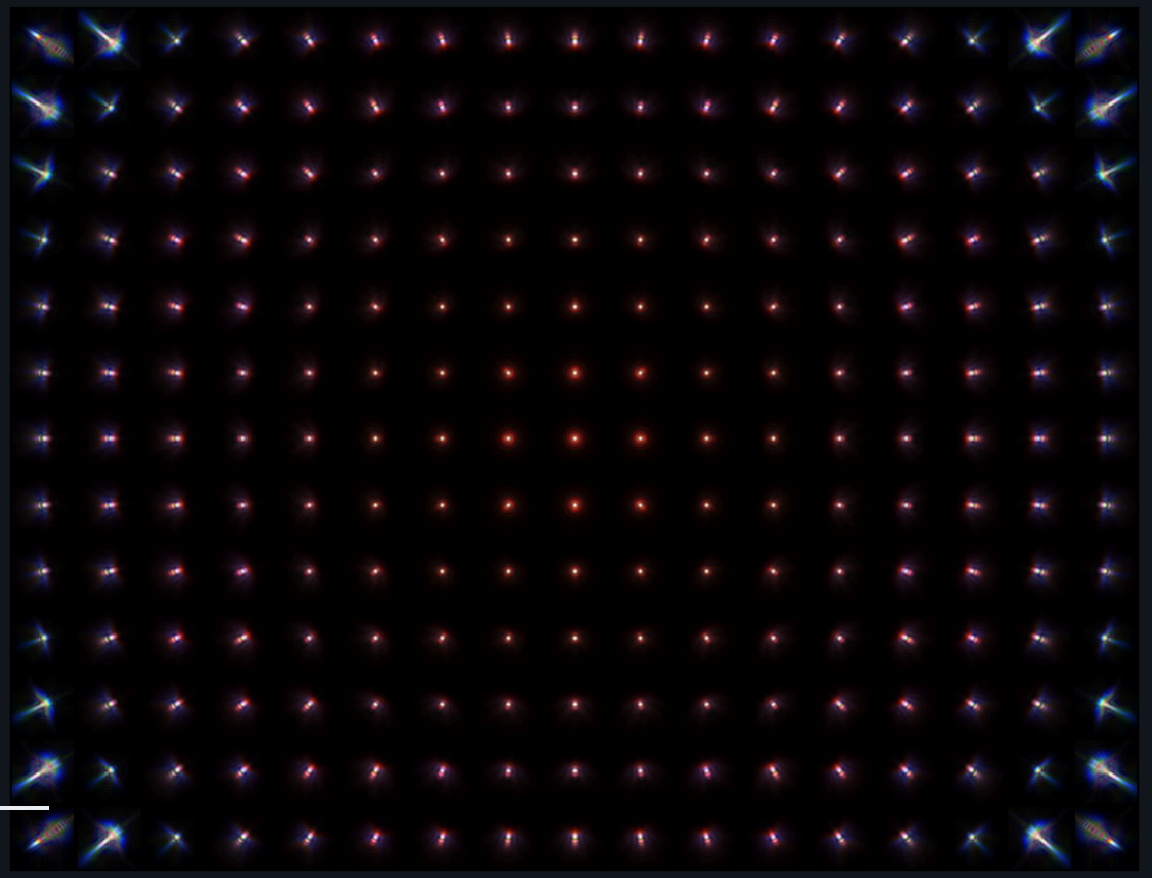
PARAXIAL CAPABILITY STUDY · FOUR CASE STUDIES · OCTOBER 2026

Designing a phone's cameras, end to end, in Paraxial

The rear main, telephoto and ultra-wide cameras, the front selfie and face-ID cameras, and the module in its phone: battery heat, cold and hot soaks, vibration and drop. Lens design, factory yield, image processing, thin films, illumination and FEA, all through the Paraxial API.



99 %
of 1 µm-class main-camera builds pass the MTF test

18.00 mm
periscope telephoto, folded by a prism

108 µm
astigmatism behind a curved cover glass

129 µm
autofocus travel, -20 to +70 °C

Every number is a saved Paraxial API response or simple arithmetic on one. The lenses are published patent designs scaled to current sensors; the phone and its requirements are generic.

