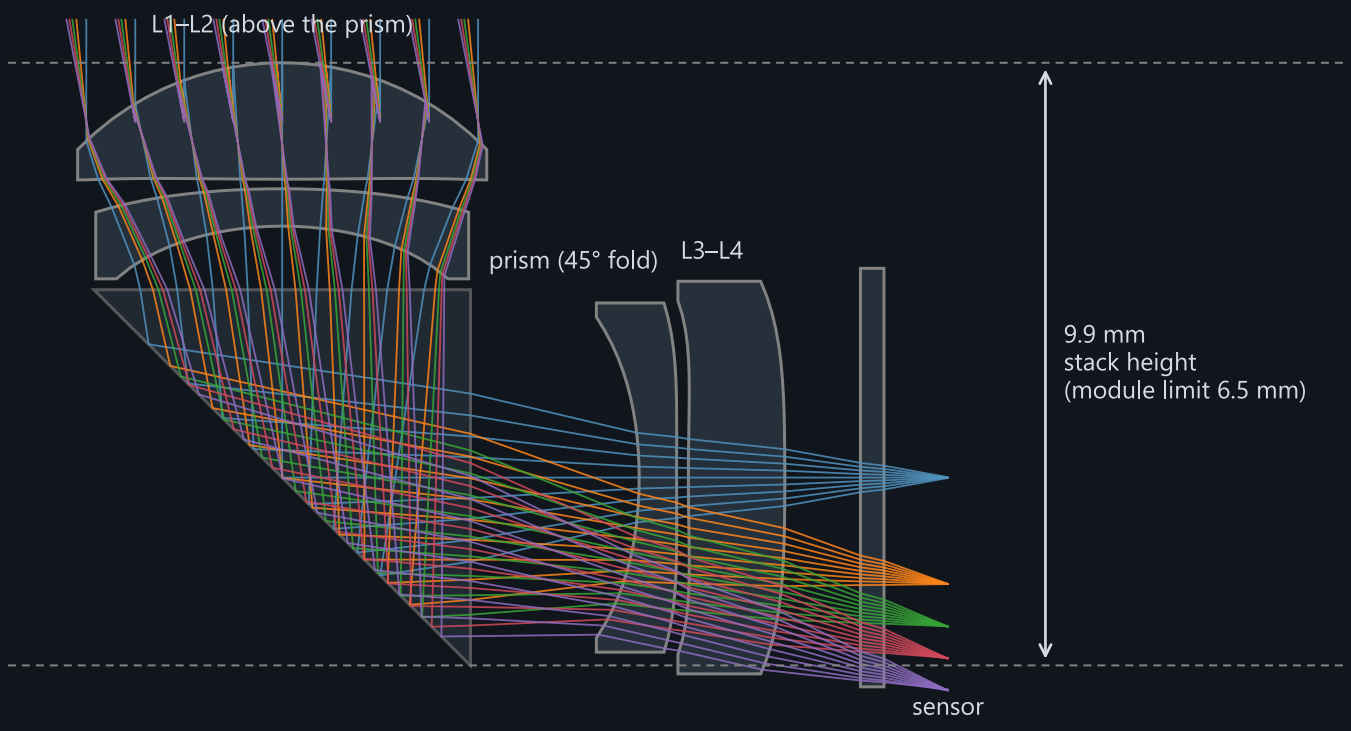
CASE STUDY 2 · SMARTPHONE REAR TELE AND ULTRA-WIDE · 22 OCTOBER 2026

An 18 mm telephoto folds into a phone; the ultra-wide focuses at 2 cm

A 5× telephoto needs an 18 mm lens and a 6 mm pupil, in a phone that is 8 mm thick. A prism folds the light sideways so the lens can lie flat. The ultra-wide on the same phone covers 120° and doubles as the macro camera, focusing down to 2 cm. This study takes a published lens for each, scales it to a 1/2.55-inch, 0.7 µm sensor, and measures sharpness, fit, stabilisation and close focus. Every optical number comes from the Paraxial API.



