Transmission Quality Measurement of Two Types of 60 GHz Millimeter-Wave Generation and Distribution Systems
Frédéric Lecoche, Eric Tanguy, Benoit Charbonnier, Hong Wu Li, Frederic Van Dijk, Alain Enard, Fabrice Blache, Michel Goix, Franck Mallecot

To cite this version:
Frédéric Lecoche, Eric Tanguy, Benoit Charbonnier, Hong Wu Li, Frederic Van Dijk, et al.. Transmission Quality Measurement of Two Types of 60 GHz Millimeter-Wave Generation and Distribution Systems. Journal of Lightwave Technology, Institute of Electrical and Electronics Engineers (IEEE)/Optical Society of America(OSA), 2009, 27 (23), pp.5469-5474. <hal-00935149>

HAL Id: hal-00935149
https://hal.archives-ouvertes.fr/hal-00935149
Submitted on 4 Feb 2014

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers. L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
Transmission Quality Measurement of Two Types of 60 GHz Millimeter-Wave Generation and Distribution Systems

Frédéric Lecoche, Eric Tanguy, Benoît Charbonnier, Hongwu Li, Frédéric van Dijk, Alain Enard, Fabrice Blache, Michel Goix, and Franck Mallécot

Abstract—In this paper, we demonstrate and compare experimentally two techniques achieving very high-data-rates (>1 Gb/s) wireless transmission in the 60 GHz window using radio over fiber (RoF) for reach extension. The first RoF link is based on a 10 GHz vertical-cavity surface-emitting laser and uses a multimode fiber. The radio signal is transmitted on an intermediate frequency of 4.5 GHz and electrically upconverted to 60 GHz after the optical link. The second uses an optical frequency upconversion from 4.5 to 60 GHz by direct modulation of a mode-locked Fabry–Pérot laser whose self-pulsating frequency is 54.8 GHz before transmission over a single-mode fiber. For both techniques, two different types of modulation were tested. The first one was an ON–OFF keying at 1.5 Gb/s and the second one was an orthogonal frequency-division multiplexing-QPSK signal compliant to the IEEE 802.15.3c prestandard (3.03 Gb/s). Radio propagation performance is also reported.

Index Terms—Home network, IEEE 802.15.3.c, OFDM, radio over fiber (RoF), wireless indoor transmissions.

I. INTRODUCTION

MULTIPLICATION of connected devices (computers, media center, etc.) of services available to the end user (videophonie and videoconferencing, television over Internet protocol (TVoIP), etc.) [1], [2] and the increase in media storage necessary (and available) for various digital media lead to look for novel home network architectures and technologies to enable wireless coverage offering a data rate above 1 Gb/s (Fig. 1) [3]. We have proposed a home network architecture based on a wired backbone distributing local very high-speed wireless connectivity in the different rooms of the house/building [3]. Optical fiber seems to be a good solution for the network’s backbone as its large bandwidth would ensure a long life span to this new wire [4]. Furthermore, the principle of using an optical fiber in the house is seen as a natural evolution of the optical access, and some studies [5], [6] consider about the convergence of different signals (WI-FI, WIMAX, 60 GHz) on this medium.

Even if the houses are well-wired, users have developed a strong taste for wireless connectivity (ease of use, flexibility, etc.), and will require that future connectivities evolve to higher data rates while staying wireless.

The only radio technology whose capacity approaches 1 Gb/s is ultra-wideband (UWB), described in present or upcoming standards such as ECMA-387 [7], IEEE802.15.3c [8], and more recently, the IEEE802.11ad [9]. From these standards, it becomes clear that the main features of emerging high-capacity radio interfaces are their large spectral bandwidth and short transmission distance (<15 m). Both requirements result from the use of an RF carrier in the 60 GHz window. The use of such carrier frequency is also pushed by recent advances in CMOS technology to provide low-cost transceiver [10], [11]. Due to the limited reach, it is necessary to deploy several radio access points to cover the whole house, as depicted in Fig. 1.

The radio home network will then become a multicellular network, where the cell interference and management issues are similar to those of larger scale mobile/radio networks [12]. In this context, the use of the optical infrastructure to link the different remote antennas and the potential offered by radio over fiber (RoF) to provide a cost-effective and flexible solution must be considered.