BACKGROUND

Five cameras and one module, four studies

A flagship phone carries a main camera, a folded telephoto, an ultra-wide that doubles as the macro camera, a selfie camera and a face-ID pair (IR camera and flood illuminator), each in a few millimetres of height, behind cover glass, next to a battery.

The question: can one platform take these from a published design to a factory yield, an image pipeline and an environmental qualification, with scripts that reproduce every number?

> Every number is a saved Paraxial API response or simple arithmetic on one. The lenses are published patent designs scaled to current sensors; the phone and its requirements are generic.

CS1 · Rear main camera

Eight molded aspheres at f/1.78; a Monte Carlo of the factory through-focus MTF test; the PSF map that the image processor needs.

CS2 · Telephoto and ultra-wide

A prism-folded 5× periscope and a 120° ultra-wide that focuses at 2 cm.

CS3 · Front module

Selfie camera, 940 nm IR camera and its band-pass filter, the IR flood illuminator, curved against flat cover glass.

CS4 · The module in its phone

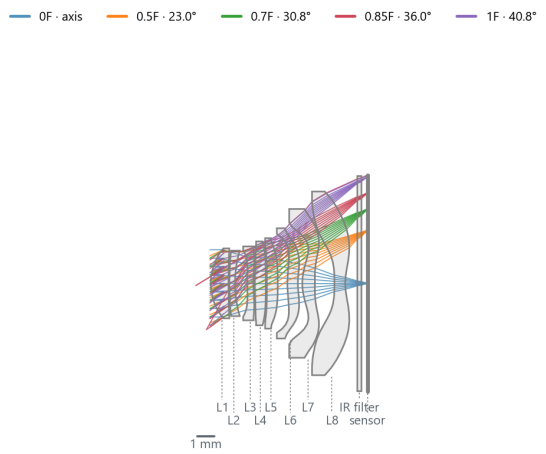
One-sided battery heating, cold and hot soaks, random vibration and a 1500 g drop, carried through to focus and image.

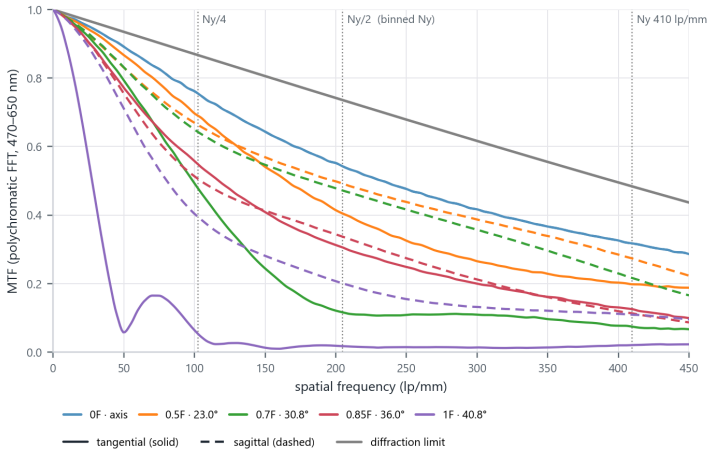
CASE STUDY 1 · REAR MAIN CAMERA, PART 1

Eight plastic aspheres in front of a 50 MP sensor

- **Start:** a published eight-element design, scaled to a 1/1.28-inch sensor: 24.3 mm equivalent focal length at f/1.78, then re-balanced on wavefront error.
- **Sharpness (Huygens MTF):** 0.54 on axis at half the pixel Nyquist. Total track 9.19 mm, chief-ray angle 35.01°, distortion 2.39 %: each just outside its target.
- **The edge of the field is the weak point:** the corner MTF peak is 0.14 and the 0.7-field focus spread 6.5 µm, so the nominal lens already fails two of the factory checks.

