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Terahertz end-to-end wireless systems supporting ultra-high data Rate applications

ThoR

Deliverable D4.1

Photonic LO performance Report

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Contents

Change register

Version	Date	Author	Organisation	Changes
A	27-Oct-2019	Guillaume Ducournau, Pascal Szriftgiser	ULIL	First draft
B	3-Nov-2019	Guillaume Ducournau, Pascal Szriftgiser	ULIL	Revision and detailed descriptions

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1. Statement of independence

The work described in this document is genuinely a result of efforts pertaining to the ThoR project. Any external source is properly referenced.

Confirmation by Authors: Guillaume Ducournau, Pascal Szriftgiser ULIL

2. Abbreviations

AWG	Arbitrary Waveform Generator
BW	Bandwidth
Gbps	Giga bits per second
InGaAs	Indium Gallium Arsenide
LNA	Low Noise Amplifier
LO	Local Oscillator
NF	Noise Figure
OMN	Output matching network
PA	Power Amplifier
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature phase shift keying
RF	Radio Frequency
SNR	Signal to Noise ratio
SSPA	Solid State Power Amplifier
TWTA	Travelling Wave Tube Amplifier

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3. Executive summary

The TeraHertz end-to-end wireless systems supporting ultra-high data Rate applications (ThoR) project aims at providing a technical solution for back- and fronthauling operating in the 300 GHz frequency range. These high frequencies offer the advantage of a high available bandwidth, which directly translates into high data rates. The ThoR system will be composed of modems in the standardized 60 and 70-80 GHz frequency bands and a high performance 300 GHz RF transmit/receive modules. These modules are fed by a local oscillator in in the 72-76 GHz frequency range. The main reason behind this approach is the control of the 300 GHz up and down converters using a spurious free millimeter-wave signal. Usually, multiplication chains or transceivers are pumped by low frequencies local oscillators (LO), and the multiplication of this LO induces some unwanted spurious components in the signal. This document presents the RF performances of the photonic LO, developed for the ThoR project. The performances of this photonic LO has been designed according to the use of the photonic LO within the ThoR project where special specifications have to be fulfilled for output power (minium required to drive the other parts of the demonstrator), phase noise (according to the MODEMS specifications).

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4. Introduction

Although it is a big technological challenge, communication systems operating at extremely high frequencies, above 100 GHz, are experiencing an exponential development due to the continuously increasing demand for high data rates. Wireless links with centre frequencies around 300 GHz (so called terahertz band) have been successfully built in the last decade and impressive data rates have been reported in [1], [2] and [3]. Until now all these successful data transmissions have been realized in a laboratory environment transmitting only pseudo-random bits sequences. Also, almost all demonstrated systems are leveraging AWGs and complex digital signal processing (D.S.P.). However, future THz systems may not use this D.S.P. and these systems have to be compliant with real signals used in networks. Moreover, the target distance of the demonstrators in the ThoR project is up to km range rather than lab distances (10-15 meters).The goal of ThoR project is to design and develop a terahertz (THz) communication system which can be used in real environments supporting a deployment of 5G and beyond 5G networks. Such communication system implies the combination of fast baseband and cutting edge terahertz devices. Fig. 1 shows the scenario of a real-life application in which the ThoR system can be successfully integrated. The main building blocks of ThoR communication device are modems, in orange, and the 300 GHz transmitter (TX) and receiver (RX), in green.

