50 GHz to 60 GHz local oscillator transmission over fiber using optical frequency multiplication

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***Abstract* : The main parameters of a local oscillator distribution in the millimeter wave range are described. The link is based on optical frequency multiplication taking benefit of the modulator nonlinearity. It is modeled using an original CAD approach. Then, various practical solutions are compared and their phase noise floor is measured.**

Key words : Microwave optical systems ; millimeter wave generation ; phase noise ; frequency reference ; optical modulator ; nonlinear modeling ; CAD of microwave optical systems.

I. Introduction

Frequency generation and distribution using optical techniques is an interesting approach, particularly at very high frequencies. Millimeter wave local oscillator distribution using optics is implemented in many applications, going from telecommunications to radio-astronomy, and on distances which can vary from a few meters (ex : plane or satellite) to a few kilometers (ex : antenna network) or even much more (ex: clock comparison between laboratories) without any significant attenuation. Moreover, the high Q factor of optical delay lines or resonators can be used to realize low phase noise microwave sources [1] such as OEOs (Optical Electric Oscillators), and the frequency reference signal delivered by such OEOs is readily available for its distribution using optical fiber. The equivalent RF Q factor of OEOs is proportional to the RF frequency, and it is thus much higher in the millimeter wave range than in the low microwave range were most of the systems are today designed because of greater availability of devices (photodiodes, modulators, amplifiers…). It is thus interesting to investigate on low cost solutions which could be able to generate a millimeter wave signal carried by optics with a high signal to noise ratio.

Two techniques are today well known for signal generation in the millimeter wave range using optics : dual frequency (or mode locked) lasers [2] and frequency multiplication [3 to 5]. Dual frequency lasers are particularly interesting to get a high output power and a high signal to noise ratio at very high frequencies. However, to get a sufficient close to carrier phase noise performance for the above described applications, the two modes have to be locked in some way (either optically, or electrically, or both). Such systems are difficult to set up, and require specific devices which are not commercially available. Frequency multiplication is, on the contrary, quite easy to set up and only requires a Mach Zehnder (MZ) modulator. In some cases, the modulator is specifically designed for this application, but a good performance can be obtained from a conventional MZ modulator (such the one used in this study). With this approach, the optical components are of course strongly correlated and the only problem is in the low level output signal, and the resulting degraded signal to noise ratio. It is thus interesting to try to improve this performance using CAD, investigating on various nonlinear modulation techniques and nonlinear orders for the frequency multiplication.

In this paper, various techniques to generate a 50 GHz or 60 GHz sinusoidal signal carried over fiber are compared, both theoretically (CAD) and experimentally. Four cases are more deeply studied, including phase noise measurement of the recovered millimeter wave signal. Finally, it is concluded on the interest of frequency multiplication by three for applications in this frequency bandwidth.

II. CAD APPROACH

The optical link under study is described in Figure 1. It uses a 20 mW (max.) 1.55 μm DFB laser (Mitsubishi) and a 10 Gb/s MZ modulator (JDSU), so relatively low cost material, on the emitter side. On the receiver side, a 75 GHz photodiode (U2T) is used.

The frequency multiplication is obtained thanks to the nonlinearity of the MZ characteristic (Figure 2). Two bias points are classically used : $V_{\pi/2}$, which corresponds to the normal bias for linear modulation (LM), and V_{π}, which corresponds to the carrier suppression (CS) and which is often used for frequency multiplication by two. However, in both cases, higher order multiplication orders can be reached with these two bias conditions when a high power RF signal is superimposed on these bias points. Around $V_{\pi/2}$, the transfer function is odd, and only the odd harmonics of the RF input signal are generated : 1, 3, 5… Near V_{π}, it is an even function, and the even harmonics are generated : 2, 4… The question is: how efficient is this process ?