0.54	31.6 %	1.34 px	0.14
MTF on axis, 205 lp/mm	corner illumination	lateral colour	corner MTF peak



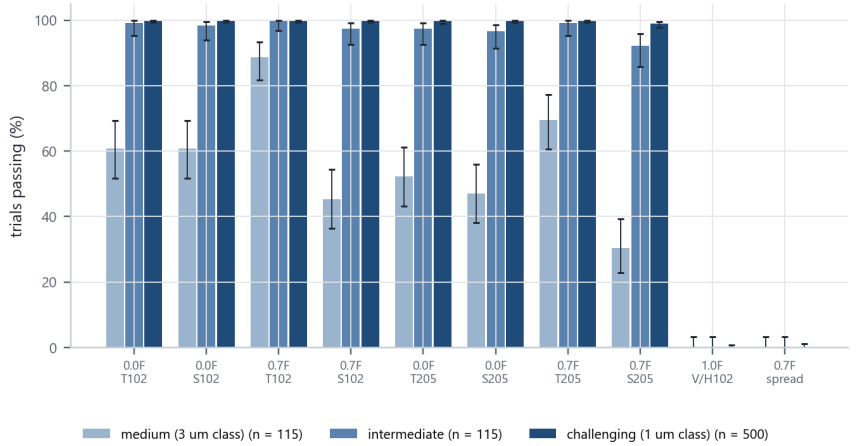


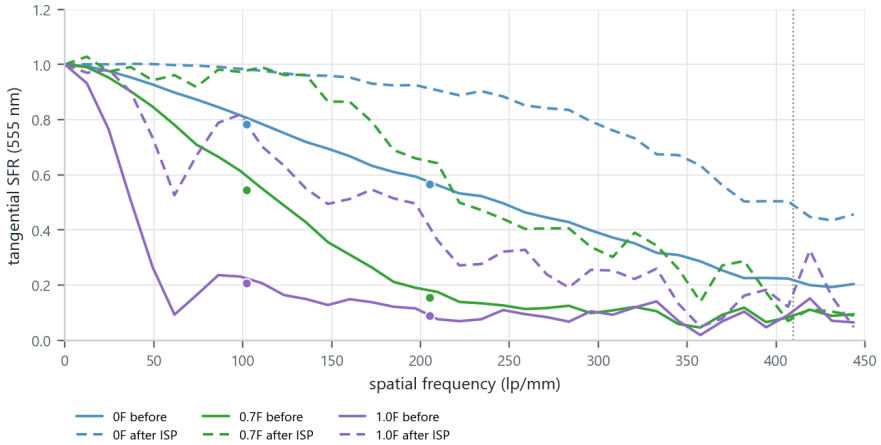
CASE STUDY 1 · REAR MAIN CAMERA, PART 2

The factory sets the yield; the ISP sets the corners

- **Monte Carlo of the production test:** 500 + 115 + 115 rebuilt modules, each refocused and through-focus scanned at 9 points.
- **Centre and 0.7-field MTF:** 99 % pass at 1 µm molding tolerances, 17 % at 3 µm. The tolerance class, not the design, decides the yield.
- **Image processor:** the API's 17 × 13 PSF map drives a modelled ISP; at 0.7 field and 205 lp/mm sharpening lifts SFR from 0.18 to 0.65, at a cost in noise.

> **Next:** re-optimise with the corner focus and the 0.7-field astigmatism as targets, then desensitise the leading tolerance drivers so the 3 µm class yields.