In this paper, we present and compare two different methods of 60 GHz radio signal generation and distribution for broadband wireless indoor transmission. The first one is based on direct modulation at 4.5 GHz of a vertical-cavity surface-emitting laser (VCSEL) before the transmission over fiber for distribution. The frequency upconversion to 60 GHz is made at the end of the fiber, after photodetection and amplification, with the help of a local oscillator (LO) at 54.5 GHz (cf., Fig. 2). This first technique uses low-cost components and silica multimode fiber (MMF). The second technique uses a frequency upconversion from 4.5 to 60 GHz by directly modulating a mode-locked Fabry–Pérot laser (ML-FPL) [13], [14] whose self-pulsating frequency is 54.8 GHz before transmission over fiber, realizing, at the same time, the distribution and upconversion (cf., Fig. 3). This second setup uses more advanced components (e.g., 70 GHz photodiode [16]) and single-mode fiber (SMF), but allows the remote access point to be free of complicated
RF parts (no 60 GHz LO and mixer) as well; in this architecture, the base station does not contain any 60 GHz circuitry. For both techniques, two different types of modulations were tested. The first was an ON–OFF keying (OOK) at 1.5 Gb/s and the second was an orthogonal frequency-division multiplexing (OFDM) signal compliant to the IEEE 802.15.3.c prestandard carrying 3.03 Gb/s. Air propagation results are also reported to reinforce the demonstration. Only the downlink experiments (i.e., when the optical distribution occurs prior to the air transmission) are reported here as similar results should be expected from the uplink tests [15].

II. RF SETUPS

In this section, we show two setups that are used to generate and distribute a 60 GHz millimeter-wave radio signal. First, we assume that the radio signals are generated at an intermediate frequency (IF) of a few gigahertz, and we concentrate on the frequency upconversion and distribution functions. The generation of this IF radio signal will be detailed afterward.

A. MMF Setup

The principle of this setup is depicted in Fig. 2. The data on IF directly modulate a VCSEL that converts the electrical signal into an optical one. This VCSEL is widely commercially available, and was originally designed for 10 Gb/s digital transmission over LANs. After transport over 300 m of MMF (OM3 with 4000 MHz.km), a 8.5 GHz bandwidth photodiode with integrated transimpedance amplifier converts the optical signal into an electrical one in order to be upconverted. After the signal has passed into a low-noise amplifier (LNA), the signal is mixed with a 54.5 GHz local oscillator (LO) to reach the 60 GHz RF window. Then the signal is filtered (59–63 GHz), amplified by a high power amplifier (HPA), and transmitted by a 20 dBi horn antenna. After a wireless transmission of 10 m, the signal is amplified by two identical 60 GHz LNA before it is analyzed.

B. SMF Setup

In Fig. 3, we show the setup that upconverts the signal to 60 GHz before transmission over fiber by using a 54.8 GHz ML-FPL. The IF radio signal is amplified to modulate directly
the ML-FPL (average bias current set to 260 mA). The optical output power of the ML-FPL is +6 dBm. The laser pulses with a repetition rate of 54.8 GHz. Its modulation produces a mixing between the pulsating frequency and the IF carrier, leading to an optical frequency upconversion of the original signal to 59.3 GHz. The optical radio signal is then transmitted through 50 m of SMF up to a commercial 70 GHz photodetector, which is followed by an LNA (LNA $G = 18$ dB from 55 to 65 GHz), a bandpass filter (58–64 GHz), and an HPA (HPA $G = 31$ dB from 58 to 63.5 GHz). The transmit antenna and the receiver radio front end are identical to those used in the MMF setup.

III. SIGNAL GENERATION AND ANALYSIS

As aforementioned, both RF setups are compared using two different radio modulation schemes, which we now describe.

A. OOK Modulation (Fig. 4)

1) Signal Generation [Fig. 4(a)]: The OOK signal under test is generated from a pseudorandom bit sequence generator (ANRITSU MP1632C, sequence length $2^{31} - 1$) with a peak-to-peak value of 600 mV. It is sent to a mixer to generate the radio signal on a 4.45 GHz carrier at 1.5 Gb/s. Then, it is sent to the VCSEL or ML-FPL, depending on the two different setups presented earlier.

2) Performance Evaluation [Fig. 4(d)]: The 60 GHz radio signal received from the experimental setup [radio front end Fig. 4(e)] is converted directly to baseband by an envelope detector. BER measurement is then performed.

B. OFDM Modulation (Fig. 5)

1) Signal Generation [Fig. 5(a)]: The OFDM signal under test is created on a PC using MATLAB following the specification of the IEEE802.15.3c group [8]. The fast Fourier transform (FFT) block size is 512 with 336 data subcarriers. Each subcarrier is modulated in QPSK. The baseband signal is sampled at 2.59 GHz. A total raw data rate of 3.03 Gb/s is achieved for a bandwidth of 1.87 GHz. The signal is generated by a 10 GS/s dual output arbitrary waveform generator (AWG Tektronix 7102), and both outputs (representing both I- and Q-OFDM components) are sent to an RF mixer to generate the radio signal on a 4.5 GHz carrier. At this point, the spectrum of the signal extends from 3.5 to 5.4 GHz and the available RF power is $-15$ dBm.