In order to model this behavior, a CAD approach has been used. This approach is based on Agilent ADS software and uses an already described modeling approach of the optical link [6]. Because Agilent ADS does not include optical or optoelectronic devices, these devices have been implemented using mathematical equations and the symbolically defined devices (SDD) module of ADS. The optical frequency is simply an RF source, with a 194 THz frequency (!), which is not a problem for the harmonic balance approach of ADS. The system handles three main frequency ranges : DC, RF frequency and its harmonics (ex : 10 GHz, 20 GHz…) and the optical frequency (194 THz). Thanks to the conversion matrices approach implemented in the harmonic balance software, it is also possible to study the nonlinear noise conversion mechanisms between the sidebands of all these carriers. This is particularly interesting, as an example, for investigating on how the laser AM and FM noise may affect the RF carrier. The results obtained with this approach have been compared to more classical analytical approaches of MZ modulators models [7-10].

Figures 3 and 4 represent the simulated and measured transfer function of the optical link, for the two bias cases under study and for two different input frequencies (10 GHz in LM and 15 GHz in CS). The agreement between simulated and measured power is excellent, at least in the power range which was available during the experiment. Only the 5^{th} harmonic is underestimated in case of $V_{\pi/2}$ bias.

III. OPTIMISATION OF 50-60 GHZ GENERATION

Our OEO application is focused in this frequency range. We have thus investigated four cases: frequency multiplication by 3 in LM mode, with an input frequency at 16.66 GHz (output at 50 GHz) and an input frequency at 20 GHz (output at 60 GHz) ; frequency multiplication by 4 in CS mode, with an input frequency at 12.5 GHz (output at 50 GHz) and an input frequency at 15 GHz (output at 60 GHz). In all these cases, the input frequency remains low enough to avoid prohibitive attenuation by the MZ modulator. Moreover, relatively low cost medium power amplifiers are available in this frequency range (10 GHz to 20 GHz).

Figure 5 represents the simulated and measured results obtained in these four cases. At low input power, the frequency multiplication by three is much more efficient than the frequency multiplication by four. At high level, this difference is not so clear, but it has to be noticed that the modulator manufacturer limits the input power at about 27 dBm. Because of these results, we have bought a 25 dBm output power amplifier for the more recent experiments.

However, the most important parameter for our application is not the output signal power but the carrier to noise ratio (CNR), which is related to the far from carrier phase noise. Including in the model the laser RIN parameter and the photodiode schottky noise, it is possible to compute this CNR. The result is depicted in Figure 6. The model shows that a CNR between 120 to 130 dB can be obtained with this technique with a 25 dBm RF input signal.

The last remaining test corresponds to the transmission of a high spectral purity signal and to the measurement of its phase noise at the output of the system. To this purpose, a low phase noise synthesizer (Anritsu) is used and the output from the optical link is measured thanks to an Agilent E5052B signal source analyser. This system allows a cross-correlation approach which ensures a very low phase noise floor, even in the millimetre wave range were two external mixers are used. Figure 7 represents the system configuration, with the various elements of the optical link and the millimeter wave mixers of the E5052B. Between the photodiode and the mixers, a low noise amplifier has been added (Spacek Labs).

Figure 8 depicts an example of such phase noise measurement. No noise is added to the synthesizer phase noise, which is simply multiplied with the same factor than the frequency, up to a relatively high frequency offset of about 3 MHz, above which the noise floor of the optical link can be measured. Table 1 summarises the results obtained in this type of experiment for both the signal (photodiode output) and the phase noise.

Finally, it is clear that there is an advantage of more than 5 dB in terms of additive phase noise (and CNR) for the multiplication by 3 approach, compared to the multiplication by 4 (carrier suppression) approach.

IV. Conclusion

The theoretical and experimental evaluation of a frequency multiplication technique to generate high spectral purity signals in the microwave range has been presented. The theoretical model uses an original CAD approach implemented on a software originally dedicated to microwave systems modeling. A good agreement is found with the experimental results, and a phase noise floor of about -130 dBc/Hz in the 50-60 GHz range has been demonstrated, which is largely sufficient for most time and frequency applications.