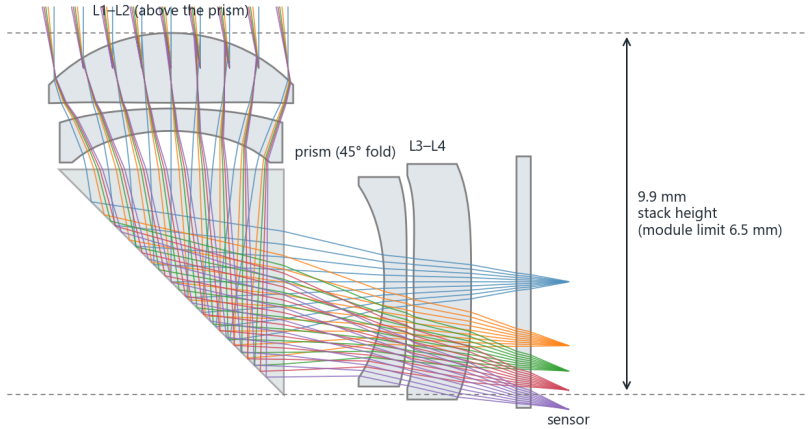


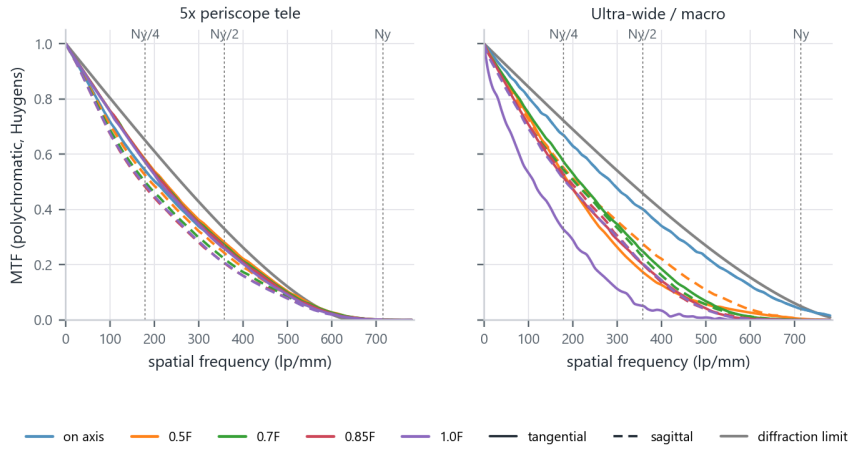
CASE STUDY 2 · TELEPHOTO AND ULTRA-WIDE, PART 1

A 5× periscope folds into the phone, but not into 6.5 mm

- **Telephoto:** a published design scaled to 18.00 mm at f/2.80, 22.0° diagonal; a 45° prism lays it flat.
- **Sharpness:** 0.26 on axis at the 12 MP Nyquist; the whole-field minimum is 0.200 against a ≥ 0.20 target.
- **Height:** two lenses sit above the prism, so the stack is 9.9 mm (stack) tall; the rear group alone is 6.46 mm. Close focus at 50 cm needs 686 µm of travel, beyond a phone VCM.

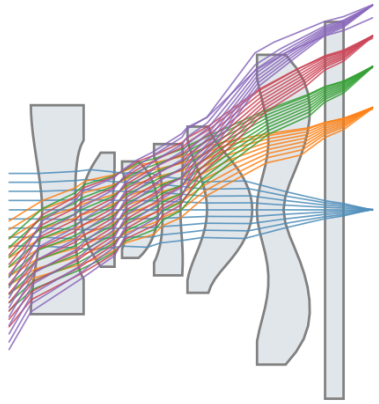
> **Decision:** put every lens after the prism and D-cut the rear group; give the telephoto its own close-focus actuator.