The 5× periscope telephoto, folded at its 45° prism (drawn from the API's unfolded layout).

0.26
tele MTF on axis at 360 lp/mm (the 12 MP Nyquist)

9.9 mm
tall as built: two lenses above the prism miss the 6.5 mm module

120°
ultra-wide field, with -27 % barrel distortion for the ISP

410 µm
AF travel for 2 cm macro: at the edge of a phone VCM

Paraxial · fea deployment (API 0.9.248) · designed and analysed by Claude through the Paraxial SDK · summary edition

BACKGROUND 01

Two cameras that bend the rules of a thin phone

Behind the main camera of a flagship phone sit two more: a telephoto that zooms 5× optically, and an ultra-wide that sees 120°. Both have the same problem. A phone is about 8 mm thick, and the telephoto's lens is 18 mm long; the ultra-wide must see almost half the world through an opening a few millimetres wide, and still focus on a coin 2 cm away for macro photographs.

The telephoto solves its problem with a prism that turns the light through 90°, so the lens lies along the phone instead of through it (a *periscope*). The ultra-wide accepts strong barrel distortion and lets the image processor straighten the picture, and it focuses close by moving the whole lens.

The question this study answers: how does a prism fold fit an 18 mm lens into a phone that is about 7 mm thick, and how does one ultra-wide lens cover 120° and still focus at 2 cm?

This is the second of four studies. Study 1 is the main camera and its manufacturing yield; study 3 the front cameras; study 4 the main camera's thermal and mechanical environment.

THE JOB 02

What the two lenses have to do

Values come from published 2025–26 flagship specifications (requirements_research.md §2–3).

WHAT THE JOB NEEDS	SPECIFICATION	WHY
5× zoom on a 0.7 µm sensor	`1/2.55″, 5.6 × 4.2 mm, ImgH 3.5 mm`	2025–26 flagship class
Telephoto focal length	`EFL ≈ 18 mm (16–19), f/2.8–2.9, 22° diagonal`	110–115 mm equivalent
Fit the phone	`module height ≤ 6.5 mm`	Phone 8–9 mm thick (ASSUMPTION)
Tele close focus	`25–50 cm`	Flagship periscopes
Optical stabilisation	`prism tilt`	One of three published OIS methods
Ultra-wide field	`120° diagonal, f/2.2`	13 mm equivalent
Macro with the ultra-wide	`focus to 2 cm, whole-lens AF`	flagships since 2021
Match the sensor microlenses	`chief-ray angle ≤ 35°`	Industry practice
Resolve the 12 MP output	`MTF ≥ 0.20 at 357 lp/mm`	Rule of thumb ≥ 0.2–0.25 at Nyquist; 2×2-binned pixel

WHY IT IS HARD 03

Three tensions

- **Pupil against height.** At f/2.8 an 18 mm lens has a 6.4 mm pupil. Lying flat, its height is the phone's thickness, so the lens either shrinks or is cut flat top and bottom (a D-cut).
- **Field against distortion.** Covering 120° with a flat sensor and a rectilinear image needs a lens whose image grows as tan θ, which runs away at 60°. Phone ultra-wides compress the edge instead and leave the straightening to the image processor, at a cost in edge resolution.
- **Close focus against travel.** Focus travel grows as f^2/distance: tiny for the ultra-wide at a metre, large for the telephoto at 25 cm, and at 2 cm the ultra-wide needs most of a voice-coil motor's stroke.

THE TELEPHOTO 04

Even sharpness across a 22° field

The cover shows the telephoto folded at its prism: two lenses (L1–L2) above the prism, two (L3–L4) after it, lying along the phone.