Acknowledgements

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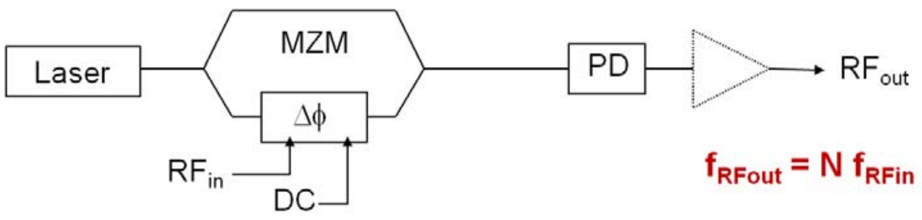

Figure1 : Schematic diagram of the experimental set-up

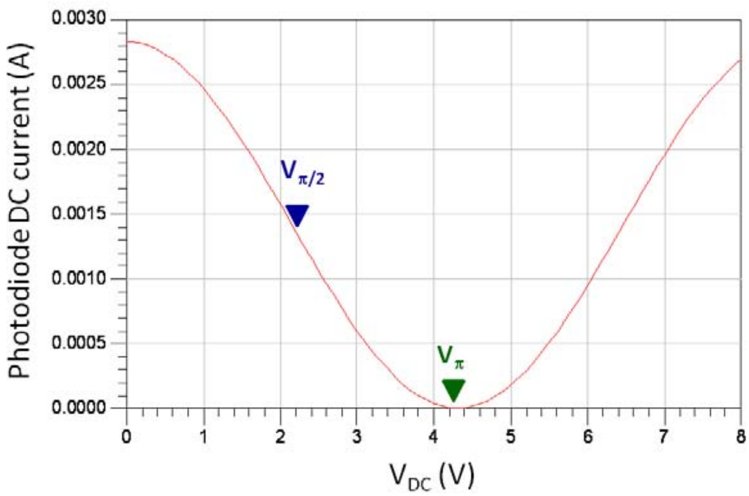

Figure 2 : Photodiode DC current versus the MZ modulator DC bias

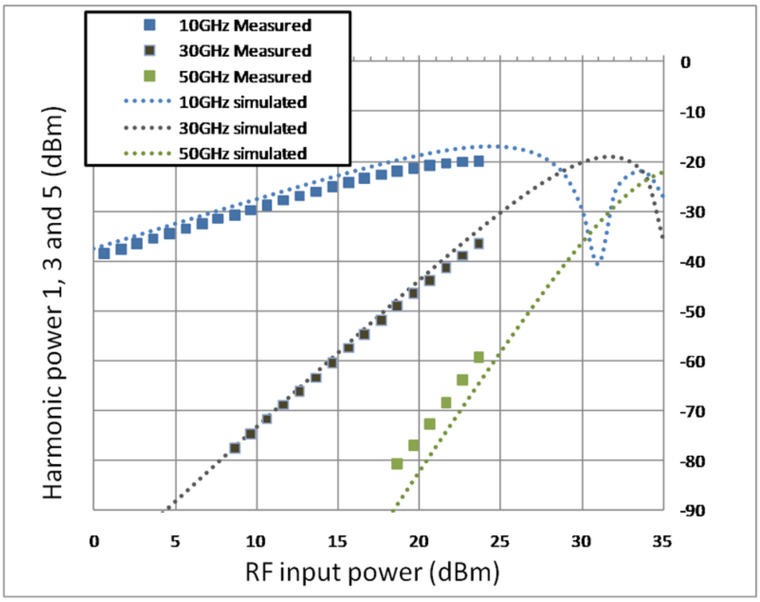

Figure 3 : Simulated and measured output power of the 1st, 3rd and 5th harmonics in LM modulation with a 10 GHz RF input

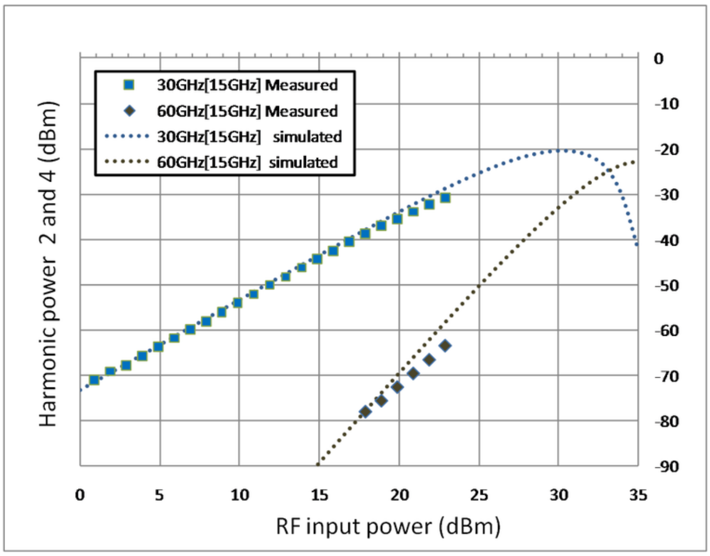

Figure 4 : Simulated and measured output power of the 2nd and 4th harmonics in CS modulation with a 15 GHz RF input

