/O conversion input to minimize the distortion, and secondly at the O/E conversion output to respect the emitted maximum power level. For the radio coverage, two different antennas are used (Tx and Rx) in order to reduce coupling issue between the two directions.

### 3. Experimental setup and results

As a baseline, we have realized the setup shown in Figure 2 for the mm-wave radio generation, propagation and reception. A radio OFDM signal with QPSK constellation at 3.08 Gbit/s is generated with Matlab according to one 2.16GHz bandwidth channel of the High Speed Interfaces mode of the IEEE 802.15.3c standard [1], composed of four channels. The baseband signal is generated by a 10GSamples/s dual output Arbitrary Waveform Generator (AWG). The in-phase (I) and quadrature (Q) signals are combined and transposed to an IF of 6 GHz. A system of amplifiers and attenuators optimizes the signal power that we fixed at -12dBm at the input of the mixer used for the final up-conversion around 60.5 GHz, corresponding to the center of the IEEE standard second channel. An up-converted radio power of 8.6dBm is applied to a Tx directional antenna with a gain of 20dB. The Equivalent Isotropically Radiated Power (EIRP) is then 28.6 dBm, very close to the maximum indoor EIRP permitted in USA, i.e. 27 dBm [1]. After the air propagation, the signal is picked up by the Rx directional antenna, boosted by amplifiers, down-converted by means of an electrical mixer fed with a 52.6GHz LO and finally, captured by a 40 GSamples/s real-time oscilloscope. The signal is finally demodulated offline with Matlab and Error Vector Magnitude (EVM) is then calculated. To optimize the link two variable attenuators have been introduced before each mixer. For a reference measurement, we have placed the oscilloscope in point A of Figure 2 and obtained EVM values lower than 4% for input RF powers ranging from -30dBm to 10dBm. We then included the air link and measured a stable EVM of 14% for air distances between 5m and 10m.

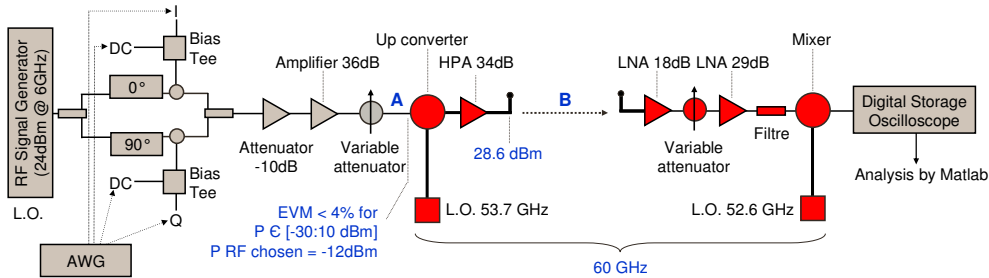


Figure 2 : Experimental setup for the mm-wave radio link.

The RoF tunnel is finally added by introducing the setup of Figure 3 in point B of Figure 2. The optical link is designed with a VCSEL and a GaAs PIN photodiode at 850 nm from Finisar, and 300m OM3 MMF. The IF is 4.5 GHz since the frequency of the first LO is 53.7 GHz.

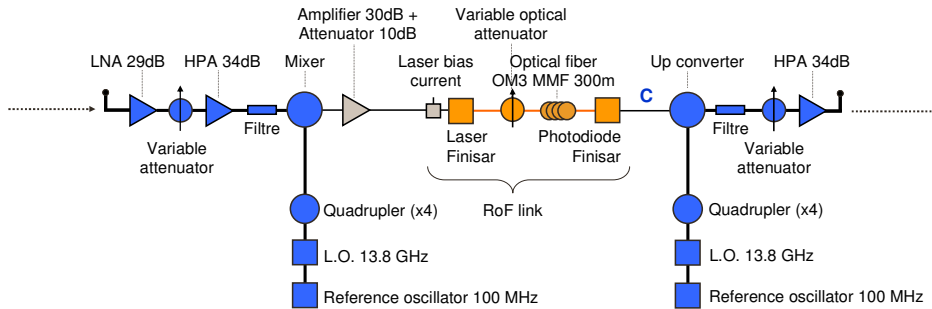


Figure 3 : Experimental setup for the optical tunnel acting as a repeater

Table 1 : EVM for 300m OM3 MMF as a function of additional optical losses and air link distance.