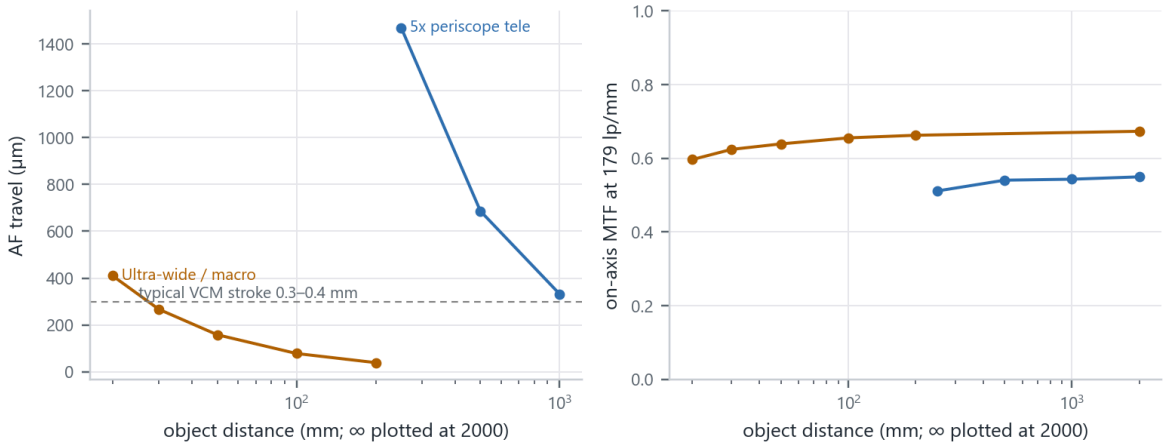




A 120° ultra-wide that is also the macro camera

- **Ultra-wide:** 120.0° at f/2.20, chief-ray angle 33.7°; -27 % barrel distortion for the ISP.
- **Sharpness:** the whole-field minimum at the 12 MP Nyquist is 0.041: the patent lens was designed for a coarser pixel.
- **Macro at 2 cm:** 410 µm of autofocus travel, at the edge of a 400 µm travel voice-coil stroke.



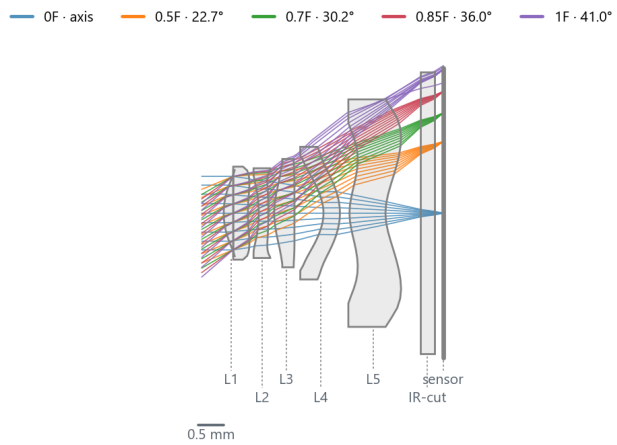


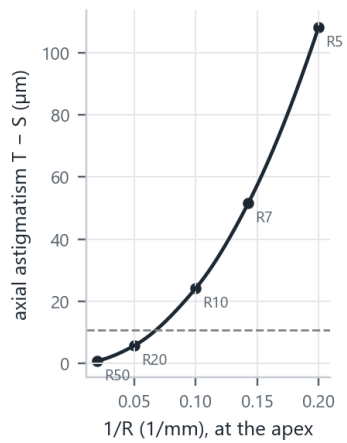
CASE STUDY 3 · FRONT MODULE, PART 1

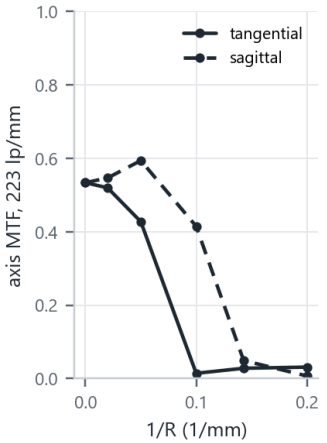
A sharp selfie lens, and why the cover glass stays flat

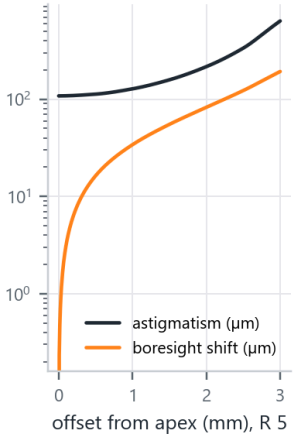
- **Selfie camera:** 3.300 mm, 82.0° diagonal; MTF on axis 0.59 at half Nyquist, 0.29 at 0.85 field.
- **Curved cover glass:** bent to a 5 mm radius over the lens it adds 108 µm of astigmatism against a 10.7 µm depth of focus. It must stay flatter than 16 mm radius over the camera.

> **Finding:** the curved edge belongs outside the camera window; over the lens the flat cover adds 0.00 µm.