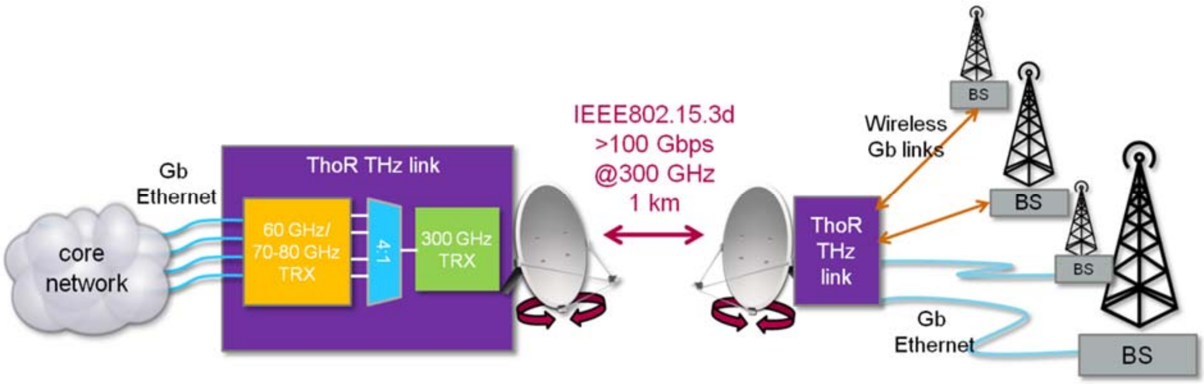

Fig. 1: The example of deployment scenario of the ThoR system. The ThoR communication device integrates baseband electronics, 60/70-80 GHz modems, 300 GHz RF transmit/receive modules (in green) and TWTA. [4]

The use of real-life MODEMs rather than AWGs already is induces several challenges at system level: a high level of linearity and high performance phase noise. These challenges are considered in the ThoR project within the work-package 4.

Linearity challenge: Among these, the linearity challenge (that will be discussed in more detail in D4.2 and D4.3, December 2019 [12,16]) is linked to the fact that one of the biggest challenges of data transmissions at 300 GHz is the low available RF-power. Currently the highest output power reported for solid-state power amplifiers (SSPAs) is around 13 dBm [5]. To overcome the high propagation loss at these frequencies (~ 145 dB for link distance of 1 km [6]) and to transmit the desired data over a larger distance (~ 1 km) a state-of-the-art travelling wave tube amplifier (TWTA) will be integrated within the 300 GHz TX-chain to achieve an output power of 30dBm (i.e. 1 W) [4].

Phase noise challenge In conventional approaches, the 300 GHz signals are often obtained using frequency multiplication of low-frequency microwave signals (< 20 GHz) [7] that generates unwanted spurious frequencies. This induces signal degradations and impairments of the whole chain. In the ThoR system, we target to go beyond these limitations by using a photonic local oscillator in the W-band (around 77 GHz), to drive the up/down sub-systems.

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Combining all these technologies, baseband electronics, photonic, radio frequency (RF) transmitter, receiver modules and a TWTA, ThoR will establish the first 300 GHz communication system usable for a real-life application such as wireless backhaul/fronthaul in incoming 5G networks. This report is dedicated to the presentation the RF performances of the photonic LO, to be used in the ThoR system defined in the D2.2 (Overall system Design) [8].

5. The photonic local oscillator (Photonic LO)

5.1. ThoR architecture and definition of the photonic LO operating frequencies

In this paragraph the ThoR architecture of the system is given. The partners responsible with the baseband electronics are developing two different kinds of modems based on IEEE 802.15.3e-2017 (60 GHz a.k.a. V-band) [9] and ETSI EN 302 217 (70/80 GHz a.k.a. E-band) [10] standards. The output of these modems represents the intermediate frequency (IF) which is the input for the 300 GHz RF transmit/receive modules. Each converter (up and down) has to be fed by a local oscillator around 220 GHz (see Fig 1 for detailed values). The local oscillator (LO) frequencies are derived from the resulting RF frequency spectrum presented in Fig. 2. For the 70 GHz modems an LO frequency of 216.625 GHz (LO1) and for the 80 GHz modems an LO frequency of 221.625 GHz (LO2) should be used to drive the RF mixer.

