

Phase Noise Performance of a Multimode Fibre Based Optical Frequency Multiplication System

A. Ng'oma, A.M.J. Koonen, I. Tafur Monroy, H.P.A. vd. Boom, and G.D. Khoe

COBRA Institute, Eindhoven University of Technology, P.O. Box 513, NL 5600 MB, Eindhoven,
The Netherlands.

Optical Frequency Multiplication is used to up-convert a 3 GHz signal to several frequencies up-to 21 GHz. Low phase noise below -100 dBc/Hz between 10 kHz and 100 kHz offset frequencies was measured for all the generated harmonic components and was limited by the measuring instrument's phase noise. The phase noise of the LO delivered over 4.4 km MMF was found to be at least 15 dB better than that of a commercially available electronic signal generator.

Introduction

Wireless coverage of the end-user domain, be it outdoors or indoors (in-building), is poised to become an essential part of future broadband communication systems. In order to offer integrated broadband services (combining voice, data, video, multimedia services, and new value added services), these systems will require higher data transmission capacities well beyond the present-day wireless standards. Wireless LAN (IEEE802.11a/b/g) offering up-to 54 Mbps and operating at 2.4 GHz and 5 GHz, and 3G mobile networks (IMT2000/UMTS) offering up-to 2 Mbps and operating at 2 GHz, are some of today's main wireless standards. There are also several recent Fixed Wireless Access standards such as the IEEE802.16, which is specified for frequencies between 2 – 66 GHz.

The need for increased capacity per unit area leads to higher operating frequencies (above 6 GHz) to delimit smaller radio cells, especially in in-door applications where the high operating frequencies encounter tremendously high losses through the building walls. The resulting large number of base stations or Radio Access Units (RAU) for a certain serving area (e.g. an office building), and the extensive feeder network needed, render the costs of deploying and maintaining such systems prohibitively high. These costs can be reduced significantly by centralising radio system functions, and thus simplifying the many radio access units [1]. Furthermore, multimode fibres (both polymer and silica), which offer relaxed coupling tolerance and a high signal transparency, may be exploited by using them in the extensive feeder network instead of the difficult-to-handle single-mode fibres. Polymer optical fibre is particularly attractive for in-home applications, due to its ductility, flexibility, and very large core diameter. However, multimode fibres offer limited bandwidth due to modal dispersion.

We have proposed the Optical Frequency Multiplication (OFM) concept to distribute LOs to remote RAUs [2]. We have previously demonstrated the OFM concept by delivering high frequency microwave signals to a RAU fed by Graded Index Polymer Optical Fibre (GIPOF) [3], and silica Multi-Mode fibre. In this paper we focus on the experimental investigation of the phase noise performance of the OFM method by comparing the phase noise of the different generated harmonic components. Phase

noise is an important parameter in wireless systems because it severely degrades performance due to its negative impact on high level x-QAM and Orthogonal Frequency Division Multiplexing modulation formats used in wireless systems.

The principal of Optical Frequency Multiplication

Optical frequency multiplication involves the periodic filtering of a swept optical signal, which after photodetection results in high order harmonic components of the sweep signal. The frequency multiplication factor, and thus the relative strength of the generated carriers are controlled by varying the frequency modulation index, β . If a Fabry Perot filter is used, then only a low finesse is needed to achieve maximum power of the generated harmonics. In the case of a sinusoidally swept system employing a Mach Zehnder Interferometer (MZI), the intensity of the generated harmonic components is proportional to the Bessel functions of the frequency modulation index, β . Figure 1 shows how the intensity of the generated harmonic components varies with β for the case when the sweep frequency is 3 GHz and the free spectral range (FSR) of the MZI is 10 GHz. It is observed that the peak power of the 6th harmonic component is obtained for when $\beta \cong 4.5$. After transmission in multimode fiber, the strength of the harmonics is further scaled by the frequency response of the fiber [4].