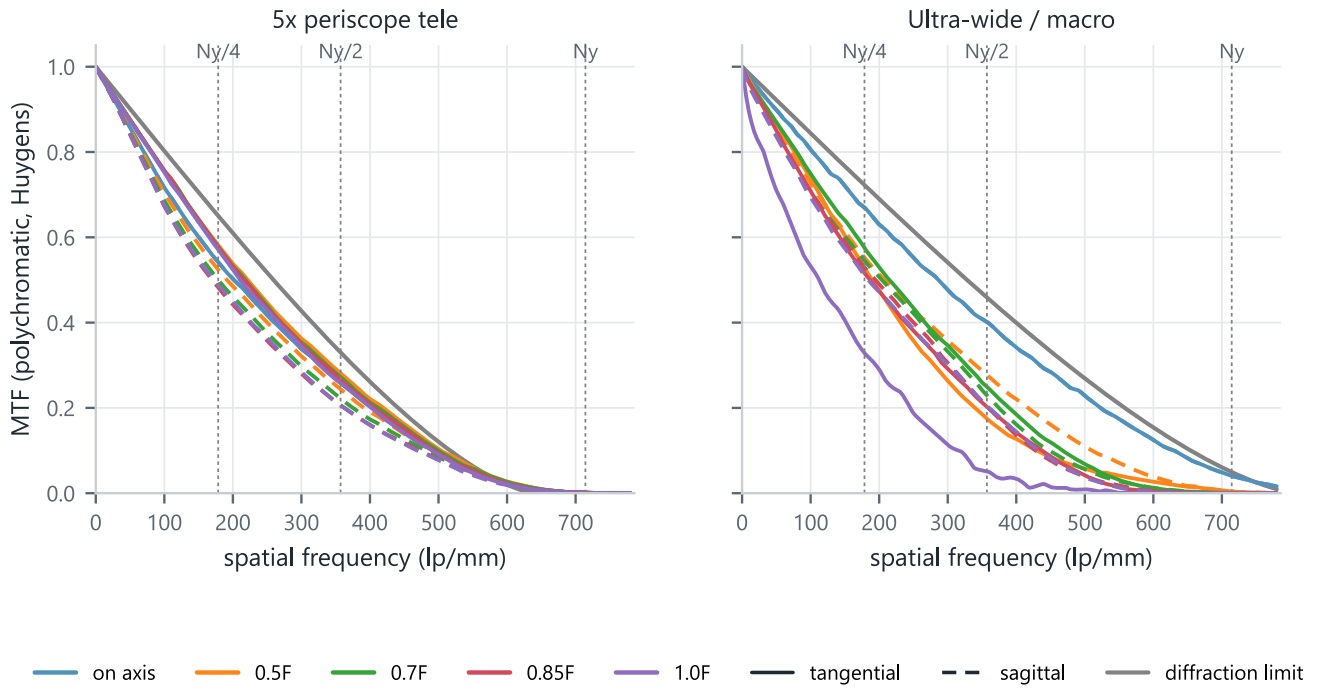


Figure 1. Polychromatic Huygens MTF (470–650 nm, design weights) for both lenses, to 1.1 × the 714 lp/mm native Nyquist. Sampling: 64 pupil samples on a 128 grid, 10 lp/mm steps; a run at half the sampling differs by at most 0.025 up to 357 lp/mm. The native Nyquist lies beyond the telephoto's f/2.8 diffraction cutoff (642 lp/mm at 555 nm), so the 0.7 µm pixels are only resolved after 2×2 binning.

> **Finding.** The telephoto is uniform: at 357 lp/mm the lowest value over the field is 0.20, against 0.26 on axis. Its chief rays meet the sensor at ≤ 16.2° and relative illumination stays ≥ 0.93: a long, slow lens has no corner problem.

FITTING IT IN 05

This split-group layout is too tall; the cure is all lenses after the prism

In the 2014 embodiment two lenses (L1–L2) sit *above* the prism, along the phone's thickness. Measured from the API geometry, the stack from the L1 vertex to the bottom of the prism is **9.9 mm**, against a 6.5 mm module. After the fold, L3–L4 lie flat, and their clear diameter becomes a height: 6.46 mm, which leaves no room for a barrel wall inside 6.5 mm.

Production periscopes therefore put every lens after the prism and cut the lenses flat top and bottom (D-cut). The D-cut was modelled as a rectangular aperture of half-height 2.5 mm on L3–L4 (a 5.0 mm clear height, leaving 0.75 mm a side for barrel and housing, an ASSUMPTION).