2) Performance Evaluation [Fig. 5(d)]: To measure the quality of the 60 GHz radio signal out of the experimental setup [front end Fig. 5(d)], it is first attenuated to the optimal power level (around $-22$ dBm), then down-converted using a conventional electrical mixer fed with a 54.5 GHz LO, and finally, it is captured by using a 40 GSa/s real-time oscilloscope (RTO Agilent DSO91304A). OFDM demodulation and error vector magnitude (EVM) [17] evaluation are then performed offline using MATLAB. Each capture records a total of 44 OFDM symbols over 10 $\mu$s, representing 296 000 bits of data.

For baseline measurement, the signal from the block [Fig. 5(a)] is upconverted to 60 GHz, and then, analyzed and captured by the RTO, giving an EVM of 6%.

IV. RESULTS AND DISCUSSION

A. OOK Modulation Results

Based on Fig. 4, the results obtained for both setups for the OOK modulation at 1.5 Gb/s are similar. For a distance of 10 m between the antennas, we have an error-free result (BER better than $10^{-10}$) in both cases. In order to know the limit of our setups, we replaced the air radio transmission (including the two 20 dBi antennas) by a series of attenuators. Table I shows the BER, depending on the attenuation value and also the equivalent covered distance (assuming free-space propagation losses) with the used setup antennas. Distance in excess of 20 m without multipath interference can be attained. Results are common for both setups and confirm their similar behaviors.

B. OFDM QPSK Modulation

In this section, we show the results obtained for an OFDM modulation and for each setup.

<table>
<thead>
<tr>
<th>Attenuation (dB)</th>
<th>Equivalent distance (m)</th>
<th>BER</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>18</td>
<td>Error-free</td>
</tr>
<tr>
<td>66</td>
<td>26</td>
<td>$4 \cdot 10^{-9}$</td>
</tr>
<tr>
<td>69</td>
<td>35</td>
<td>$7 \cdot 10^{-7}$</td>
</tr>
</tbody>
</table>
1) **MMF Setup**: The principle of this test bed is depicted in Fig. 6. The electrical power at the input of VCSEL is set to $-10$ dBm and the power at the output of the 20 dBi horn antenna is around 10 dBm.

In Figs. 7 and 8, we present, respectively, the spectrum of the received OFDM signal and the associated constellation diagram obtained after demodulation. In spite of a strong disturbance of the spectrum, the computed EVM from the captured signal is 18.7% for an SNR of 23 dB. From the calculated EVM, a BER can be estimated around $10^{-10}$ [17]. This measured SNR should provide a theoretical EVM of 7% [17]. The difference between the two values of EVM (measured and theoretical from the SNR) is attributed to the residual nonlinearities of our system as well as multipath interferences during radio transmission.

2) **SMF Setup**: Fig. 9 shows the complete setup used for the test. For comparison, the level of radiated power is similar to the previous setup at the output of the transmit horn antenna.

In Figs. 10 and 11, we exhibit the spectrum of the received signal and the QAM diagram constellation, respectively. The computed EVM is 19% for an SNR of 21.5 dB. The value of BER can be estimated at $10^{-10}$ [17]. Again, the measured SNR should provide a theoretical EVM of 8.4% [17]. Strong distortions, multipath interferences, and nonlinearity still affect the calculated EVM, but results are still acceptable.

**V. CONCLUSION**

In this paper, we presented two different techniques for very high data rate 60 GHz wireless transmission using RoF. The first one uses low-cost commercial components (VCSEL and
remote antenna. On the other hand, the SMF setup allows the remote antenna to be simplified but the components are not readily available.

ACKNOWLEDGMENT

This work was supported in part by the European Commission, by the European Integrated Project Integrated Photonic mm-Wave Functions For Broadband Connectivity under Grant 35317, and by the Media and Networks cluster in the French Regions Bretagne and Pays de la Loire under the project Techim@ges.

REFERENCES

[9] Very High Throughput in 60 GHz IEEE802.11Task group AD.
Frédéric Lecoche was born in Charleville-Mézières, France, on July 12, 1978. He received the Engineering degree in optoelectronics from the Ecole Nationale Supérieure des Sciences Appliquées et de Technologie, Lannion, France, in 2002, the M.Sc. degree from the Université de Bretagne Occidentale, Brest, France, in 2003, and the Ph.D. degree in modeling and simulation of all optical cross-connects using wavelength selective switch from the TELECOM Bretagne, Rennes, France, in 2008. In 2008, he joined the Advanced Studies on Home and Access Networks of Orange Labs, Lannion, France. His current research interests include radio-over-fiber systems, microwave generation, and optronics.