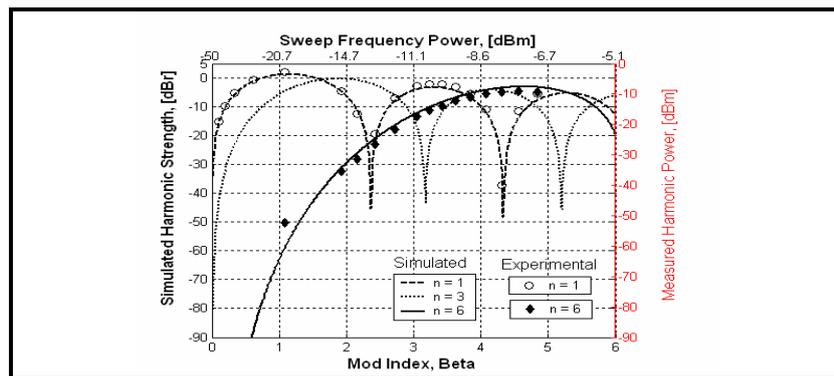


Figure 1: Simulated and measured effect of the frequency modulation depth on the intensity of the OFM generated harmonic components.

Experimental Set-up

The set-up used in the experiments is shown in **Figure 2**. At the headend, the 10mW CW light emitted by the DFB laser at 1316 nm was sinusoidally swept by an optical phase modulator driven by a 3 GHz signal. The resulting optical signal was immediately fed into a custom-made fibre-based Mach Zehnder Interferometer (MZI), having a 10 GHz FSR. The output of the MZI was then butt-coupled to the 4.4 km long 50 μ m-core multimode fiber and transmitted over the length of the fiber to a remote RAU. The remote RAU comprised only a photodetector and a Low Noise Amplifier (LNA). The output of the LNA was analysed on the FSQ 40 Rohde & Schwarz Spectrum Analyser.

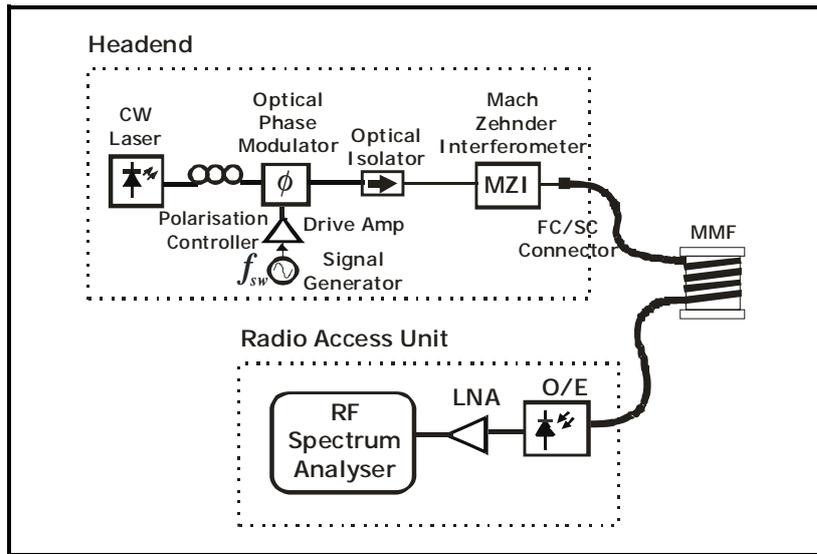


Figure 2: Optical Frequency Multiplication experimental setup.

Results

The frequency response and electrical bandwidth of the 4.4 km graded-index MMF under the SMF-butt coupling launch condition were measured by using a lightwave signal analyser, and are shown in **Figure 3**. In order to measure the frequency response accurately, a calibration measurement was first carried out with the CW laser, the IM, and the O/E converter, all included in the setup. By so doing, the response measured was solely attributed to the MMF. The frequency response showed a 3dB bandwidth of about 950 MHz, with a few higher transmission lobes.