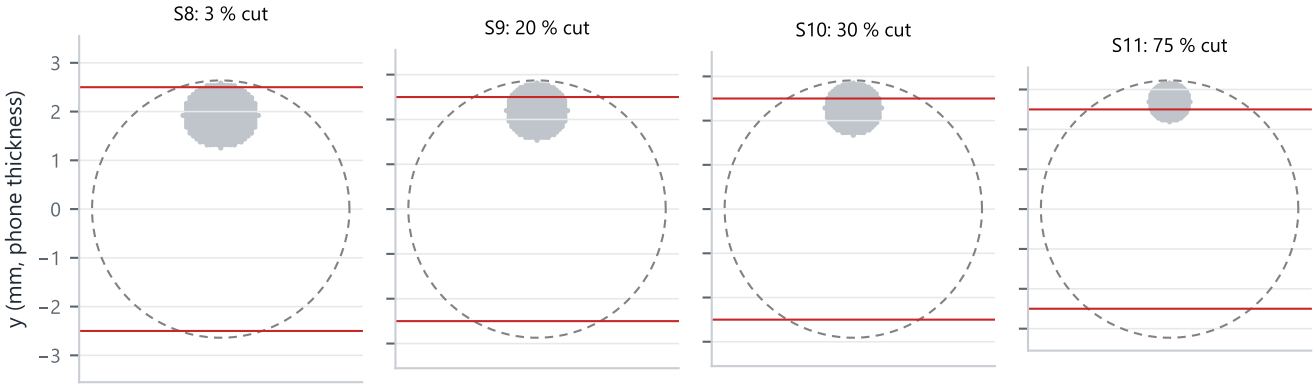


Figure 2. Ray footprints of the corner field on the four L3–L4 faces with the D-cut lines (red) and the round clear apertures (dashed). The share of the corner beam outside the cut is in each title (API footprint).

Finding. A 5 mm D-cut clips 75 % of the corner beam at the last lens face and 3 % at the first: with this form the corner would lose most of its light. The fix is a layout change (all lenses after the prism, a smaller rear group), not a bigger cut.

Decision. Report the D-cut through its geometry only. The API's image-quality analyses do not treat the rectangular aperture consistently (relative illumination ignores it, a single-field MTF returns the on-axis curve), so no D-cut MTF is quoted.

STABILISE AND FOCUS 06

The prism steers the image; close focus costs a millimetre

Prism-tilt OIS. Tilting the fold mirror by δ turns the beam by 2δ. It was modelled in the unfolded lens as a 2δ rotation of the stop and L1–L2 about the mirror point (the prism faces' own tilt, a plane plate turned by ≤ 0.5°, is neglected: ASSUMPTION).