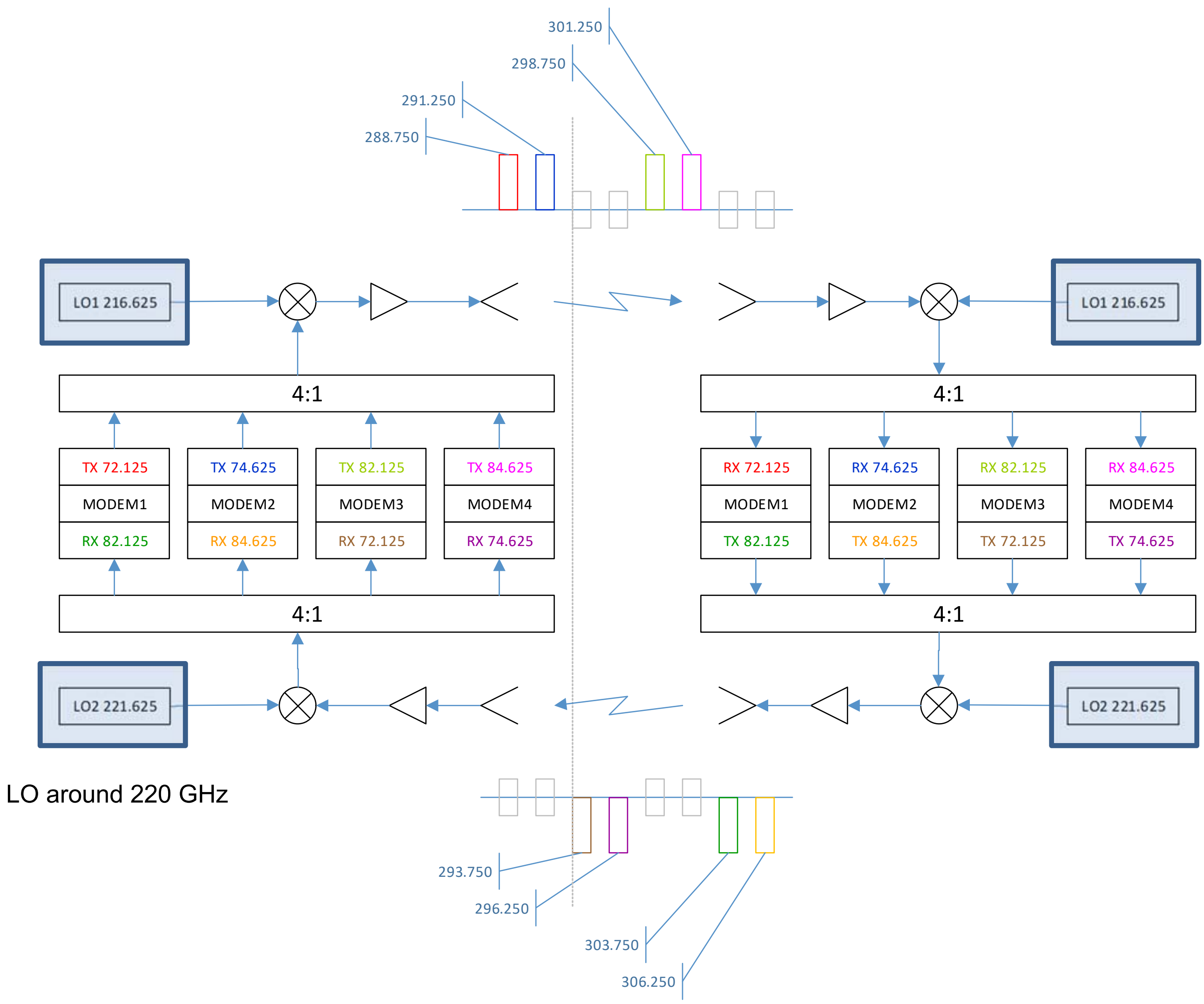

Fig. 2: ThoR system: Two LO are used to ensure the pumping of the up/down converters at Tx and Rx stages. In this architecture, aggregation of 4 MODEMS channels in the 300 GHz is achieved [10].

The photonic local oscillator ("Photonic LO") will be the driver for the up and down conversion in the main transmit and receive units. This photonic LO is targeted to provide a frequency equal to one third of the LO frequency, before combining with IF signals in mixer. To create a ~220 GHz LO, the

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photonic LO has to be operating in the ~77 GHz band. In detail, the photonic LO has to feature some tunability to cover the different LO frequencies around 220 GHz, detailed in the figure 1. Thus it has to be compliant within a bandwidth of about 72- 76 GHz, in correspondence to the 10 GHz bandwidth of the tripler stage.

The photonic LO in the ThoR system is the initial frequency reference that will drive a monolithically integrated tripler stage (belonging to the solid-state circuits, that will be described in the D4.2 and D4.3 of the ThoR project). This deliverable describes the system to generate the 77 GHz reference.

5.2. General overview – concept of the photonic LO

The architecture of the photonic LO is based on the generation of a dual wavelength optical signal, frequency locked, optically down-converted within a photodiode acting as an optical mixer, see Fig. 3.