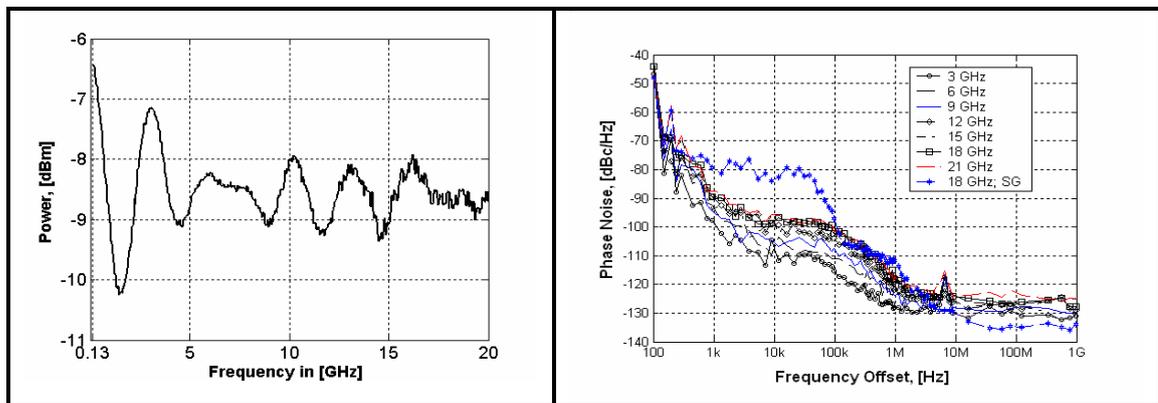


Figure 3: Frequency response of 4.4 Km MMF.

Figure 4: Measured phase noise of harmonics 1 – 7 (3 GHz to 21 GHz) generated by OFM and that of an 18 GHz signal directly from a commercial high-frequency signal generator

Varying the power of the sweep signal directly varied the intensity of the generated harmonic components. The measured response for the 1st and the 6th harmonic components is given in Figure 1. The measured result shows excellent agreement with the simulated result, confirming the predicted system behaviour.

The results of the phase noise measurement of the harmonic components 1 to 7 (3 GHz to 21 GHz) generated without the MMF link are given in **Figure 4**. The figure also shows the phase noise of an 18 GHz signal obtained directly from a commercially available electronic signal generator. The measured phase noise of all the harmonic components was found to be in the neighbourhood of the phase noise of the measuring instrument. Therefore, the actual phase noise of the harmonic components is expected to be lower than the phase noise given in the figure. Due to the same reason, it was not possible to accurately determine the relative phase noise differences between the various harmonic components. However, the result in **Figure 4** clearly shows that OFM produced carriers with much better phase noise than the electronic signal generator. The phase noise of the OFM generated 18 GHz LO was about 20 dB better than the phase noise of the electronic signal generator for offset frequencies ranging from 1 kHz to 100 kHz. The low phase noise obtained is attributed to the low phase noise of the low-frequency sweep signal generator and to the OFM process, which cancels the effects of laser linewidth.

The phase noise of a 17.2 GHz signal delivered over 4.4 km of MMF by OFM was measured and compared with that of the electronic signal generator. It was observed that the OFM-delivered LO's phase noise was about -95 dBc/Hz at 10 kHz offset, which was 15 dB better than the phase noise of the electronic signal generator.

Conclusions

The capability of Optical Frequency Multiplication to remotely deliver pure LOs with low phase noise ($\cong -95$ dBc/Hz at 10 kHz offset, for a 17.2 GHz LO) over multimode fibre links using pure low-frequency signals has been demonstrated. The low-frequency signal generator may be shared by several radio access units by using Optical Frequency Multiplication over multimode fibre links of more than 4 km, thereby reducing the system-wide installation and maintenance costs of future broadband wireless systems.

The measured phase noise results could not accurately determine the phase noise differences between the various harmonic components because the measured phase noise was too close to the measuring instrument's phase noise.

References

- [1] L. A. Johansson and A. J. Seeds, "Generation and Transmission of Millimeter-Wave Data-Modulated Optical Signals Using an Optical Injection Phase-Lock Loop", *IEEE JLT*, Vol. **21**, pp 511 – 520 (2003).
- [2] Ton Koonen, Anthony Ng'oma, Peter Smulders, Henrie van den Boom, Idelfonso Tafur Monroy, Giok-Djan Khoe, "In-house networks using multimode Polymer Optical Fiber for broadband wireless services", *Photonic Network Communications*, Vol. **5**, pp. 177-187 (2003).
- [3] Anthony Ng'oma, Ton Koonen, Idelfonso Tafur-Monroy, Henri van den Boom, Peter Smulders, Gjik-Djan Khoe, "High-Frequency Carrier Delivery to Graded Index Polymer Optical Fiber Fed Next Generation Wireless LAN Radio Access Points", in *Proceedings of the ECOC'03*, Vol. 3, 2003, pp. 508 – 509.
- [4] A.M.J. Koonen, et al, "Novel cost-efficient for Microwave signal delivery in Fiber Wireless Networks", in *Proceedings of the ECOC'04*, Vol. 5, 2004, Stockholm, pp. 120-123.