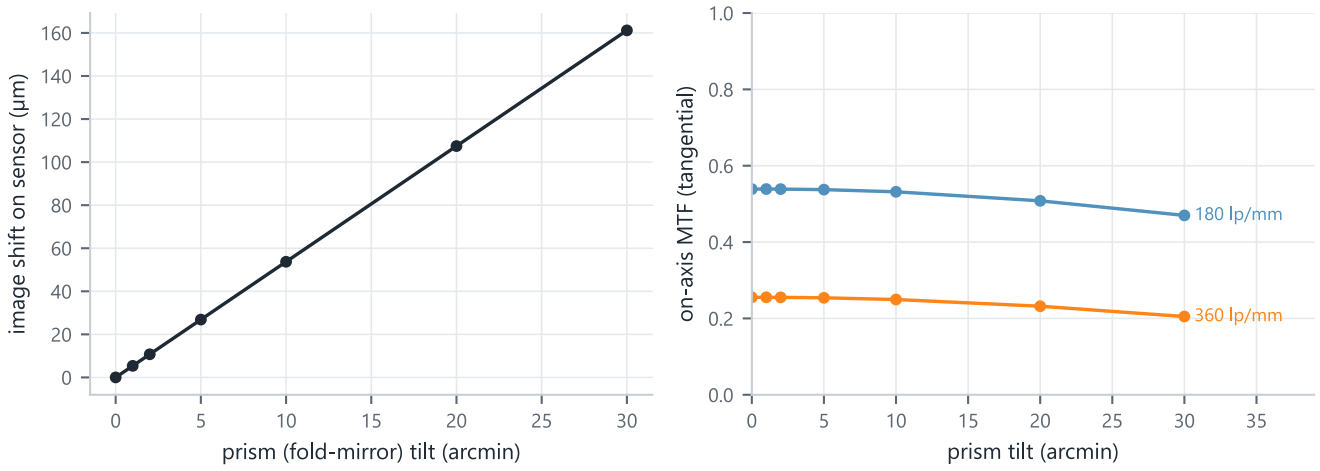


Figure 3. Left: image shift of the on-axis chief ray against prism tilt. Right: on-axis Huygens MTF (tangential) at 179 and 357 lp/mm.

> **Finding.** One arcminute of prism tilt moves the image 5.37 µm; one arcminute of hand shake moves it 5.24 µm (from the 0.3F field point). So the prism tilts about as far as the hand shakes. At 30′ the on-axis MTF at 179 lp/mm drops by 13 %.

Close focus. Focus by moving the sensor (or the whole lens) was found per object distance with a Huygens through-focus scan; the API's quick-focus was used only as a first guess.

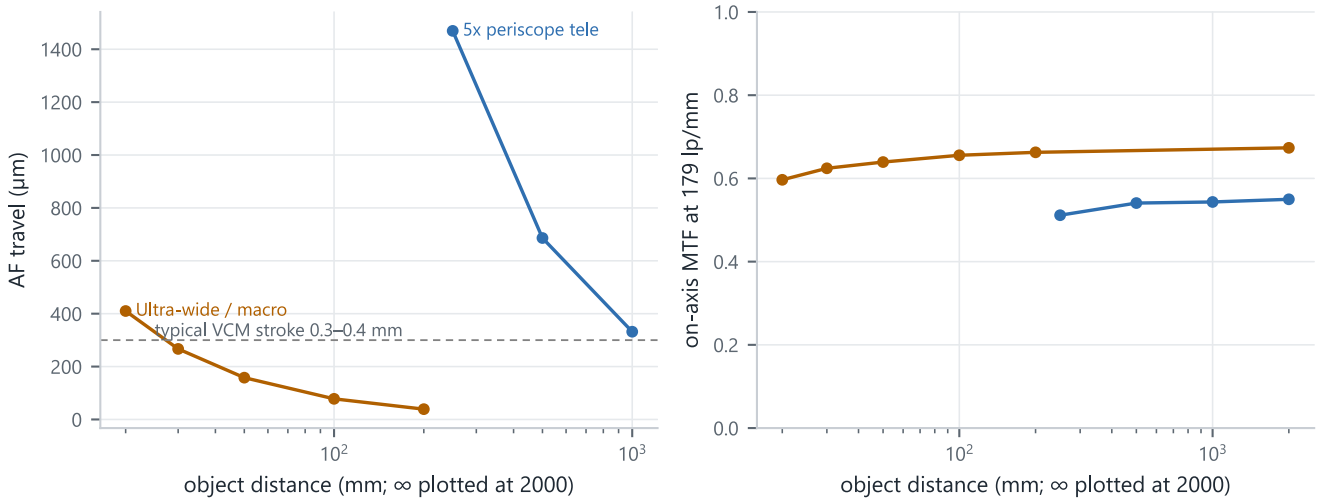


Figure 4. Left: AF travel against object distance for both lenses; the dashed line is a typical phone voice-coil stroke. Right: on-axis polychromatic Huygens MTF at 179 lp/mm at each focus.

> **Finding.** The telephoto needs 686 µm of travel for 50 cm and 1469 µm for 25 cm, two to four times a main-camera VCM. Sharpness holds (0.51 on axis at 25 cm), so close focus is a motor and packaging problem, which is why periscopes stop at 25–95 cm.