Distance	Optical losses	Average EVM
5m + 5m	0dB	24,32%
5m + 5m	1dB	23,94%
5m + 5m	2dB	24,15%

Distance	Optical losses	Average EVM
5m + 5m	3dB	25,05%
5m + 2m	1dB	22,51%
2m + 5m	1dB	22,47%

The results reported in Table 1 show the feasibility of the optical tunnel with two hops in the air. The gain at the reception after one hop in free space has been adjusted thanks to RF variable attenuator in order to optimize the results. In Table 1 optical losses represent the additional losses introduced by the optical attenuator. This last one

and the 300m OM3 MMF have 2.2dB total built-in losses. For a point-to-point link EVM is always lower than 25%, corresponding to a theoretical BER better than  $10^{-5}$  [6], i.e. error-free transmission after coding implementation. There is no significant difference between 5m plus 2m and 2m plus 5m, thus meaning that any of the two hops is more limiting for the system performances. Figure 4 shows the OFDM spectrum signal and constellation at the final reception. The center frequency is 7.1 GHz since the frequency of the second LO is 52.6 GHz.

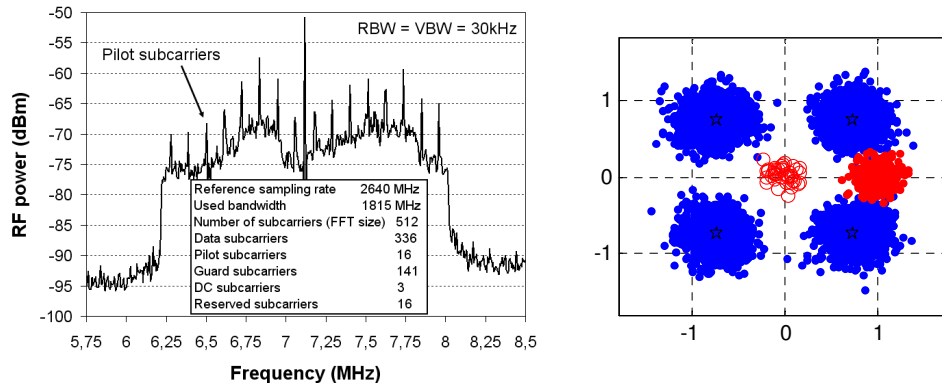


Figure 4 : IEEE 802.15.3c OFDM spectrum and constellation at the reception, for 300m OM3 MMF, 1dB optical losses and 5m + 5m air distance. Here, the corresponding EVM is 22.40% with an average EVM of 23.94%

Finally, we have tested the optical tunnel RoF architecture with a real-time bi-directional connection between two commercial wireless High Definition Multimedia Interface (HDMI) transmitters (Gefen) based on the wireless-HD standard [3]. In one room we have a first 60GHz AP receiving a mm-wave signal from a 60GHz Wireless-HD transmitter module fed from a Blu-ray player. In another room, we placed a second 60GHz AP reemitting the mm-wave signal to a 60 GHz receiver connected to a HD screen. The distance realized is 5m plus 5m. The wireless products have a transmitting power of 27 dBm and a receiver sensitivity of -65 dBm. The overall radio downlink (from the WirelessHD TX to RX) is operated at 3Gbit/s with 16-QAM (Quadrature Amplitude Modulation) modulation. The radio uplink (from the Wireless-HD RX to TX) is operated at a lower data rate in parallel. Each Rx and Tx couple antennas are separated from 10cm each other. The signal is transposed at IF as described in Figure 3 on both directions, but RoF is implemented only in downlink. The uplink IF radio signal is transported by a coaxial cable. This setup worked for both 50m-length OM2 MMF and 100m-length OM2 MMF (2 x 50m) without changing any settings. These distances are typical for HAN. At the output of the photodiode, in point C of Figure 3, a variable attenuator is inserted to change the RF power. From 0 to 27dB additional RF losses the system still works; beyond the connection cuts.

#### 4. Conclusion

The use in the coming years of high-speed radio for the HAN naturally leads to RoF technology. We have demonstrated that RoF technology allows two 60GHz wireless devices located in two rooms far away from each other to communicate as if they were visible to one another. Inside each room, the distance between the AP and the 60 GHz device can be 5m, and between the rooms it can be 300m of OM3 MMF. We have also realized a real data transmission using commercially available 60 GHz transmitter/receiver modules. Further studies will focus on more advanced RoF network architectures, as multipoint-to-multipoint based on a passive optical splitter [7] and integration of the RoF AP.

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