Optoelectronic Frequency Synthesizer With World-Record Phase Noise

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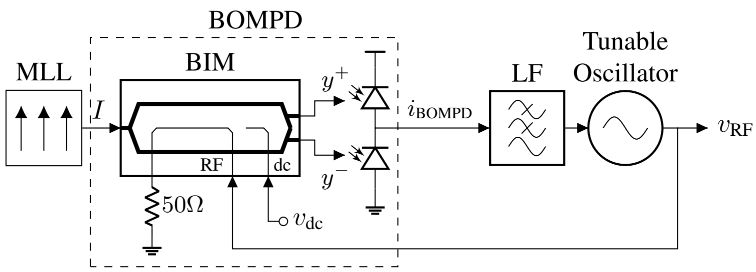
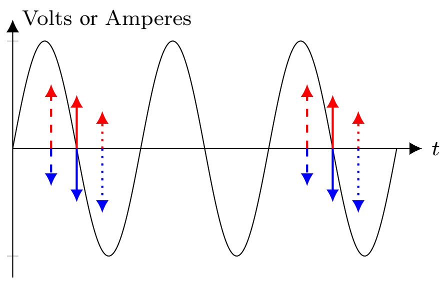
Abstract: In this demo we show an ultra-low phase noise optoelectronic PLL (OEPLL) based on optical clock source. The output signal of this type of PLL is in the electrical domain and its reference oscillator, typically a mode-locked laser, operates in the optical domain. The OEPLL has a frequency range of 2-20 GHz. The OEPLL has an in-band phase noise of below -150 dBc/Hz at 100-kHz offset frequency for a carrier frequency of 10 GHz. This phase noise level is 10–20 dB better than state-of-the-art commercial frequency synthesizers.



(a)



(b)

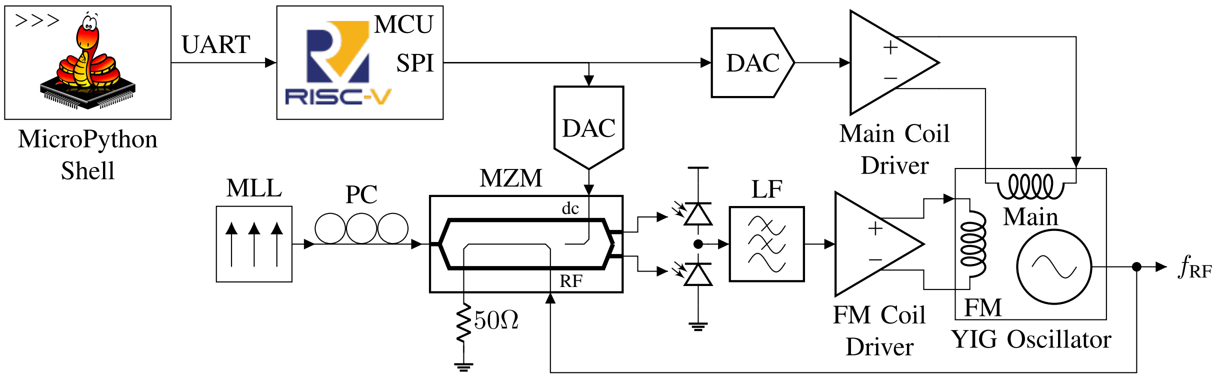
Fig. 1. (a) Simplified block diagram of the OEPLL and (b) corresponding waveforms: (black) voltage waveform at the RF port of BIM, (red) upper photodiode current and (blue) lower photodiode current when (solid) the phase of RF signal and the optical intensity are aligned, (dashed) the optical intensity has a phase lead and (dotted) the optical intensity has a phase lag; MLL, mode-locked laser; BIM, balanced intensity modulator; LF, loop filter; BONPD, balanced optical microwave phase detector.

1. Optoelectronic Phase-Locked Loop Theory

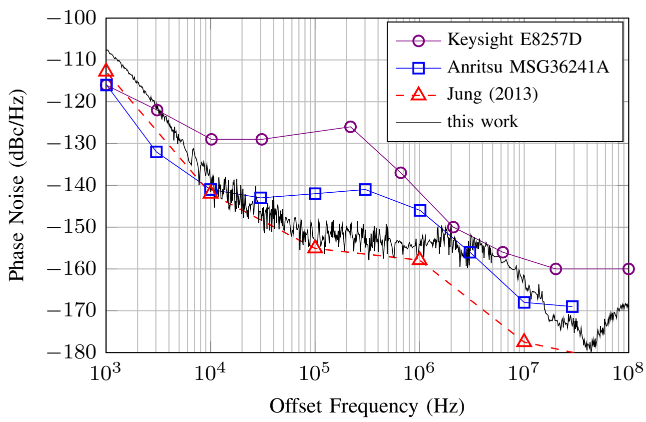
The block diagram of the OEPLL is shown in Figure 1(a). The optical pulses of the MLL are intensity-modulated with the RF signal from the tunable oscillator, as shown in Figure 1(b). The modulator has two optical outputs with complementary intensities. The optical outputs of the modulator are then converted to electrical currents and subtracted using a pair of photodiodes connected in series. This current is then integrated at the loop filter and converted into an error voltage, which aligns the phase of the tunable oscillator with the phase of the envelope of the optical reference signal.