THE ULTRA-WIDE 07

120° with barrel distortion, and a 2 cm macro

Six plastic aspheres, 5.65 mm from the first lens to the sensor, cover 120° at f/2.2.

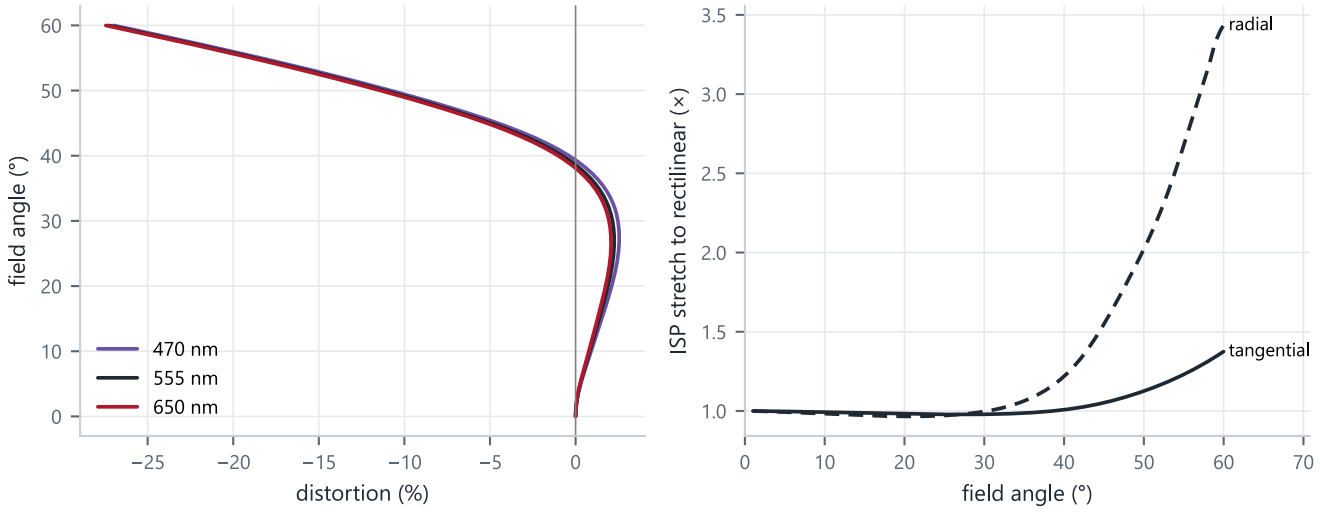


Figure 5. Left: distortion at 470, 555 and 650 nm against field angle (API, 61 points, reference f·tan θ). Right: the stretch the image processor applies to make the picture rectilinear, from the same API samples: tangential = reference / real height, radial = its local derivative (arithmetic on the API data).

> **Finding.** At the 60° corner the image is 27 % smaller than a rectilinear image; straightening it stretches corner pixels 1.37× tangentially and 3.4× radially, so the corrected picture loses that much resolution there. Relative illumination bottoms at 0.31 and the chief ray stays ≤ 33.7°.

Macro. The whole lens moves (no floating element); travel found by Huygens through-focus.

> **Finding.** At 2 cm the lens must move 410 µm, at the top of a 0.3–0.4 mm voice-coil stroke, for 0.15× on the sensor; sharpness holds (0.60 on axis) but the depth of field is 0.55 mm. The paraxial focal length (2.78 mm) is longer than the 2.1 mm a rectilinear lens of the same field would have, and travel goes as f^2, so a barrel-distorting ultra-wide needs more stroke than the nominal estimate.

