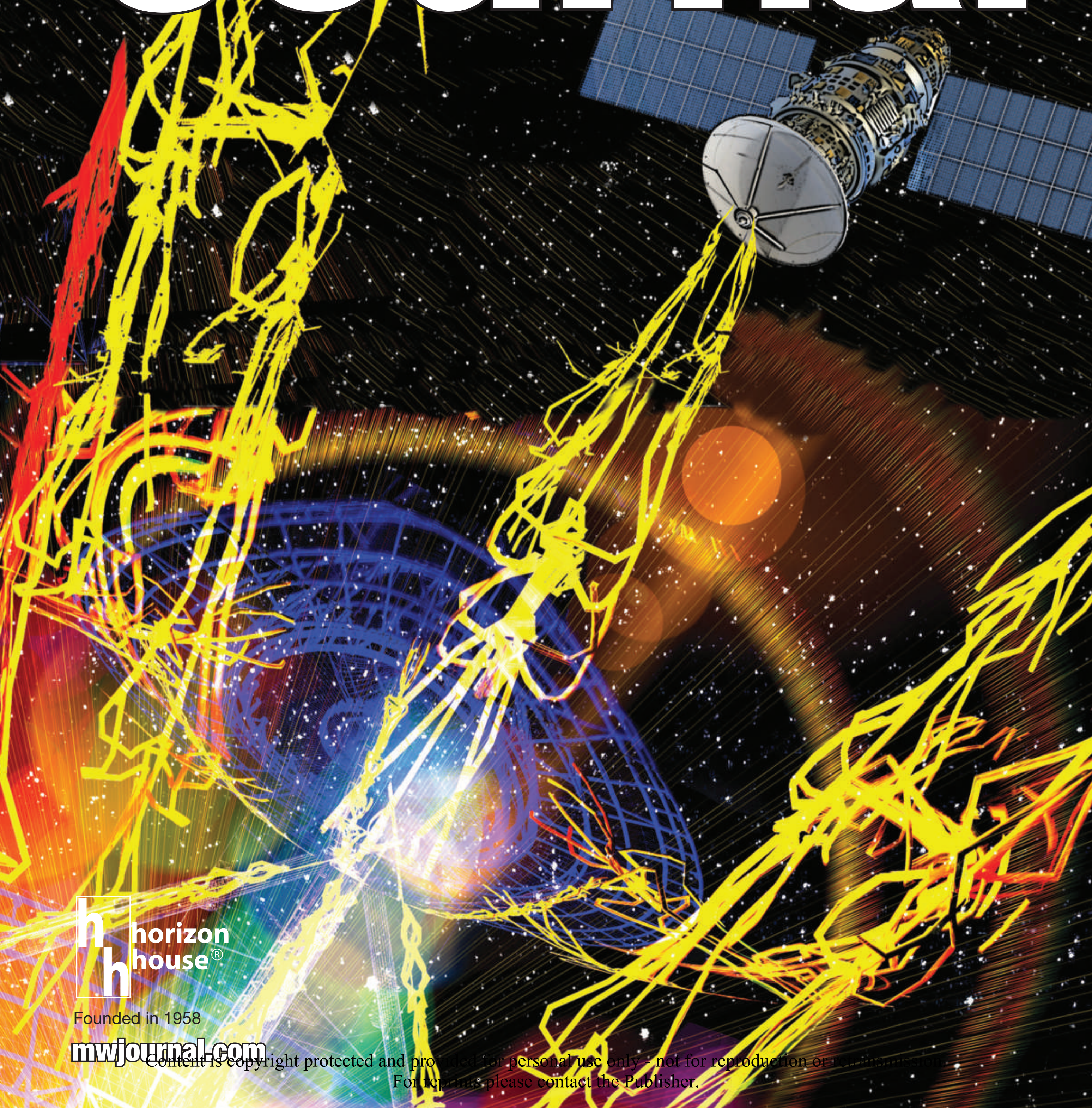
Vol. 64 • No. 8

August 2021

# Microwave Journal



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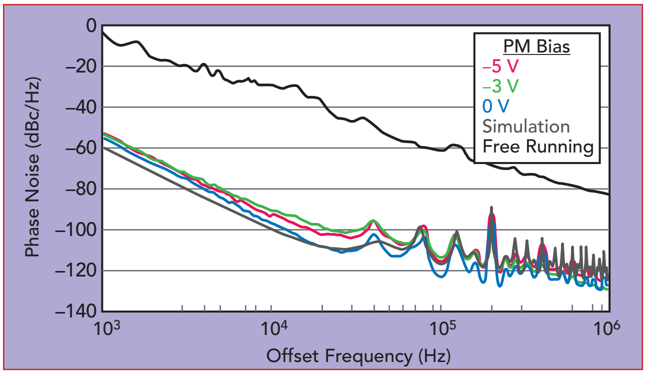


**Fig. 5** Simulated vs. measured phase noise of self-forced SILPLL-stabilized inter-modal MML oscillator vs. bias. SIL: 5 km, STPLL: 500 m/1 km/ 3 km. Carrier frequency = 11.54 GHz, 3.59 dBm output. Free running oscillator shown for comparison.

polarization controller after the optical delay line provides a high efficiency optical injection signal to the optical waveguide.

The performance parameters of phase-locking range and time to pull-in to phase-locking state[17] for the SPLL is enhanced when SIL is incorporated to SPLL. The delayed and non-delayed signals are simultaneously compared in a phase detector that is realized using a mixer and lowpass filter amplifier (see Figure 4). Any instantaneous low frequency phase error pulls the frequency deviation back to the original RF oscillation phase-locking using the PM section of the MML. The PLL loop bandwidth of 50 MHz was selected to completely cover 30 MHz of frequency drift. Different offset bias conditions of the PM section were compared using optimized self-injection locking 5 km and triple, self-phase-locking 0.5, 1 and 3 km delay lines to test the phase noise (see ***Figure 5***). Triple non-harmonically related delay loops[16] suppress the peaks of the side modes from -30 to -90 dBc. In the best scenario, the timing jitter was 0.448 ps, 600× better than the free-running jitter. The accuracy of self-forced oscillation modeling results are validated and experimentally reported for phase noise of both DRO[11-14] and optoelectronic oscillators.[4]