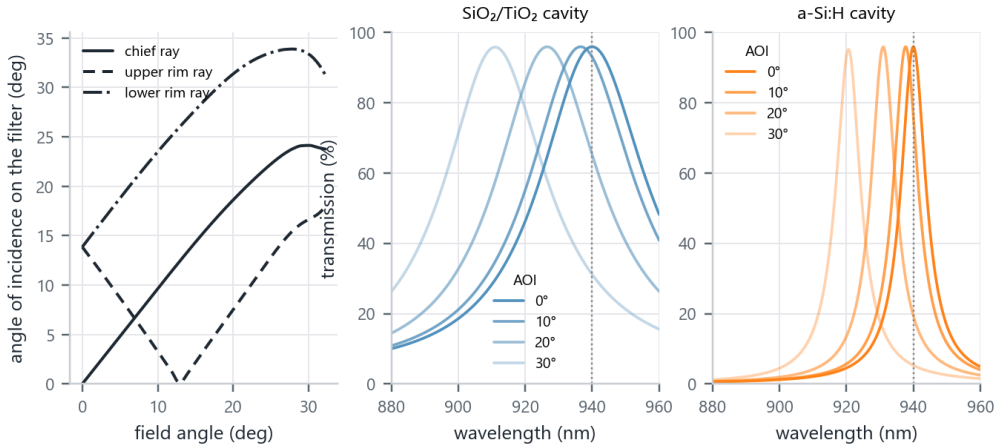


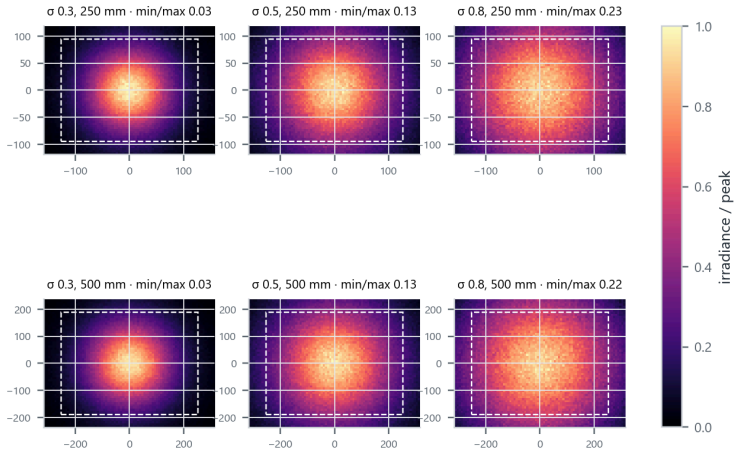


CASE STUDY 3 · FRONT MODULE, PART 2

Face ID: the filter shifts, the flood is uneven

- **940 nm band-pass at 30°:** an oxide stack shifts 29.0 nm, a-Si:H 19.4 nm, both beyond the 12 nm target: the IR camera needs a narrower ray cone or a wider pass band.
- **IR flood illuminator** (seeded non-sequential traces): at best the irradiance over the IR camera's field is 0.23 min/max; light leaking into the IR window is 0.0028 % or less.

