FB-MOTE rebuilt and improved: fewer photons per pulse, less noise folding, fewer LED pulses

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Paper: R. Jiao *et al.*, "A 43 μm × 269 μm light-adaptive optoelectronic autonomous microsystem for neural recording," IEEE TBioCAS, vol. 20, no. 2, 2026 (Prof. Sunwoo Lee's group with Cornell co-authors). **All my results are simulation**; the paper's numbers are measurements.

What I did. I rebuilt the FB-MOTE recording chain block by block as a behavioural model (amplifier whose bandwidth and noise follow the light-dependent current, relaxation-oscillator PWM encoder with pseudo-chopping, PPM pulse pairs, a photon-counting optical link, and the paper's decoder of Sec. V) and checked it against the measured curves: bandwidth, noise density and oscillator period within 5.8, 8.3 and 1.5 % RMS, a flat 9.9 μV_{rms} predicted against about 10 measured, and the noise under light as 1.43× the electrical noise at every light level. SKY130 transistor-level replicas reproduce the key physics: over the paper's 0.317-0.43 V supply the amplifier current changes 9.4× while its integrated noise stays within 3.5 %.

Three limits the model shows. The decoder's single threshold per 100 ms batch needs about 15 detected photons per pulse; at high light the encoder samples at 15.7 kHz while the amplifier is 12.9 kHz wide, so amplifier noise folds into the spike band (4.1 dB at 1.2 μA); and every sample costs two LED pulses.

What I propose (the mote's circuits stay; pulse timing and reading change):

- **P2, grid-tracking soft-decision decoder**: a loop locks onto the reference pulses; every photon cluster is scored by its photon count and expected position; a lost pulse is imputed. 4, 8, 10 instead of 15 photons per pulse at 2×10^4, 2×10^5, 10^6 background counts/s.
- **P3, bandwidth clamp**: a switched capacitor holds the amplifier corner below $0.4 f_s$; spike-band noise 9.43 to 6.97 μV at 1.2 μA with no extra pulses (a SKY130 replica bias, letting f_s follow the bandwidth, holds f_s/f_L within 2.76-3.52).
- **P4, reference pulse every 8th period**: a divide-by-8 Johnson counter (SKY130: works at 0.317 V, under 1 nA, no glitches) gates it; 1.125 instead of 2 pulses per sample, spike F1 0.837 (0.828 with every period) under light flicker.
- **P1, gain read from the measured period**: decoded gain error under light flicker 4.18 to 1.14 % RMS.

Metric	Published, measured	Published, our model	Proposed, our model	Change	By
Integrated input noise, electrical (μV_{rms})	about 10	9.9 (Eq. 8)	unchanged	-	
Sampling rate against amplifier bandwidth at 1.2 μA (kHz)	about 14 / 12	15.7 / 12.9	15.7 / 6.3	$f_s > 2f_L$	P3
Photons per pulse for 95 % of perfect-link spike detection, 2×10^4 / 2×10^5 / 10^6 counts/s	-	15 / 15 / 15	4 / 8 / 10	1.5-3.8× fewer	P2
LED pulses per sample	2 (Fig. 20)	2	1.125	-44 %	P4
Spike-band noise after sampling at 1.2 μA (μV)	-	9.43	6.97	-26 %	P3
Amplifier bandwidth at 1.2 μA (kHz), a cost	about 12	12.9	6.3	narrower	P3
Decoded gain error under light flicker (% RMS)	-	4.18	1.14	-73 %	P1