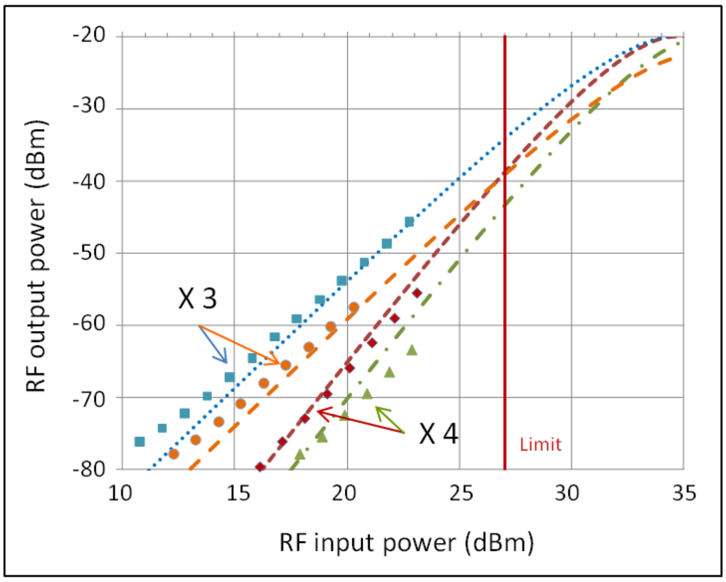

Figure 5 : Simulated (lines) and measured (dots) output power level at 50 GHz and 60 GHz. At low input power, the higher level is measured for a 50 GHz signal obtained from 16.66 GHz muliplied by 3, then a 60 GHz signal obtained from 20 GHz (X3), then a 50 GHz signal obtained from 12.5 GHz (X4) and finally a 60 GHz signal obtained from 15 GHz (X4).

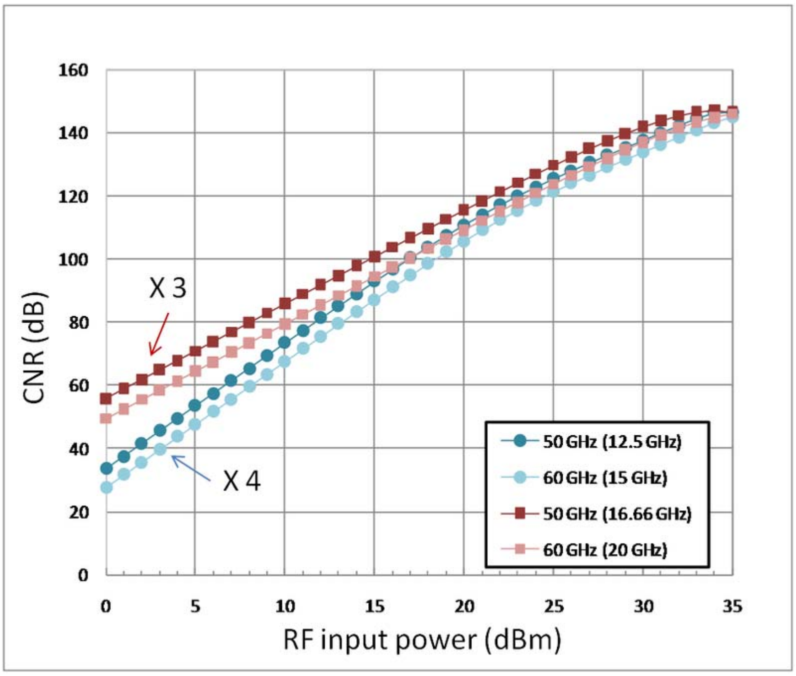

Figure 6 : Carrier to noise ratio (CNR) simulated for 3rd harmonic in LM and 4th harmonic in CS modulation