STRAY LIGHT AND VARIANTS 08

Ghosts between the rear lenses; the prism's paths need a 3-D model

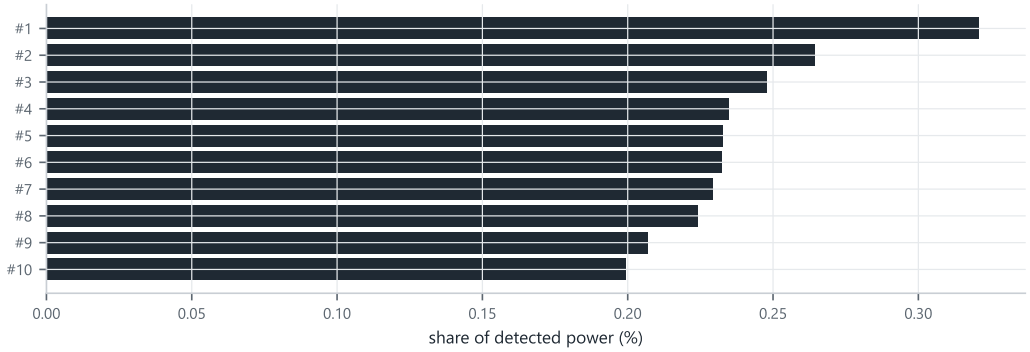


Figure 6. The ten strongest two-reflection ghost paths of the telephoto on axis (API ghost analysis, 5000 rays). Strongest: 0.32 % of the detected power; all ten together give a stray-to-signal ratio of 9.8 %.

The strongest paths bounce between the faces of L3 and L4 and the IR filter, behind the fold. The prism's own stray paths (light reflected at the entrance face, total internal reflection at the exit face) exist only in the folded geometry; they need a non-sequential model with the prism's real faces and masks, which this study did not build.

Variants (discussed, not modelled). A tetraprism reflects four times inside three prisms to quadruple the path in one block; an all-lenses-on-prism layout puts all lenses on top of the prism with a round aperture and a 22 % shorter module. Both answer the height problem found above.

THE RESULT 09

The telephoto resolves the 12 MP grid, the ultra-wide not at every field; the tele's layout and close-focus stroke do not fit

REQUIREMENT	TARGET	RESULT	STATUS
Tele EFL	16–19 mm	18.00 mm	✓ Met
Tele f-number	f/2.8–2.9	f/2.80	✓ Met
Tele diagonal field	22°	22.0°	✓ Met
Tele MTF @ 357 lp/mm, whole field	≥ 0.20	0.200	◐ Partly
Tele module height	≤ 6.5 mm	9.9 mm (stack)	✗ Not met
Tele rear-group clear height	≤ 6.5 mm	6.46 mm	◐ Partly
Tele close focus 50 cm on a VCM	≤ 400 µm travel	686 µm	✗ Not met
Tele chief-ray angle	≤ 35°	16.2°	✓ Met
UW diagonal field	120°	120.0°	✓ Met
UW f-number	f/2.2	f/2.20	✓ Met
UW MTF @ 357 lp/mm, whole field	≥ 0.20	0.041	✗ Not met
UW chief-ray angle	≤ 35°	33.7°	✓ Met
UW macro 2 cm on a VCM	≤ 400 µm travel	410 µm	◐ Partly

Next steps

- **Re-lay the telephoto with every lens after the prism.** Then D-cut the rear group and check the corner light against the cut.
- **Model the folded prism non-sequentially.** Entrance-face and TIR stray paths, and the masked facets Corephotonics patents.
- **Choose the close-focus mechanism.** Sensor-shift or a dedicated tele actuator for 25 cm; a longer stroke or a slightly shorter macro distance for the ultra-wide.

METHOD 10

How the numbers were made

Every optical number is a saved Paraxial API response, or arithmetic on one, and every status is computed from it. The telephoto is US 9,316,810 B2 (emb. 510) scaled to EFL 18.00 mm, the ultra-wide US 10,761,289 B2 (emb. 1) scaled to EFL 2.78 mm at f/2.2; both were checked against their patents, then only refocused. MTF is polychromatic Huygens (470–650 nm); focus travel comes from Huygens through-focus scans. The full report adds the layouts, patent checks, per-field tables, relative illumination and chief-ray angle, prescriptions, scripts and run times.