The intensities of the BIM outputs are equal when the RF signal is phase-aligned with the envelope of the optical reference, as shown in Figure 1(b) with solid red and blue colors. Therefore, when the OEPLL is phase-locked, the current difference of the pair of photodiodes will be zero and the applied voltage to the tunable oscillator and its phase will not change. Any change in the phase difference causes an unbalance between the output intensities of the BIM as shown in Figure 1(b) with the dashed and dotted blue and red optical pulses. These optical pulses generate a nonzero current difference in the pair of the photodiodes. This current difference can be considered as an error current, which is integrated by the loop filter and realigns the tunable oscillator phase.

Figure 2(a) shows the block diagram of the implemented OEPLL. The core of this setup is similar to the block diagram shown in Figure 1(b). An yttrium iron garnet (YIG) oscillator with a bandwidth of 2–20 GHz is used as a tunable oscillator because of its high bandwidth and low phase noise. The main coil of the YIG oscillator has a high tuning sensitivity and is used to coarse-tune the frequency. The current of this coil is set via a current driver circuit and a low-noise DAC. The FM coil is driven with a low-noise operational amplifier (Op-Amp), which gets its input voltage from the loop filter output voltage. The optical reference is an MLL from Menhir photonics with a center wavelength of 1560 nm, a repetition rate of 250 MHz, and a pulsewidth below 200 fs. The BOMPD was implemented with a lithium niobate (LiNbO3) MZM with complementary outputs and a pair of InGaAs photodiodes to convert the optical output of the MZM into an electrical current. The output current pulses of the photodiode pair are then integrated via a series RC loop filter and converted into a voltage. Since the MZM performance is sensitive to the polarization of the input optical field, a polarization controller is placed between the MLL and the MZM to align the polarization of the input field with the required polarization of the MZM. Another low-noise DAC controls the bias voltage of the dc electrode of the MZM.



(a)



(b)

Fig. 2. (a) Opto-electronic PLL using BOMPD and (b) comparison of this work with state of the art at 10 GHz carrier frequency; MCU, microcontroller unit; DAC, digital to analog converter; MLL, mode-locked laser; MZM, Mach-Zehnder modulator; PC, polarization controller; LF, loop filter; YIG, Yttrium Iron Garnet.

2. Innovation

In modern WDM transmission systems the transmitter and receiver use ultra-broadband data converters for the generation and detection of the data symbols with bandwidth of around 20 to 40 GHz. Currently, these data converters exhibit a quite limited effective resolution of only 4-5 bits which is fundamentally physically limited by the clock jitter. In radar systems, accurate tracking of an object also requires a low-jitter local oscillator.

The current state of traditional electronic reference technologies such as quartz ans surface acoustic wave (SAW) oscillators, on the one hand, has reached its limits and further significant improvements in their phase noise or jitter is not expected. Mode-locked lasers (MLLs) and optical frequency combs, on the other hand, have demonstrated better phase noise by orders of magnitude. Therefore, in our frequency synthesizer, we use an MLL as the frequency reference to generate an ultra-low-jitter GHz clock. With an electro-optical mixed-domain phase detection technique, the RF signal from an ultra wideband YIG oscillator is synchronized with the pulse train of an MLL, achieving a world-record low phase noise, 20 dB better than any state-of-the-art commercial frequency synthesizer in the market at offset frequencies between 50 kHz to 1 MHz for a carrier frequency of 10 GHz. The measurement result of our OEPLL in comparison with the state-of-the-art signal generators is shown in Figure 2(b). In a future WDM system the MLL or any low-jitter frequency comb could be used for the generation of the optical local oscillator signals as well as for the low-jitter sampling clocks driving the data converters.

Further details about the technical background of the demo can be found in [1, 2, 3, 4, 5]

3. Demo content & implementation section

The objective of the demo is to show the phase noise of the OEPLL. In our demo, we show an operating OEPLL in the frequency range of 2-20 GHz. The output signal of the OEPLL is then characterized by a phase noise analyzer (APPH20 from Anapico). There will be 2 units, the OEPLL and the phase noise analyzer on a table, for this purpose. The visitor can set the OEPLL on any frequency in this range (250 MHz steps) and measure the phase noise and integrated rms-jitter.

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