Eric Tanguy was born in 1969. He received the Engineering degree in electronics and microwave from the National Polytechnic Institute of Grenoble, Grenoble, France, in 1993, and the Ph.D. degree in erbium laser for eye safe rangefinder from the University of Paris XI, Orsay, France. Since 1996, he has been an Associate Professor of electrical engineering at the Institut de Recherche en Electrotechnique et Electronique de Nantes Atlantique, University of Nantes, Nantes, France. He was involved in photonic microwave antennas based on polymers and laser cleaning of patrimonial objects until 2006. His current research interests include radio over fiber for high-bit-rate transmission in domestic networks.

Benoit Charbonnier was born in Versailles, France, in 1971. He received the Engineering degree and the Ph.D. degree in 40-Gb/s soliton transmission from the Ecole Nationale Supérieure des Télécommunications de Paris, Paris, France, in 1994 and 1997, respectively. In 1997, he joined the Advanced Communications Group, Nortel Network, Harlow, U.K., where he was engaged in 80-Gb/s long-haul transmission. In 2001, he joined Marconi Communications to develop an ultra-long-haul 10-Gb/s based transmission product. Since 2004, he has been a Research Engineer at France Télécom Research and Development, Lannion, France, where he is engaged in next-generation optical access network, especially in building networks with radio-over-fiber techniques.

Hongwu Li was born in Henan, China, in 1960. He received the B.S. degree in optical engineering from Beijing Institute of Technology, Beijing, China, in 1982, and the Ph.D. degree from the University of Besançon, Besançon, France. From 1987 to 1990, he was a Research Fellow at the University of Angers, where he was engaged in photorefractive crystals for optical image processing. In 1990, he joined the Ecole Nationale d’Ingénieurs de Brest, Brest, France, where he was an Associate Professor until 2001, and was involved in semiconductor optical amplifiers and acousto-optic Bragg cells for telecommunications applications, data packet switching, in particular. From 2001 to 2005, he was a Professor at the Institut d’Electronique, de Microélectronique et de Nanotechnologies, University of Sciences and Technologies of Lille, Lille, France, where he was engaged in RF signal generation with optoelectronic oscillators and InGaAsP/InP digital optical switches. Since 2005, he has been a Professor of electrical engineering at the Institut de Recherche en Electrotechnique et Électronique de Nantes Atlantique, University of Nantes, Nantes, France. His current research interests include radio over fiber for high-bit-rate transmission in domestic networks and broad-bandwidth microwave photonic devices based on polymers.

Frédéric van Dijk received the Ph.D. degree from the Université Paul Sabatier, Toulouse, France, in 1999. In 2000, he joined Thales Research and Technology, Orsay, France. He is currently with Alcatel-Thales III-V Lab, Marcoussis, France, where he is engaged in design, fabrication, and characterization of laser sources for microwave applications. His current research interests include directly modulated DFB lasers, mode-locked lasers for frequency synthesis and clock recovery, and microwave photonic systems. He is also involved in the European Project Integrated Photonic mm-Wave Functions for Broadband Connectivity, dealing with optical devices for millimeter wave systems, and in the European Project FUTON, dealing with radio over fiber for mobile networks.

Eric Tanguy was born in Versailles, France, in 1971. He received the Engineering degree in electronics and microwave from the National Polytechnic Institute of Grenoble, Grenoble, France, in 1993, and the Ph.D. degree in erbium laser for eye safe rangefinder from the University of Paris XI, Orsay, France. Since 1996, he has been an Associate Professor of electrical engineering at the Institut de Recherche en Electrotechnique et Electronique de Nantes Atlantique, University of Nantes, Nantes, France. He was involved in photonic microwave antennas based on polymers and laser cleaning of patrimonial objects until 2006. His current research interests include radio over fiber for high-bit-rate transmission in domestic networks.

Fabrice Blache is currently with Alcatel–Thales III-V Lab, Marcoussis, France.

Alain Enard is currently with the Alcatel–Thales III-V Lab, Marcoussis, France.

Michel Goix is currently with the Alcatel–Thales III-V Lab, Marcoussis, France.

Franck Mallécot graduated from the Ecole Universitaire d’Ingénieur de Lille, Lille, France, in 1984, and the Ph.D. degree in optoelectronic from the Université de Lille, Lille, in 1988. In 1989, he joined the Institut National des Télécommunications, Evry Cedex, France, as a Research/Teacher in the field of optics applied to optical telecommunications. In 1990, he joined Alcatel-Lucent Bell Labs France, Marcoussis, France, where he was involved in research in the field of optoelectronic components. From 2002 to 2003, he was engaged in the technology transfer of new generation of DFB lasers at Alcatel-Optronics. He is currently leading the Module and Integration Group, Alcatel-Thales III-V Lab, Marcoussis, where his main activities are focused on advanced micro and optoelectronic packaging technology developments mainly devoted to Telecom applications. He is author or coauthor of more than 30 technical papers. He is the holder of more than 15 patents.