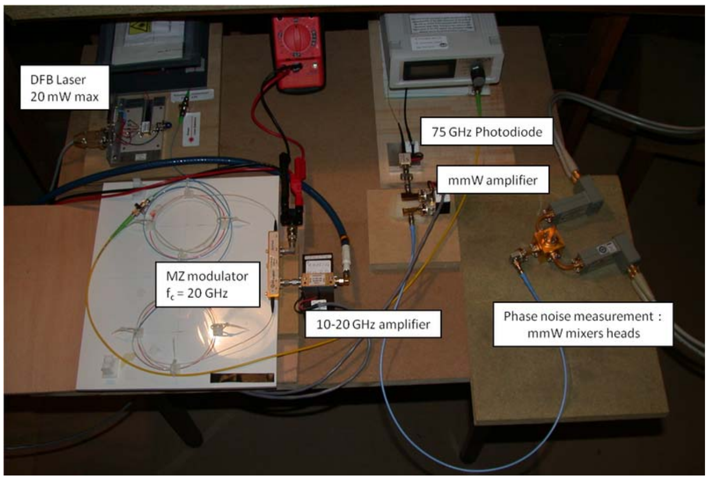

Figure 7 : Overview of the experiment, including the output amplifier and external mixers used for the millimeter wave phase noise measurement

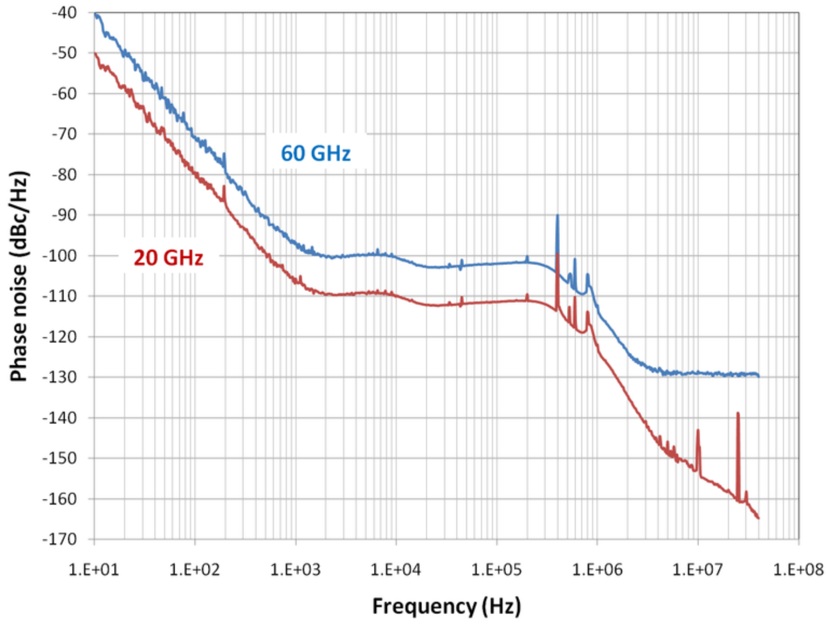

Figure 8 : Phase noise spectrum of the output 60 GHz signal (top curve) compared to the phase noise spectrum of the 20 GHz source (bottom curve) in case of a multiplication by 3. The two curves are perfectly parallel, with a difference of 9.5 dB corresponding to the multiplication factor. Above 3 MHz offset, the noise floor of the optical link can be observed

MZ Bias	$Freq_{IN}$	$Freq_{OUT}$	P_{out} @ P_{in} = 25 dBm	Phase noise floor
CS - Vπ	12.5 GHz	50 GHz	-49 dBm	-128 dBc/Hz
LM – Vπ/2	16.6 GHz	50 GHz	-37 dBm	-135 dBc/Hz
CS - Vπ	15 GHz	60 GHz	-50 dBm	-124 dBc/Hz
LM – Vπ/2	20 GHz	60 GHz	-42 dBm	-129 dBc/Hz

Table 1 : Summary of the results obtained in the four cases (signal and noise)