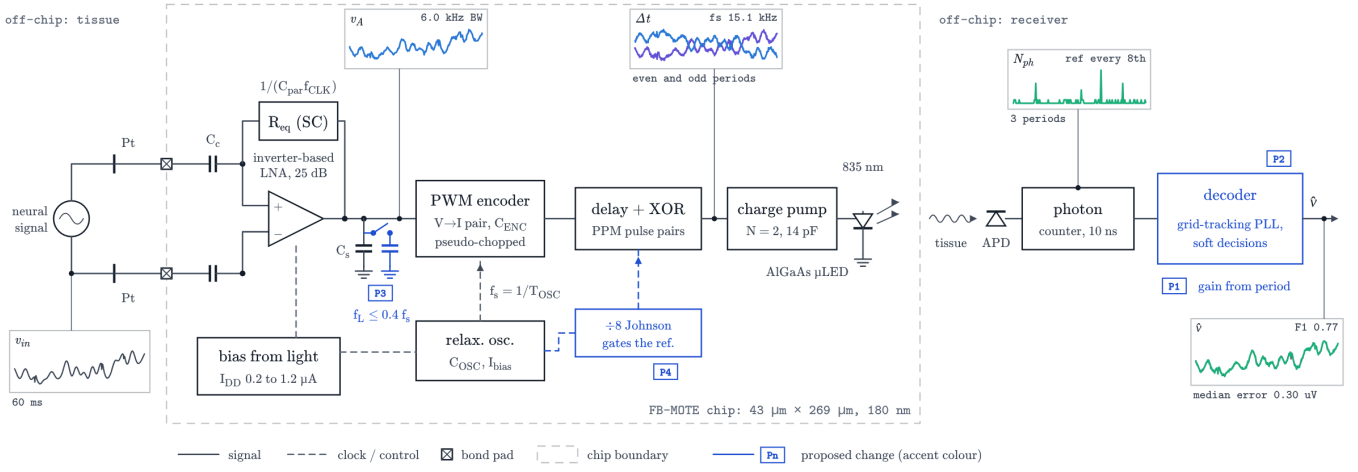

Figure 1: The proposed chain: the published FB-MOTE (ink) with the four changes in blue (P-tags). The small plots are a run of this chain in the web model at 900 $\mu W/mm^2$ with 10 detected photons per pulse.

Negative and partial results, kept. A chopper-first input (the mixer-first idea at the electrodes) is worse with real SKY130 switches at 0.3-0.43 V; ratio-locked sampling alone loses spikes at the lowest light; decoding by period separates two equal-amplitude motes (F1 0.702 against 0.053) but not four or more; send-on-delta encoding keeps spike detection with 4663 instead of 14798 samples/s on a perfect link, but its analog memory is not designed yet. **Assumed**: the photon-counting channel and background, a 50 Hz flicker corner, the full-scale range, 1e-4 oscillator jitter; SKY130 is not the paper's 180 nm process. Full report: 9 pages.

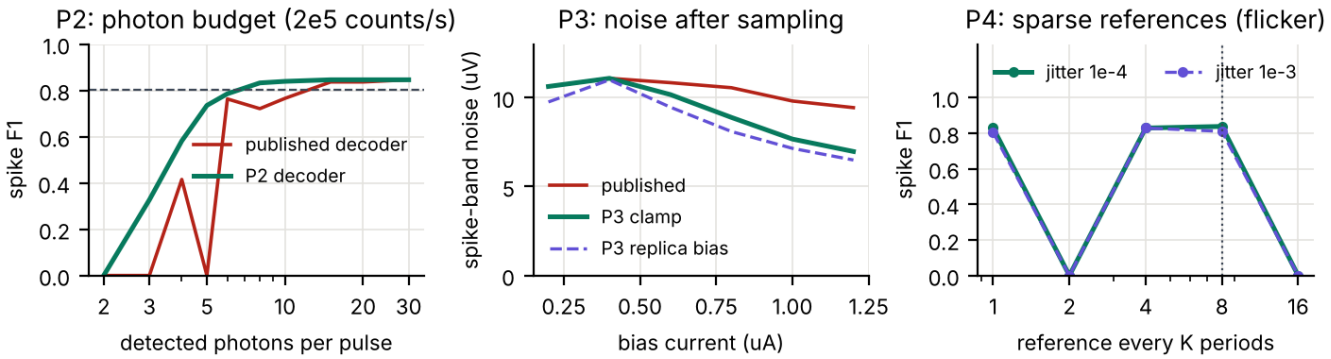

Figure 2: Evidence (Python model). Left: spike F1 against detected photons per pulse; dashed, 95 % of the perfect-link F1. Middle: amplifier noise in the 300 Hz-6 kHz band after sampling. Right: spike F1 against the reference decimation under light flicker; $K = 2$ fails at acquisition and $K = 16$ loses lock.