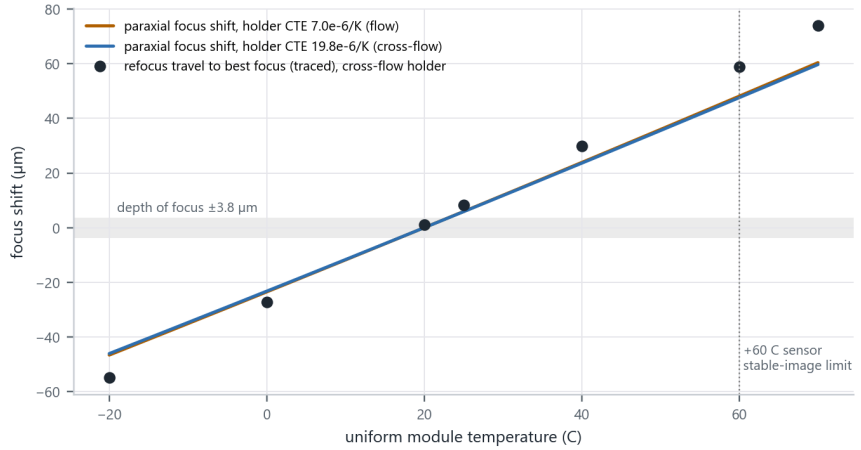


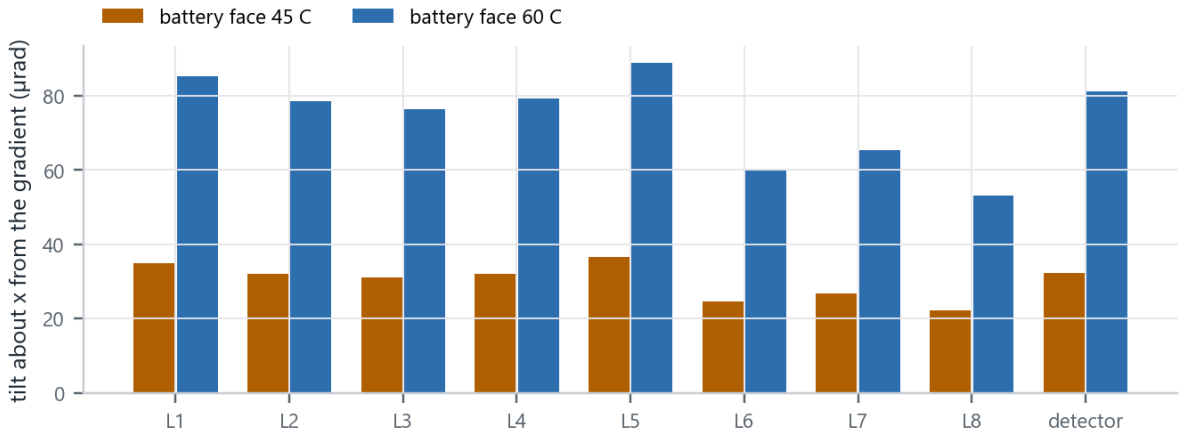


CASE STUDY 4 · THE MODULE IN ITS PHONE, PART 1

Plastic optics follow temperature; the battery barely matters

- **Soaks:** focus moves 1.19 µm/K, so the autofocus travels -54.8 to +73.9 µm over -20…+70 °C, inside the voice-coil stroke.
- **After refocus** the 0.75-field MTF at 102 lp/mm goes 0.27 / 0.47 / 0.37 at -20 / 20 / +70 °C: the plastics' index change rebalances the field.
- **Battery on one side** (45 / 60 °C): lens at 41.0 / 44.9 °C, extra focus +0.29 / +0.57 µm, image shift 0.13 / 0.33 px. Lens and sensor tilt together.