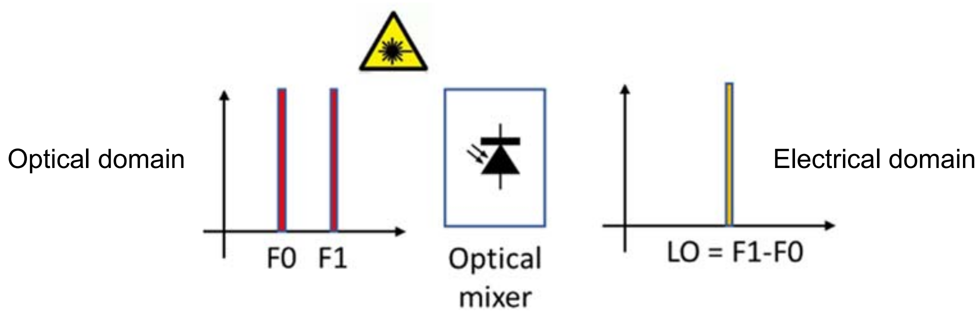

Fig. 3: Basic operation of the photonic LO in which an optical mixer is down-converting optical signals to electrical domain. The desired LO frequency is generating by mixing two optical signals, frequency locked at F_0 and F_1. The result of the mixing is then corresponding to the difference of the optical frequencies, i.e. F_1-F_0.

The principle use in the optical to mm-wave generation is using the photomixing concept, illustrated in the figure 4. In this method, a dual tone optical signal is feeding an ultra-fast optical detector. In the detector, the optical absorption is proportional to the square of the electrical fields.

The photomixing process is not limited to continuous wave (CW) signal generation. For ThoR, we target to use the photonic-based LO using CW signals, but this approach can be used to generate a modulated beating signal (grey) and a broadband (blue) as well, but these last two are not used in the ThoR project.

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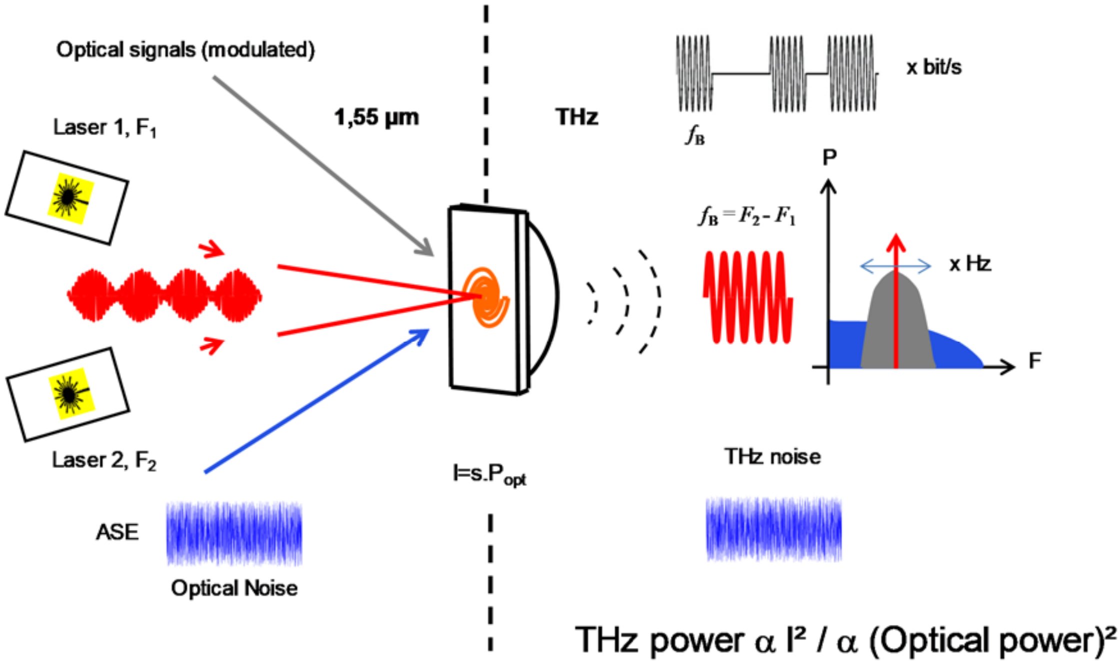

Fig. 4: The photomixing process (red part): a fast device is illuminated using two laser lines (F1, F2) to produce a beating frequency that corresponds to F_2-F_1.

In general, the fast opto-electronic device can be a photo-conductor or a photodiode. In this photonic LO developed for ThoR, the optical mixer is an InGaAs-based photodiode with a bandwidth compatible to the operation up to the 77 GHz range. In addition, in the ThoR project, two photonic LOs have to be established and as outdoor operation of the photonic LO is targeted, certified components has been chosen to reduce the risks. An existing and packaged 70 GHz photodiode available at ULIL, as well as fiber-based optical 20 GHz phase modulator and RF amplifier was chosen for the photonic LO development and the second photonic LO will be a duplication of the first one, two of these photonic LOs being developed specifically for ThoR project.