**Fig. 6** Shared DBR-based multimode semiconductor laser with symmetric multi-section multimode lasers on the left and right of a shared DBR. Chip dimensions = 4.6 mm x 1.2 mm.

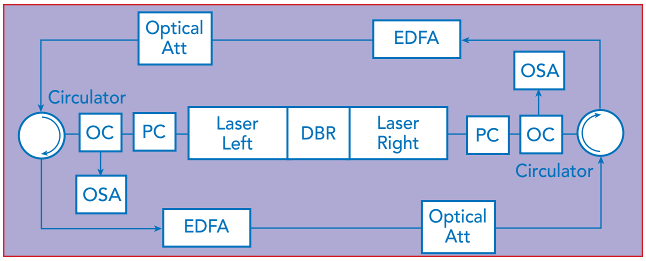


**Fig. 7** SML method with two counter-propagating feedback waves of symmetric laser pairs. The current realization uses modular components off the InP chip.

## FREQUENCY SYNTHESIS USING SML

To achieve broadband frequency synthesis, two MML pairs (see Figure 1) were configured to produce counter-propagating laser light feedback to form an RF synthesizer (see ***Figure 6***). This SML process[7] combined with frequency detuning the multimode laser sections easily provides tunable RF beat notes. ***Figure 7*** shows a block diagram of this novel SML method, which does not rely on standard active mode-locking where an external frequency reference is required. The symmetric outputs of multi-section laser pairs interact as two counter-propagating feedback waves. The larger the number of modes locked to one another, the lower the close-in phase noise, i.e., the better the RF frequency stability.[7,8]

The SML technique forces one laser output to be coherent with the other by locking the overlapped modes of the counter-propagating lasers, as bias currents of the SOA and voltages of the PM and EAM are tuned through the shared DBR and added external feedback. As shown in Figure 7, the amplified outputs from the left and right lasers are coupled back to the