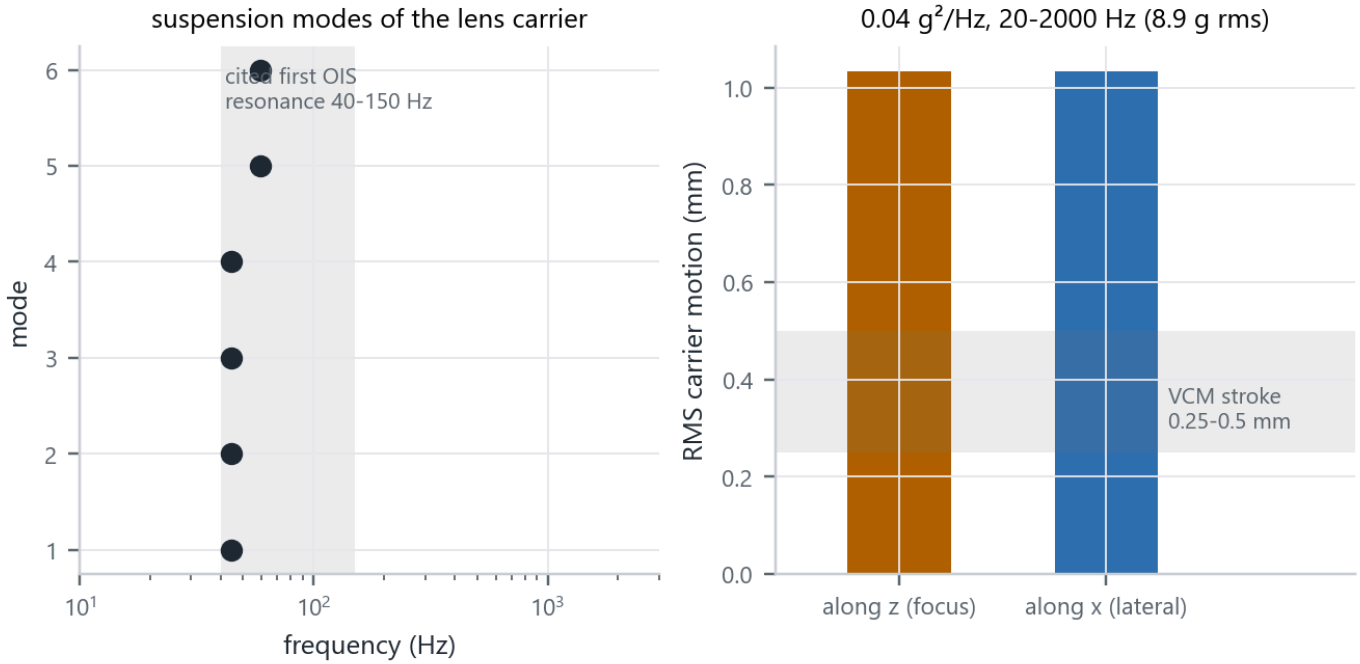


CASE STUDY 4 · THE MODULE IN ITS PHONE, PART 2

Vibration and a drop ride the end stops; the optics are not stressed

- **Suspension modes** 44.6 and 59.4 Hz, inside the cited first-resonance band.
- **Random vibration** (8.9 g RMS): the carrier swings 1034 µm RMS, far past its stroke. Sharp images need the closed-loop OIS and a short exposure.
- **1500 g drop:** a free carrier would travel 16.7 mm; on the end stop the largest stress is 4.1 MPa (barrel) and 2.2 MPa in a lens.

> **Limit of this study:** lenses are mass-matched discs in one material, and the springs and end stops are linear; the stresses are indicative.



Suspension modes against the cited first-resonance band; RMS carrier motion against the VCM stroke.

SUMMARY

Five cameras, one module, one platform

STUDY	SUBJECT	HEADLINE	CHECKS
CS1	Main camera, yield, ISP	`MTF 0.54 on axis; 99 % yield at 1 µm, 17 % at 3 µm`	4 ✓ · 5 ◐ · 3 ✗
CS2	Telephoto and ultra-wide	`18.00 mm folded tele, 9.9 mm (stack) tall; 120° UW, macro 410 µm`	7 ✓ · 3 ◐ · 3 ✗
CS3	Front module	`Selfie MTF 0.59; filter shift 29.0 nm; cover 108 µm`	9 ✓ · 0 ◐ · 5 ✗
CS4	Environment	`AF 129 µm; battery 0.33 px; vibration 1034 µm RMS`	6 ✓ · 0 ◐ · 3 ✗

One model, end to end

CS1's lens went on to its Monte Carlo, its PSF map and ISP, and into the CS4 module for heat, vibration and drop.

The factory's own test

A custom through-focus MTF-peak Monte Carlo, scored like a module line, with yield intervals.

Reproducible

Every number comes from an API response saved with the script that made it; statuses are computed, not typed.

Fast

Four studies in 6.1 h of agent time, with API jobs running for 5.4 h of it, several at once.

Every number is a saved Paraxial API response or simple arithmetic on one. The lenses are published patent designs scaled to current sensors; the phone and its requirements are generic. Platform issues found along the way are listed in each INTERNAL report and in CASE_STUDIES_README.md.