5.3. Photonic LO architecture

In general, several approaches can be use to generate a photonic-based LO [11]. The figure 5 is showing the photonic LO architecture. A stable laser is phase-modulated using a microwave reference from a synthesizer 19.25 GHz, which is frequency doubled to reach 38.5 GHz. After phase modulation a multi-line frequency signal is obtained in the optical domain, with a 38.5 GHz separation between the lines. Then, a combination of optical coupler and optical filtering is further employed to extract two optical frequencies, separated by 77 GHz (2 x 38.5 GHz). The final multiplication factor of the photonic LO is N=4.This final optical signal is then coupled to a fast InGaAs photodiode to generate the 77 GHz signal. Last, an amplifier is used to reach a suitable power level to drive the solid-state circuits (to be described in the D4.2 and D4.3 [14]).

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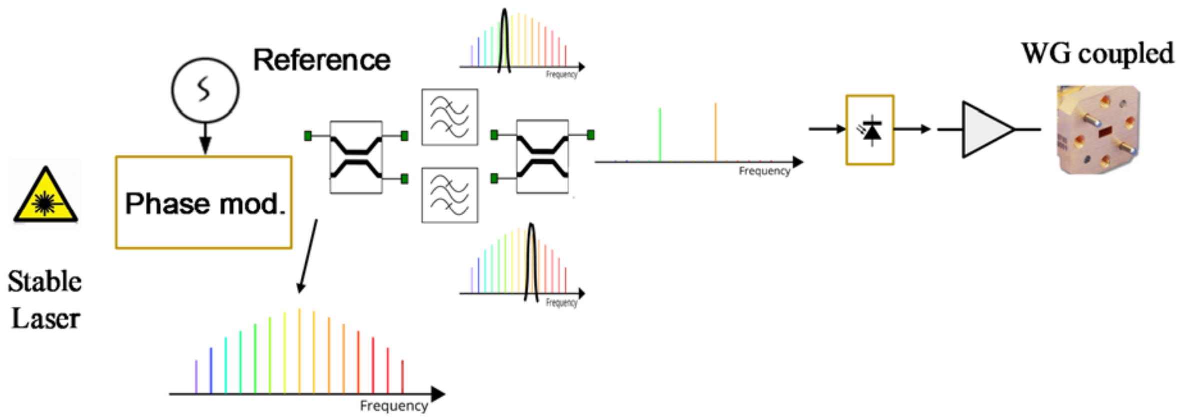

Fig. 5: Architecture of the photonic LO. Waveguide output is used at the end, as defined in the D2.3 (Specification of the RF Design).

5.4. Photonic LO measured performances in the 77 GHz range

The photonic local oscillator performances have to be evaluated using a set of RF characterizations. Among key performance indicators (KPI), the power level of the photonic LO, the phase noise and the spectrum has to be checked to validate the system. The figure 6 is presenting the power-level performance of the photonic LO. Such a measurement can be done using different approaches, ie using a calibrated spectrum analyser or a calibrated power meter. The later one has been chosen from the power-level to be measured, for power levels beyond 10 dBm, waveguide power meter PM5 [13] is featuring a very good accuracy and an absolute power-level determination (figure 6). Typical power level required for the photonic LO was targeted to be > 10 dBm. The figure 7 is giving the actual power level obtained performance and over 69-82 GHz, the photonic LO is compliant to this value. The actual power level can be adjusted according to the driving optical power of the photodiode. Thanks to the photomixing process, the output power-level is proportional to the square of the photodiode current, and therefore the photonic LO power can be tuned to the desired value during system-level experiments and demos.

Fig. 6: The PM5 power meter from VDI [13].

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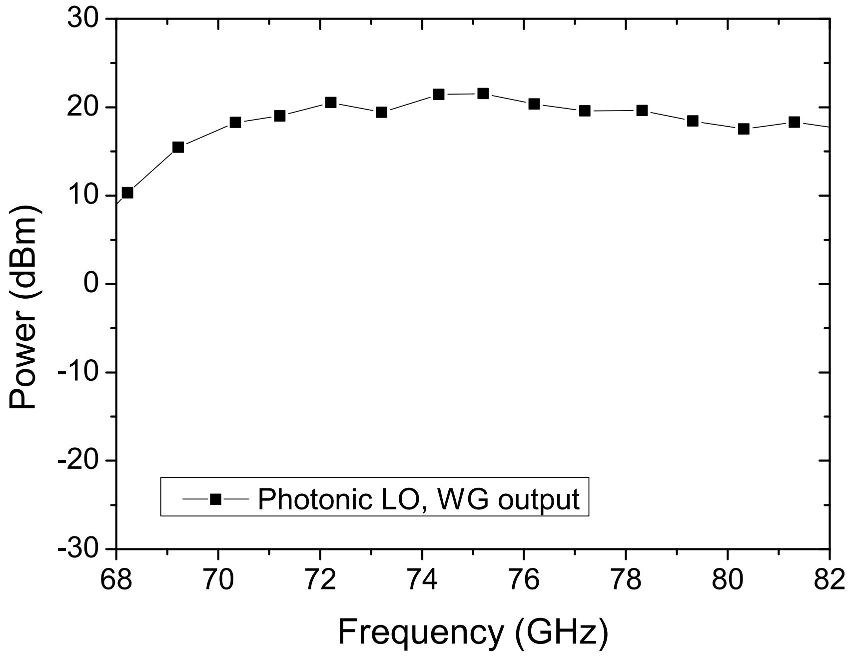

Fig. 7: Power level of the photonic LO, 68-82 GHz range, using a PM5 power-meter from VDI [13].

The figure 8 is the result of the phase noise of the photonic LO, for a carrier frequency of 77 GHz. This phase noise has been measured using a FSU 67 spectrum analyzer associated with a 75-110 GHz passive external mixer. It should be noted that kind of measurement system (passive mixer) has conversion losses in the range 20-30 dB. In such a case, the noise figure (NF) of this receiver is thus quite high and limit the dynamic range. This feature is assumed to contribute to the constant value of phase noise measured beyond 1 MHz, -110 dBc/Hz. The obtained performance is coherent to what can be expected from theory of the frequency multiplication: the phase noise evolution from microwave reference used in the figure 5 is 20.log(N), with N = 4 in the photonic LO, while ensuring a spurious free signal compared to conventional multiplication chains. However it should be noted that the overall gain using the photonic LO in comparison to a traditional multiplication chain will be tested during the full system validation scheduled in the second/third years of the ThoR project.

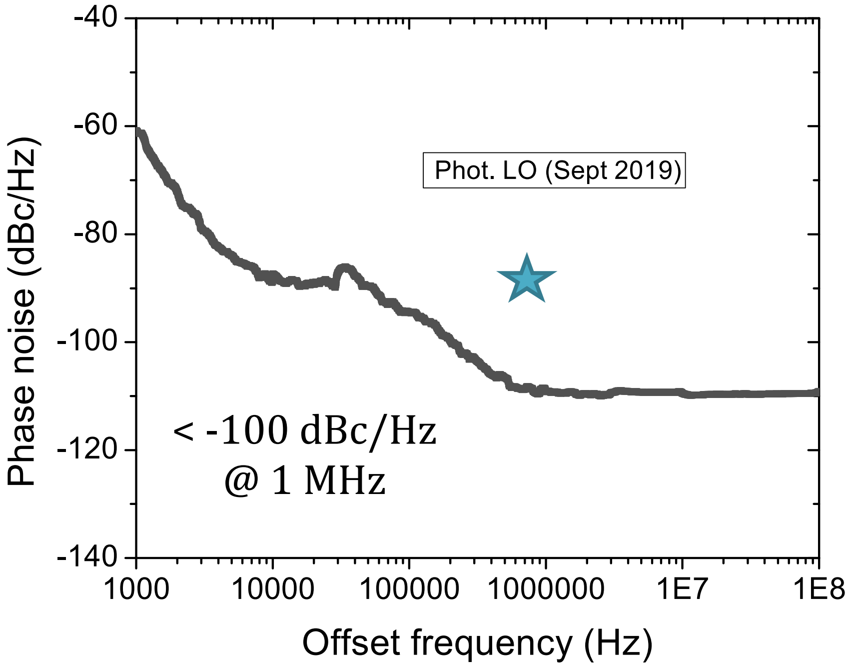

Fig. 8: Phase-noise performance of the photonic LO at 77 GHz. The star is the graph is the minimum required phase noise for the MODEMS defined in the deliverable D3.4 [14] of the ThoR project.

As mentioned previously, the phase noise performance has a potential strong impact on the performance of the system. According to the MODEM performances (described in the deliverable D3.4 [14]), the phase noise performance of the modulated signals should be better than -90 dBc/Hz @ 1 MHz offset frequency to maintain the highest modulation format (thus the highest spectral efficiency). For a worse phase noise, performance might be reduced (lower data rate) as EVM value will increase. Here, the the obtained performance of the photonic LO is -110 dBc/Hz at 77 GHz. Taking into account the multiplier by 3 in the RF front end, the phase noise will be degraded by at least 20.log(3) = 9.5 dB, thus around -100 dBc/Hz @ 1 MHz at 220 GHz (77 GHz*3). The photonic LO performance is thus beyond minimal requirement, and a 10 dB margin is obtained. However, it should be noted that overall system performance might also be affected by the signal to noise ratio of 300 GHz radio and non-linear effects, not yet known at this moment.

The spectrum performance of the photonic LO has also been checked. One of the outcomes of the DEMO-1 (Deliverable D6.1, [15]) was the observation of high signal to noise (SNR) requirement for any LO feeding multiplication stages in the solid-state chain. The figure 9 is presenting the photonic

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LO spectra. In this spectra, no spurious tone was observed, due to the fact that 38.5 GHz or 115.5 GHz (3x 38.5 GHz) can be coupled out from the last stage of the system (waveguide filtering effect and amplifier gain bandwidth).

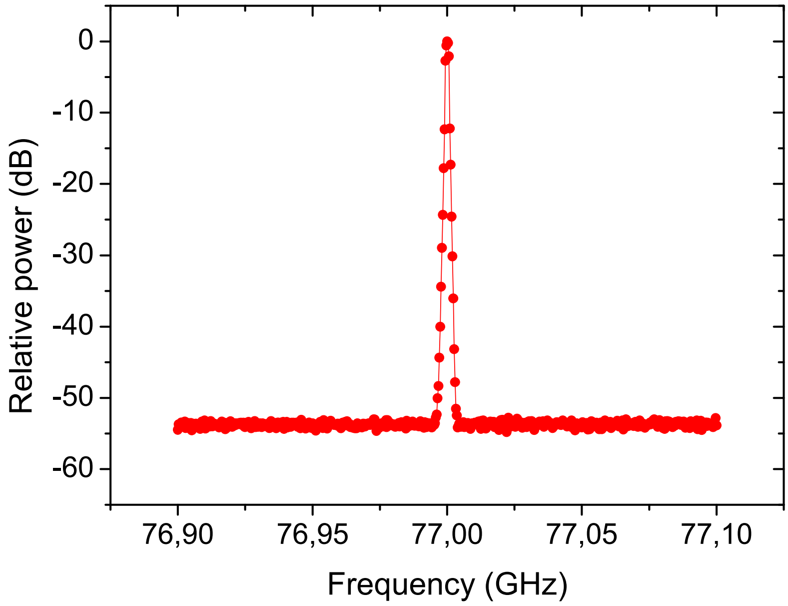

Fig. 9: Output spectra of the photonic LO at 77 GHz. A 50 dB SNR is obtained (so far limited by the conversion losses of the harmonic mixer used in the experiment).

Table 1: Photonic LO specifications

Parameter	Specification	Comments
Band of operation	68 GHz – 82 GHz	
Output power	>10 dBm	See figure 7
Phase noise	- 100 dBc/Hz @ 1 MHz	See figure 8 for other offset frequencies
SNR (Signal to Noise Ratio)	50 dB	Measured close to carrier at 77 GHz (figure 9)

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6. Summary and conclusions

This document presents the performances of the photonic LO, measured at the 77 GHz. The chosen architecture is featuring a 68-82 GHz frequency tenability and > 10 dBm output power. The phase noise has been checked to be compliant to the requirements from MODEM specifications. This photonic LO will be used to further drive the frequency multiplication stages (triplers) of the up and down converters. At that point, additional conclusions will be made to validate the use of a photonic-based LO in the ThoR architecture, where advanced modulation formats like QAM should be used. For such modulation formats, a high quality of the carrier frequencies is mandatory in addition to a very good system linearity (this last point will be investigated in D4.2 [12] and D4.3.[16]).

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